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Influence of Elastic Deformations and Temperature on the Tensoresistive Properties of the Compound $TIIn_{1-x}Co_xSe_2$ (0 $\leq X \leq 0.5$)

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Abstract: The paper presents the results of studying the influence of various external physical factors, including elastic deformations and temperature, on the tensoresistive mechanisms of single crystals of solid solutions $TIIn_{1-x}Co_xSe_2$ ($0 \le x \le 0.5$). The effect of temperature on the strain sensitivity of $TIIn_{1-x}Co_xSe_2$ single crystals in the cobalt concentration range $0 \le x \le 0.5$ was determined. A mode of synthesis and growth of single crystals of solid solutions $TIIn_{1-x}Co_xSe_2$ ($0 \le x \le 0.5$) by the improved Bridgman-Stockbarger method with the use of electronic temperature controllers was developed to maintain the optimal thermal regime during crystallization. The directional crystallization rate was about 0.9 mm/h. $TIIn_{1-x}Co_xSe_2$ single crystals had p-type conductivity. The samples for the study were made by cleaving single crystals in two mutually perpendicular planes of a natural cleavage and had the shape of a rectangular parallelepiped. The dimensions of the studied samples were $10x10x0.25 \text{ mm}^3$. Ohmic contacts are obtained by spot welding of the corresponding wires ($\theta = 0.01 \text{ mm}$) by a capacitor discharge on the ends of samples heated in an inert gas flow. A technique has been developed for strain gauge measurements in a static mode at a temperature of 300–400 K. The study of tensoresistive mechanisms of $TIIn_{1-x}Co_xSe_2$ solid solution single crystals has led to very interesting results. First of all, it should be emphasized that these crystals exhibit a strong piezoresistive effect in the direction of the [001] crystallographic axis, which, in combination with their mechanical, elastic, crystallographic and other features, makes them very promising materials for creating new miniature highly sensitive and reliable electromechanical transducers.

Keywords: Monocrystals, Tenzoresistive Characteristics, Solid Solutions, Tenzosensitivity of Crystals, Electromechanical Transformers

1. Introduction

To date, silicon and germanium are the most widely used materials in semiconductor electronics. This is due to the wide distribution of silicon on earth, the proximity of the structure of germanium and silicon, the unique properties of these materials and, as a result, the best knowledge of their physicochemical characteristics.

However, the needs of modern electronics and nanotechnology are not satisfied only by these materials and require materials with a variety of properties. Therefore, along with the improvement of the properties of existing ones, the search for new semiconductor materials and the study of their various characteristics is currently one of the cardinal general tasks of modern semiconductor physics and leads to the discovery of many semiconductor materials, including ternary and more complex compounds. The discovery of new materials, the study of the relationship between the composition, structure and properties of multicomponent semiconductor compounds, in addition to deepening fundamental scientific ideas about semiconductors, also opens up new perspectives: new compounds, as a rule, exhibit new qualities and, thereby, contribute to the solution of necessary technical problems.

Among semiconductor crystals, a special place is occupied by layered and chain semiconductors with their inherent strong anisotropy of physical properties along different crystallographic directions.

According to the above, in recent years, interest in semiconductor strain gauges has increased dramatically. The reasons that caused such a rapid development of semiconductor strain gauges lie in the new wide possibilities that semiconductor strain gauges open up for experimenters working in the aviation and oil refining industries to study the strength of materials, designs for designers, nanotechnological transducers of mechanical quantities (force, pressure, moment, etc.) into electrical signals.

So far, the physical mechanisms of the tensoresistive property of crystals of multicomponent semiconductor compounds of the $A^{III}B^{III}C_2^{VI}$ type and solid solutions based on them remain poorly understood. An important stimulus to the study of semiconductors with a strongly anisotropic structure is their increasing practical importance.

The strong anisotropy of the chemical bonding forces between atomic complexes in the low-symmetry crystal structure of complex compounds $TlIn_{1-x}Co_xSe_2$, in some cases (the structure contains chain structures), in the study of their physical properties, predetermines the specific features due to which these compounds become objects for model representations.

The study of tensoresistive mechanisms of single crystals of $TlIn_{1-x}Co_xSe_2$ solid solutions in this respect led to very interesting results. First of all, it should be emphasized that these crystals show a strong piezoresistive effect in the [001] direction, which, in combination with their mechanical, elastic, crystallographic and other features, makes them very promising materials for creating new miniature highly sensitive and reliable electromechanical transducers.

Therefore, the purpose of our study was to study the influence of various external physical factors, including elastic deformations and temperature, on the tensoresistive properties of the $TIIn_{1-x}Co_xSe_2$ compound.

2. Experimental Technique

Alloys of a given composition were synthesized by fusing components in accordance with stoichiometry in evacuated to a pressure of 1.2×10^{-4} mm. rt. Art. quartz ampoules with a diameter of 12 - 15 mm, a melt height of 50 - 60 mm, especially pure elements were used as initial components: thallium 000, indium 000, cobalt 000, sulfur of high purity - 16 - 5 and selenium of high purity - 17 - 4.

Single crystals were grown by the improved Bridgman-Stockbarger method with the use of electronic thermostats to maintain the optimal thermal regime during crystallization. The directional crystallization rate was about 0.9 mm/h. $TlIn_{1-x}Co_xSe_2$ single crystals had p-type conductivity. Samples for research were made by cleaving single crystals in two mutually perpendicular planes of natural cleavage and had the shape of a rectangular parallelepiped. The dimensions of the studied samples were 10x10x0.25 mm³. Ohmic contacts are obtained by spot welding of the corresponding wires ($\emptyset = 0.01$ mm) by a capacitor discharge on the ends of samples heated in an inert gas flow [1-3].

The strain sensitivity of the samples was measured in the temperature range of 300-410 K in the static mode specified by the technique in [4].

3. Results of the Study and Their Discussion

The paper reports the results of our study of the effect of directional deformation on the tensoresistive properties of $TlIn_{1-x}Co_xSe_2$ solid solutions, on the basis of which an assumption was made about the most probable locations of extreme in the Brillouin zone. It is shown that $TlIn_{1-x}Co_xSe_2$ single crystals, due to their high strain sensitivity, significant flexibility and the ability to chip onto the desired filamentous plates with mirror faces in the direction of the maximum piezoresistive effect, are extremely effective materials for semiconductor strain gauges. The obtained new $TlIn_{1-x}Co_xSe_2$ single crystals satisfy the basic general requirements of semiconductor strain gauges: - if possible, a high coefficient of strain sensitivity; linear dependence of resistance change with deformation; no hysteresis characteristics; minimal sensitivity to the influence of side external physical factors.

The parameters listed above are determined mainly by the properties of the semiconductor material itself, although they can also be significantly influenced by the technology of manufacturing strain gauges.

To emphasize the uniqueness of the proposed new material $TlIn_{1-x}Co_xSe_2$, first of all, we note that their characteristics should be compared with the parameters of the known and most widely used materials in semiconductor strain gauges.

The study of $TIIn_{1-x}Co_xSe_2$ crystals in this regard led to very interesting results. First of all, it should be emphasized that crystals of solid solutions $TIIn_{1-x}Co_xSe_2$ show a strong piezoresistive effect in the [001] direction, which, in combination with their mechanical, elastic, crystallographic and a number of other features, makes them promising for creating new miniature highly sensitive and reliable electromechanical converters. as sensors of displacement, force, pressure, etc.

The efficiency of new $TIIn_{1-x}Co_xSe_2$ crystals in comparison with known crystals in semiconductor tensometry is provided mainly by the following three of their features, namely: - high (record) strain sensitivity (see tab. 1); high elasticity and tensile strength; the ability to easily cleave onto the desired identical fusiform rectangular plates with mirror edges in the direction of maximum piezoresistive effect [5-8].

Despite a number of common shortcomings of semiconductors for their practical application in strain gauges, due to their high strain sensitivity and small size, the number of developments of strain gauges based on various semiconductor materials is growing every day [9-13].

№	Load cell crystal composition	K _{aver} , When compressed	K _{aver} ., When stretched	Note
1.	TlInSe ₂	577	406	With relative deformation
2.	$TIIn_{0,99}Co_{0,01}Se_2$	2752	6641	with relative deformation $a = 0.57 \cdot 10^{-3}$
3.	$TIIn_{0,9}Co_{0,1}Se_2$	2839	6881	$\varepsilon = 0.5710$ T = 200 V
4.	$TlIn_{0,5}Co_{0,5}Se_2$	2941	7143	1 - 300 K

Table 1. The average value of the strain-sensitivity coefficient (Ksr) of solid solutions $Tlln_{1-x}Co_xSe_2$ ($0 \le x \le 0.5$) in comparison with the initial $TllnSe_2$ crystals along the [001] axis.

However, in terms of the magnitude of the strain sensitivity coefficient, the crystals of no known binary semiconductors are superior to silicon, although they have a number of distinctive features.

The highest strain sensitivity is currently found for crystals α - SiC p - type of conductivity (K = 470) [5]. Crystals TlIn₁. _xCo_xSe₂ in their sensitivity to deformation significantly exceed all materials known to date in semiconductor tensometry (Table 1).

The effect of temperature on the tensoresistive properties of $TlIn_{1-x}Co_xSe_2$ single crystals has been studied. The temperature dependence of the initial resistance and the change in the piezosensitivity coefficient with temperature are the most important indicators of semiconductor strain gauge materials. In the case of applying semiconductor strain gauges to a part with a variable temperature, it becomes necessary to take into account both changes. The change in the initial resistance of the sensor with temperature is taken into account by applying appropriate compensation methods, and the change in strain sensitivity is taken into account by introducing a correction. Nevertheless, the loss in sensitivity at elevated temperatures turned out to be inevitable: for the strain sensitivity of all materials known in semiconductor strain gauges decreases significantly with increasing temperature.

In this regard, the following valuable specificity of $TIIn_{1-x}Co_xSe_2$ crystals deserves special attention: with increasing temperature, the sensitivity to deformation increases significantly (Table 2). In this case, the strain gauge coefficient increases linearly with temperature. The strain sensitivity coefficient of $TIIn_{1-x}Co_xSe_2$ crystals of various compositions depending on temperature and relative deformation is given in Table 2.

The temperature coefficient of strain sensitivity per degree in percent, GT was determined by the formula: $G_{\rm T} = \frac{\Delta K / K_0}{\Delta T} \cdot 100\%$, where ΔK is the change in the strain gauge factor when the temperature changes by ΔT , K_0 is the initial strain gauge factor at 300K, and the calculation results are shown in Table 3. The temperature coefficient of strain sensitivity of these crystals varied markedly from sample to sample, depending on its resistance - impurity concentration. The samples with the highest impurity concentration were characterized by the lowest value of the above temperature coefficients. The value of the latter significantly depended on the considered regions of the temperature interval.

Table 2. Dependence of the strain sensitivity coefficient of solid solutions $TlIn_{1x}Co_xSe_2$ on the composition and temperature [6].

N⁰	Т, К	TIInSe ₂	TIIn0,99C00,01Se2	TIIn _{0,9} Co _{0,1} Se ₂	TIIn _{0,5} Co _{0,5} Se ₂	Note
1.	300	577	1741	2839	2951	
2.	320	586	2442	3652	3460	With relative
3.	350	592	3170	4841	5011	deformation
4.	375	610	3930	5184	5928	$\varepsilon = 0,57 \cdot 10^{-3}$
5.	410	655	4242	6088	7466	

Thus, strain gauges made of $TlIn_{1-x}Co_xSe_2$ crystals make it possible to provide high registration accuracy under temperaturecontrolled operating conditions. And in conditions of variable temperature, it is necessary to take into account the appropriate temperature corrections.

Table 3. Temperature coefficient of strain sensitivity (G_T) of single crystals of solid solutions $Tln_{1-x}Co_xSe_2$ on the composition.

N₂	T _{cp} , K	TIInSe ₂	TIIn _{0,99} Co _{0,01} Se ₂	TIIn _{0,9} Co _{0,1} Se ₂	TIIn _{0,5} Co _{0,5} Se ₂	Note
1.	310	0,078	2,01	1,43	0,86	
2.	325	0,052	1,64	1,41	1,39	$T = 20 + \frac{1}{4} AT$
3.	337,5	0,034	1,67	1,10	1,34	$\Gamma_{cp} = 20 + \frac{-\Delta}{2}$
4.	355	0,052	1,31	1,04	1,39	

Another important feature of $TlIn_{1-x}Co_xSe_2$ crystals from the point of view of semiconductor tensometry was, as already noted, their significant flexibility (elasticity) and mechanical tensile strength; for example, $TlIn_{1-x}Co_xSe_2$ single crystals with dimensions of 0.25 x 1 x 10 mm withstand bending deformation with a curvature radius of up to 6 - 9 mm [5].

 $TlIn_{1-x}Co_xSe_2$ crystals differ from all materials known in semiconductor tensometry by the advantage that the

structural features of their crystal lattice provide splitting in the right direction into filamentous samples with mirror faces and the required geometric configuration.

4. Conclusion

In conclusion, it should be emphasized that the presence of a strong piezoresistive effect in $TlIn_{1-x}Co_xSe_2$ crystals allows

us to hope that highly sensitive displacement, force, and pressure sensors can be created on their basis. acceleration and torque sensors. It should also be noted that it is possible to significantly increase the sensitivity of sensors from single crystals of $TIIn_{1-x}Co_xSe_2$ solid solutions to measured values using temperature and optical illumination. The latter feature provides the simplest technology for manufacturing strain gauges; on their basis, a promising highly sensitive material appears for creating a modern strain gauge measuring transducer used to study the physical properties of materials, strains and stresses in parts and structures of the aviation and oil refining industries.

These strain gauges have a certain advantage compared to materials known in the literature:

- 1. small dimensions and weight;
- 2. short inertia, which allows the use of strain gauges for both static and dynamic measurements;
- 3. has a linear characteristic;
- 4. allow to carry out measurements remotely and at many points using the method of multipoint strain gauge;
- the method of installing them on the parts and structures under study does not require complex devices and does not distort the deformation field of the part under study;
- 6. The work of strain gauges is based on the phenomenon of the piezophotoresistive effect, which consists in changing the active resistance of conductors when they are simultaneously exposed to mechanical deformation, temperature and optical illumination.;
- 7. The properties of these crystals remain stable with thousands of repetitions of the deformation and temperature test cycles at variable deformation ($p = \pm 1.4 \cdot 10^7$ Pa) does not exceed 1.0 2.3% and they are more stable at critical temperatures and long-term loads compared to with strain gauges known in the literature, which indicates that single crystals of TlIn_{1-x}Co_xSe₂ solid solutions are promising materials for electronic technology.

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Experimental Validation of TCal for DC Voltage Calibrations Through Internet

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Abstract: In 2018, as contribution to the area of Metrology for Industry 4.0, the concept of Touchless Calibration (TCal) was introduced. In the next three years, in many papers presented on conferences, the most important aspects of the TCal were considered. All these considerations showed that the TCal could provide a benefit for the manufacturing companies in regards the calibrations of the measurement systems used in the production processes. The next step was the experimental validation of the TCal for DC voltage calibrations and, it was done for two possible cases. The results, analysis and comments on the practical experiment in both cases, were pretty much encouraging. The work presented in this paper deals with the experiment regarding the case of use of TCal through Internet for the companies in the manufacturing industry. The experiment is done for DC voltage calibrations in the range from 0 to 10V by using a VFC (Voltage to Frequency Converter) as a Sensor&Transducer and a FVC (Frequency to Voltage Converter) as a Sensor & Actuator. The experiment is designed and executed without any physical connection between the Sensor&Transducer and Sensor&Actuator. The idea was to investigate the use of TCal through Internet, without the digital communication provided by the Industry 4.0 network. The focus was set on the worst-case scenarios. In this paper, it is shown that, the TCal through Internet can be used by the manufacturing companies for the calibration of measurement systems used to measure DC voltages in the range from 0V to 10V with tolerances (USL – LSL) bigger than 1.0677V ($\pm 0.534V$).

Keywords: Industry 4.0, TCal, Touchless Calibration, Voltage Calibration

1. Introduction

The concept of Touchless Calibration (TCal) was introduced in 2018 [1] as contribution to the Metrology for Industry 4.0. The idea was to use the advanced digitalization of the production processes, which will be provided by Industry 4.0 and to decrease the costs, needed resources and the speed of calibrations for the measurement systems in the manufacturing industry. For the last few years, many aspects of TCal were analyzed with intention to determine and, possibly, to check its feasibility and its range of use in the manufacturing companies.

The considerable analysis of the Type A and Type B uncertainties [2] showed that the TCal is superior regarding the Type A uncertainties comparing to the classical calibration. Regarding the Type B uncertainties, the TCal highly depends on the method chosen for transducing the calibration data at the Transmitter side and its recreation at the Receiver side. The Cost-Benefit analysis [3] in regards the costs and the time,

showed that there is considerable benefit of using the TCal by the manufacturing companies. In the scope of the requirements for the laboratories expressed by ISO 17025:2017 standard, the FMEA for TCal was produced and analyzed [4] for voltage calibrations. It showed that there are no considerable risks to implement TCal in the laboratories. Having in mind that, the most critical for decreasing the Type B uncertainties and with intentions to provide more guidance for general application of TCal, some considerations regarding the method chosen for TCal were presented in [5].

At the end of 2020, the experiment for validation of the TCal was executed in the calibration laboratory of the Institute for Measurements and Electric Materials at the Faculty of Electrotechnics and IT (FEIT) in Skopje. The experiment [6] provided the criteria in which situations, based on the product tolerances, the TCal could be used in the manufacturing industry for DC voltage calibrations in the range from 0 to 10V.

2. Previous Works in Regards Internet Calibration

Internet and its benefits are highly appreciated in the scientific community, so it is understandable, that in the past two decades, there were few attempts to provide calibrations of measurement systems through Internet. Anyway, most of these attempts were limited in their content and their applications.

A paper presented in IEEE Transactions on Instrumentation and Measurement by M. M. Albu et. al. in 2005 [7] was regarding the communication capabilities embedded in modern measurement system. The design of secure communication system for Internet-enabled calibration services was considered by M. Jurchevic et. al. [8]. An excellent paper was presented in Measurements (Elsevier) by T. Kobata et. al. in 2012 [9]. It was regarding the Internet-supported calibrations for measurement systems used for the pressure measurements.

The most theoretical and practical efforts to promote the Internet calibration were put by O. Velychko who, alone or together with co-authors, has published few papers regarding this topic. His paper [10] at X International Congress of Electrical Metrology (X SEMETRO) deals with calibration of Digital Multimeters for electrical signals, a topic similar to the one presented in this paper.

The main point of all these efforts was that they use a Transferring Standard which is calibrated in the laboratory where the Reference Calibration Standard (RCS) is. The Transferring Standard is then sent to the manufacturing (customer) laboratory and the calibration is done at the customer location. So, the Internet services are used only for the remote monitoring and control of the Transferring Standard by the calibration laboratory.

The concept of TCal is quite different [1, 2]. With TCal, there is a Sensor&Transducer which transduces the calibration data from the RCS in the calibration laboratory and these data are sent through Industry 4.0 network to the company's laboratory. There, the received data are recreated (an inverse transducing is done) by the Sensor&Actuator and recreated data are used for the calibration. To provide traceability and to increase the accuracy of the calibrations, the process of Relative Calibration is executed between the Sensor&Transducer and Sensor&Actuator in the company's laboratory. When the necessary pairing between these two devices is achieved [2], the Sensor&Transducer is sent to the calibration laboratory and connected there to the RCS.

So, if the TCal is used, there is no travel of the measurement system or any standard between the calibration and company's laboratories. Only the Sensor&Transducer travels and there is only interchange of the data between the calibration and company's laboratories.

3. Experiment for Checking the TCal Through Internet

The experiment, used to check the suitability of TCal

through Internet calibrations of DC voltage digital multimeters in the range from 0 to 10V, is similar to the experiment used for the TCal validation explained in [6].

The experiment and connections between the instrumentation are presented on Figure 1.



Figure 1. Connection of the devices for TCal for DC calibration through Internet.

As it can be seen on Figure 1, in the "calibration laboratory", there were Voltage Standard, VFC and Frequency Meter (FM). In the "company laboratory", there were Signal Generator (SG), FVC and UUT.

Of course, the "calibration laboratory" and "company's laboratory" were just simulated. The experiment was done in the same laboratory as the experiment in [6] and the same instrumentation was used (Figure 2):

- 1) digital multimeter Fluke 8846A used as UUT;
- Voltage calibration standard Fluke 5500 used as Voltage Standard;
- 3) Voltage to Frequency Converter (VFC); and
- 4) Frequency-to Voltage Converter (FVC).

In addition, there was a need for Frequency Meter (Fluke 8846A was used) and Signal Generator (Fluke 5500 was used).



Figure 2. Calibration system used for TCal for DC calibration through Internet.

3.1. The Experiment

The experiment was conducted by alternate changes of the Calibration Laboratory configuration (upper part of the Figure 1) and Company Laboratory configuration (lower part of the Figure 1). The reason for that is that the Fluke 5500 was alternatively used as Voltage Standard and as SG and the Fluke 8846A was alternatively used as UUT and as Frequency Meter in the different phases of the experiment. So, the overall experiment was done in two configurations, each of them

executed as separate phase. It means that there were two phases where two configurations were changed alternatively.

The first phase was:

The configuration for the "calibration laboratory" was set: The Fluke 5500 (as Voltage Standard) was connected to the input of VFC and the output of the VFC was connected to the Fluke 8846A (in the mode of operation as Frequency Meter).

The operator will adjust the voltage of 1V on the Fluke 5500 and he will read the frequency shown on the Fluke 8846A (the "eye" on Figure 1). The operator will write it, in previously prepared, measurement table. When this is done, the Fluke 5500 and Fluke 8846A would be disconnected from that configuration.

The second phase was:

The configuration for the "company's laboratory" was set: The Fluke 8846A (as UUT) was connected to the output of FVC and the input of the FVC will be connected to the Fluke 5500 (in the mode as Signal Generator).

The operator will adjust the frequency (corresponding to 1V from the first phase) on the Fluke 5500 and the voltage shown on the Fluke 8846A will be read by the operator. He will write the measured value in, previously prepared, measurement table.

These two phases will be changed alternatively for each voltage in the range from 1V to 10V in increments of 1V.

How this experiment simulates the TCal in the reality?

The simplified version looks like this:

The manufacturing company will purchase the VFC and FVC for the ranges of DC voltages which are subject of calibrations. The company will execute the Relative Calibration in its laboratory and they will send the VFC to the calibration laboratory. The calibration laboratory will connect the input of the VFC to their standard and the output to the Frequency Meter. The readings of the Frequency Meters will be presented to the Internet dedicated channel on the calibration laboratory website. The operators in the company's laboratory will have a User Name and Password to access this dedicated channel and they will read the output of the Frequency Meter.

In the company's laboratory, the input of the FVC will be connected to the Signal Generator and the output to the UUT. The read value from the Internet channel will be adjusted on the Signal Generator. The output of the FVC will generate the voltage which will be used to calibrate the UUT. Different voltages will be represented through different frequencies and the changes of the calibration voltages will be periodically provided in reasonable time intervals.

Of course, there will be some signed agreement in advance, between the calibration laboratory and the company, so all details about timings and transfer of data will be coordinated. In addition, all legal matters will be clarified.

3.2. Practical Realization of VFC and FVC Devices

The VFC and FVC are the same devices as for experiment explained in [6].

The VFC is based on the VFC 320 integrated circuit (produced by Burr&Brown Corporation) and the FVC device is based on the LM2907N integrated circuit (produced by National Semiconductor). To provide better accuracy and

stability of the devices, particular emphasize is given to both power supplies.

For the VFC power supply, the 78L15 and on the 79L15 integrated circuits were used, because there is need for +15V and -15V. In addition, two lowpass filters in π -configuration were used to provide better stability of the voltages.

The FVC power supply is made to provide +13V and it is based on a switch technology by using a TNY254P device (Tinny-Switch II produced by Power Integration Inc.). This component is separated from the output with a CNY17-2 optocoupler (produced by Vishay). The voltage of 13V is chosen with intention to provide 30% more voltage than the highest voltage of 10V used for calibration.

Procedure for TCal through Internet

The following calibration procedure was used to check can the TCal be used for DC voltage calibrations through Internet:

- 1) All devices (Fluke 5500, VFC, FVC and Fluke 8846A) were switched on and a 15-minute warming time was given in order to stabilize the input and output signals;
- 2) The Relative Calibration [2] for pairing between the VFC and FVC was executed. The Fluke 8846A and Fluke 5500 were used to provide the pairing. The 10 measurements in 5 series, each with additional adjustments, were used for the pairing;
- 3) For the calibration itself, the 10 series in total with 10 measurements in each series, in both phases and configurations, were executed. Each series started from 1V and continued, in increments of 1V, until reaching 10V;
- 4) Before starting each of the series, the VFC and FVC were not switched off because there was no need to do that due to alternate connections and disconnections for the two configurations necessary for the two phases;
- 5) After finishing all 10 series, the Voltage Standard (Fluke 5500) was connected directly to the UUT (Fluke 8846A) and the classical calibration was executed with 10 measurements (each in increments of 1V) in the same range from 0 to 10V; and
- 6) All measurements were analyzed and compared with the classical calibration results and the manufacturing industry's requirements for the manufacturing tolerances and for the Measurement System Analysis (MSA) [6].

4. The Analysis of the Results

The same criteria, as explained in details in [6], were used also to analyze the results from this experiment. The used criteria are for the manufacturing companies (tolerances and MSA) and these two criteria have more importance than those for scientific purposes (based on the uncertainties presented by the standard deviations).

For more details how the criteria for manufacturing tolerances were established, you may consult [11-15]. The basis for this criterion is the Precision Index (C_p) which is defined as:

$$C_P = \frac{USL - LSL}{6\sigma} = \frac{USL - LSL}{V_T} \tag{1}$$

where USL - LSL is the range of tolerances and V_T is total

variability of the used measurement system calculated by the use of Average and Range (A&R) method (known also as Gauge R&R or GRR) for the MSA. By this method, the V_T is calculated as:

$$V_T = \sqrt{R_p^2 + R_d^2} \tag{2}$$

The values for the R_r (Repeatability) and R_d (Reproducibility) are calculated by:

$$R_p = \frac{6 \cdot AR}{d_2} \tag{3}$$

$$R_d = \sqrt{\left(\frac{6 \cdot AD}{d_2}\right)^2 - \frac{R_p^2}{n \cdot r}} \tag{4}$$

where AR is the Average of Ranges (see Table 5 in the Appendix); the d_2 is a coefficient which depends on the number of operators (3) and the number of series (10 measurements each series) by each operator. In this case, for 3 operators and 2 series by each operator, the value of d_2 is equal to 1.91; AD is the Average of Differences (see Table 6 in Appendix) and $n \cdot r$, in this case, is 20 (2 operators x 10 measurements in each series).

Having in mind that for the MSA there is need for 3 operators and 2 series for each of them, there is need for 6 groups of data. These data were calculated by scaling the values [6] from the measurements of 1V (Session 1.1), 3V (Session 1.2), 5V (Session 2.1), 7V (session 2.2), 9V (Session 3.1) and 10V (session 3.2).

For more details how the criterion for the MSA was established, you may consult [16-18]. For more details how the comparison of TCal and classical calibration is done, you my consult [6], 19-22].

The criteria for the manufacturing processes and the MSA are actually combined into one criterion expressed by:

$$USL - LSL > C_p \cdot V_T \cdot 6\sqrt{82} \text{ or}$$
$$USL - LSL > 17.93 \cdot V_T$$
(5)

4.1. Comments Regarding the Results of TCal for DC Voltages by Comparing Uncertainties

Considering the results of presented in Table 2 in the Appendix, it can be noticed that for all measurements, the TCal through Internet, can achieve an accuracy of up to 10mV. In all range from 0 to 10V, the difference between different measurements is on the 2^{nd} and the bigger decimal places.

For the comparison of the values of Type B uncertainties (σ_{ds}) for TCal [6] to the values of Type B uncertainties for classical calibration (Tables 2 and 3 from the Appendix), there is need to know the DC voltage uncertainty for the classical calibration in the range of interest (between 0V and 10V). Calculating the average value of the error [21, 22] from the Table 3 of the calibration uncertainty for classical calibration is 0.0000524.

Using the data in the Table 2, for the calculation of the average standard deviation for the TCal (σ_{ds}), gives the result

of 0.0060161. Comparing these two values, for TCal and for classical calibration, it can be noticed that the Type B uncertainties for TCal are bigger 149 times.

It may look inappropriate, but please have in mind that this experiment was executed by having in mind the worst-case scenarios. In addition, please have in mind that theoretical calculations, done before the experiment predicted that this uncertainty will be approximately 330 times bigger for the TCal than for the classical calibration. So, the practical realization of TCal through Internet showed, approximately, two times better results than theoretical prediction.

Looking at the results and the analysis for each voltage in the range from 0 to 10V, it can be concluded that the manufacturing company can use TCal for calibration of their multimeters, only if the required range of accuracy is not bigger than 10^{-1} . This is the same criteria which applies for scientific purposes.

4.2. Comments Regarding the Results of TCal for Manufacturing Companies in Regards the Tolerances and MSA

The point in this analysis is given to finding the tolerances established (or accepted) by the manufacturing companies if they would like to use TCal through Internet for calibration of their multimeters for DC voltages from 0 to 10V.

For this purpose, the (5) is used. By including, calculated from the experiment, the value for the V_T in (5), the result will be USL – LSL = 1.0677V. It means that the manufacturing companies may use the TCal through Internet if their tolerances for the DC voltage measurements are $USL - LSL = \pm 0.534$ V.

5. Conclusion

It can be noticed that, by using the criterion with uncertainties for the TCal through Internet, the TCal can be used when the manufacturing company is satisfied with the accuracy of 10^{-1} .

However, this is not applicable criterion for the manufacturing companies, so the TCal through Internet can be used there for the calibration of any measurement system used to measure DC voltage in the range from 0 to 10V with tolerances bigger than $USL - LSL = \pm 0.534V$.

6. Discussion for Improvement

This is the criterion which is coming from the connection of the C_p and MSA. Anyway, for proper execution of the MSA for the manufacturing companies, there are plenty other parameters (linearity, sensitivity, etc.) which need to be considered [17]. In this work and in the [6], the emphasize is given only to the V_T , because this is the biggest factor that contributes to the applicability of the TCal [1, 2]. All other parameters for the MSA, are same as for the classical calibration, so they were not included in the analysis.

Furthermore, the experiment and the analysis were done for the worst-case scenarios which can be produced. For example, the value for $C_p = 1.33$ was used, but in reality, $C_p = 1.67$ (even $C_p = 2$) can be used as well. Using the $C_p = 1.67$, gives a $C_p = 1.33$ for the product variability [17] and the rest (1.67 - 1.33 = 0.34) can be associated to the V_T . If the $C_p = 1.67$ instead $C_p = 1.33$ is used, the assumed value for V_T of 10% will increase to 20% [6] which will provide better results about the applicability of the TCal through Internet.

Next area for worst-case scenario is the expression of the calibration results. In the calibration procedure of the Institute for Measurements and Electric Materials of the Faculty of Electrotechnics and IT (FEIT) in Skopje, the results are expressed as $\mu \pm 2\sigma$. This result is associated with the probability of less than 95% that the true value of measurement is in that interval. In this paper, the interval $\mu \pm 3\sigma$ was used, which is associated with probability of 99.73% that the true value of the measurement is in that interval. Using $\mu \pm 2\sigma$ will provide more improvement the results in Table 2 from Appendix.

Another area for the worst -case scenario is calculation of R_p and R_d . In (3) and (4), the multiplication with 6 is used which is again, very strong requirement, because it represents 99.73% of the Repeatability (R_p) and Reproducibility (R_d)

ranges. In the automotive industry, where the MSA is requirement for the ISO/TS 16949 standard certification, the multiplication with 5.15 is used in (3) and (4). With this value the R_p and R_d ranges will be 95%. Using this value in (3) and (4) will additionally improve the results for USL - LSL.

Also, having in mind that as Frequency Meter and as Signal Generator were used Fluke 8846A and Fluke 5500 respectively, using the high-end Frequency Meter and Signal Generator will also improve the results.

Finally, this experiment was done by the VFC and the FVC devices produced in-house. The author did not have the resources available to established companies who deal with the design and the production of high-end measurement equipment. Having high-end VFC and FVC devices, will also improve the picture about applicability of the TCal through Internet.

The presented results in this paper will hopefully provide interest for further development of the VFCs and FVCs. Improving them and using more realistic assumptions regarding worst-case scenarios used for this experiment, will also improve the results presented here.

Appendix

Table 1. Units for results	of experiment regarding	TCal for dc voltage	calibration with frequencies
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Series No. 1			-	Series No. 2			
Standard	FM (Hz)	SG (Hz)	UUT (V)	Standard	FM (Hz)	SG (Hz)	UUT (V)
1	988.9	989	1.0160	1	989.6	990	1.0190
2	1978.4	1978	2.0241	2	1979.5	1980	2.0244
3	2967.7	2968	3.0263	3	2969.4	2969	3.0268
4	3957.0	3957	4.0234	4	3959.0	3959	4.0243
5	4946.4	4946	5.0123	5	4949.0	4949	5.0142
6	5935.7	5936	6.0010	6	5938.7	5939	6.0049
7	6925.4	6925	6.9858	7	6929.0	6929	6.9918
8	7915.3	7915	7.9787	8	7918.6	7919	7.9820
9	8905.7	8906	8.9642	9	8909.3	8909	8.9665
10	9896.4	9896	9.9490	10	9900.0	9900	9.9483
Series No. 3				Series No. 4			
Standard	FM (Hz)	SG (Hz)	UUT (V)	Standard	FM (Hz)	SG (Hz)	UUT (V)
1	990.6	991	1.0190	1	989.1	989	1.0165
2	1981.7	1982	2.0268	2	1978.6	1979	2.0234
3	2972.6	2973	3.0295	3	2968.1	2968	3.0237
4	3963.4	3963	4.0260	4	3957.7	3958	4.0186
5	4954.1	4954	5.0150	5	4947.0	4947	5.0079
6	5944.7	5945	6.0050	6	5936.7	5937	5.9948
7	6934.8	6935	6.9920	7	6926.6	6927	6.9794
8	7925.7	7926	7.9915	8	7916.7	7917	7.9670
9	8916.8	8917	8.9659	9	8907.1	8907	8.9494
10	9908.7	9909	9.9466	10	9898.1	9898	9.9290
Series No. 5				Series No. 6			
Standard	FM (Hz)	SG (Hz)	UUT (V)	Standard	FM (Hz)	SG (Hz)	UUT (V)
1	989.4	989	1.0147	1	989.1	989	1.0150
2	1979.2	1979	2.0208	2	1978.8	1979	2.0210
3	2968.9	2969	3.0205	3	2968.6	2969	3.0205
4	3958.6	3959	4.0163	4	3958.6	3959	4.0167
5	4948.3	4948	5.0018	5	4948.7	4949	5.0039
6	5938.2	5938	5.9909	6	5939.2	5939	5.9916
7	6928.1	6928	6.9770	7	6930.0	6930	6.9787
8	7918.2	7918	7.9641	8	7921.5	7922	7.9683
9	8908.9	8909	8.9480	9	8913.5	8913	8.9560
10	9899.1	9899	9.9265	10	9906.7	9907	9.9380

Series No. 7				Series No. 8			
Standard	FM (Hz)	SG (Hz)	UUT7 (V)	Standard	FM (Hz)	SG (Hz)	UUT (V)
1	990.4	990	1.0159	1	989.3	989	1.0138
2	1981.4	1981	2.0227	2	1979.3	1979	2.0194
3	2972.3	2972	3.0232	3	2969.4	2969	3.0186
4	3963.1	3963	4.0198	4	3959.8	3960	4.0163
5	4953.6	4954	5.0058	5	4950.4	4950	5.0046
6	5944.3	5944	5.9939	6	5941.3	5941	5.9958
7	6935.1	6935	6.9818	7	6932.6	6933	6.9860
8	7926.2	7926	7.9680	8	7924.6	7925	7.9790
9	8917.1	8917	8.9530	9	8917.0	8917	8.9670
10	9909.2	9909	9.9270	10	9911.6	9912	9.9590
Series No. 9				Series No. 10			
Standard	FM (Hz)	SG (Hz)	UUT (V)	Standard	FM (Hz)	SG (Hz)	UUT (V)
1	990.4	990	1.0166	1	989.1	989	1.0136
2	1981.3	1981	2.0247	2	1978.7	1979	2.0193
3	2972.3	2972	3.0254	3	2968.4	2968	3.0169
4	3963.0	3963	4.0212	4	3958.3	3958	4.0118
5	4953.7	4954	5.0078	5	4948.6	4948	5.0001
6	5944.4	5844	5.9936	6	5938.8	5939	5.9876
7	6934.7	6935	6.9824	7	6930.4	6930	6.9750
8	7925.2	7925	7.9668	8	7920.4	7920	7.9615
9	8916.5	8917	8.9511	9	8912.2	8912	8.9470
10	9908.1	9908	9.9238	10	9905.6	9906	9.9239

Table 2. Units for Results of Experiment regarding TCal For DC Voltage Calibration.

Series	1 V	2 V	3 V	4 V	5 V	6 V	7 V	8 V	9 V	10 V
1	1.0160	2.0241	3.0263	4.0234	5.0123	6.0010	6.9858	7.9787	8.9642	9.9490
2	1.0190	2.0244	3.0268	4.0243	5.0142	6.0049	6.9918	7.9820	8.9665	9.9483
3	1.0190	2.0268	3.0295	4.0260	5.0150	6.0050	6.9920	7.9915	8.9659	9.9466
4	1.0165	2.0234	3.0237	4.0186	5.0079	5.9948	6.9794	7.9670	8.9494	9.9290
5	1.0147	2.0208	3.0205	4.0163	5.0018	5.9909	6.9770	7.9641	8.9480	9.9265
6	1.0150	2.0210	3.0205	4.0167	5.0039	5.9916	6.9787	7.9683	8.9560	9.9380
7	1.0159	2.0227	3.0232	4.0198	5.0058	5.9939	6.9818	7.9680	8.9530	9.9270
8	1.0138	2.0194	3.0186	4.0163	5.0046	5.9958	6.9860	7.9790	8.9670	9.9590
9	1.0166	2.0247	3.0254	4.0212	5.0078	5.9936	6.9824	7.9668	8.9511	9.9238
10	1.0136	2.0193	3.0169	4.0118	5.0001	5.9876	6.9750	7.9615	8.9470	9.9239
μ	1.0160	2.0227	3.0231	4.0194	5.0073	5.9959	6.9830	7.9727	8.9568	9.9371
$\sigma_{ds}{}^2$	0.000003545	0.000006120	0.000015860	0.000019096	0.000026187	0.000034745	0.000034281	0.000091530	0.000067945	0.000163203
σ_{ds}	0.001882935	0.002473953	0.003982517	0.004369897	0.005117334	0.005894527	0.005854998	0.009567125	0.008242903	0.012775102
Rounded $3\sigma_{ds}$	0.0056	0.0074	0.0119	0.0131	0.0154	0.0177	0.0176	0.0287	0.0247	0.0383
Final	$1.0160 \pm$	$2.0227 \pm$	$3.0241 \pm$	$4.0201 \pm$	$5.0073 \pm$	$5.9959 \pm$	$6.9830 \pm$	$7.9727 \pm$	$8.9616 \pm$	$9.9371 \pm$
results	0.0056	0.0074	0.0119	0.0131	0.0154	0.0177	0.0176	0.0287	0.0247	0.0383

Table 3. Results For Classical DC Voltage Calibration.

	1 V	2 V	3 V	4 V	5 V	6 V	7 V	8 V	9 V	10 V
Measured	0.999986	1.99997	2.99998	3.99995	4.99994	5.99993	6.99992	7.99991	8.99990	9.99999
Error	0.000014	0.00003	0.00002	0.00005	0.00006	0.00007	0.00008	0.00009	0.00010	0.00001

Table 4. Measurement Results	for MSA	Calculations	Using A&R Method.
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Series	Session 1.1	Session 1.2	Range 1	Session 2.1	Session 2.2	Range 2	Session 3.1	Session 3.2	Range 3
1	1.0160	1.0088	0.0072	1.0025	0.9980	0.0045	0.9960	0.9949	0.0011
2	1.0190	1.0089	0.0101	1.0028	0.9988	0.004	0.9963	0.9948	0.0015
3	1.0190	1.0098	0.0092	1.0030	0.9989	0.0041	0.9962	0.9947	0.0015
4	1.0165	1.0079	0.0086	1.0016	0.9971	0.0045	0.9944	0.9929	0.0015
5	1.0147	1.0068	0.0079	1.0004	0.9967	0.0037	0.9942	0.9927	0.0015
6	1.0150	1.0068	0.0082	1.0008	0.9970	0.0038	0.9951	0.9938	0.0013
7	1.0159	1.0077	0.0082	1.0012	0.9974	0.0038	0.9948	0.9927	0.0021
8	1.0138	1.0062	0.0076	1.0009	0.9980	0.0029	0.9963	0.9959	0.0004
9	1.0166	1.0085	0.0081	1.0016	0.9975	0.0041	0.9946	0.9924	0.0022
10	1.0136	1.0056	0.0080	1.0000	0.9964	0.0036	0.9941	0.9924	0.0017
	1.01601	1.0077	0.00831	1.00148	0.99758	0.0039	0.9952	0.99372	0.00148

Average for Operator 1 Average for Operator 2 Average for Operator 3 **Total Average** Average of Ranges (AR) Repeatability 1.011855 0.99953 0.99446 1.001948 0.004563333 0.02427305 Table 6. Data For Reproducibility Calculations Using A&R Method. Highest Difference Series Smallest 1 0.9960 1.0160 0.0200 2 0.9963 1.0190 0.0227 3 0.9962 1.0190 0.0228 4 0.9944 1.0165 0.0221 5 0.9942 1.0147 0.0205 6 0.9951 1.0150 0.0199 7 0 9948 1 0159 0.0211 8 0.9963 1.0138 0.0175 9 0.9946 1.0166 0.0220 10 0.9941 1.0136 0.0195 1 0.9949 1.0088 0.0139 2 0.9948 1.0089 0.0141 3 0.9947 1.0098 0.0151 4 0.0150 0.9929 1.0079 5 0.9927 1.0068 0.0141 6 0 9938 1 0068 0.0130 7 0.9927 1.0077 0.0150 8 0.0103 0.9959 1.00629 0.9924 1.0085 0.0161 10 0.9924 1.0056 0.0132 Average of Differences (AD) 0.017395

Table 5. Results For Repeatability Calculations Using A&R Method.

Table 7. Values For V_T Calculated Using A&R Method.

Repeatability	Reproducibility	VT
0.02427305	0.054373757	0.05954567

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The Physical Properties of Thermal Expansion of Solid Matter

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Abstract: Thermal expansion is the tendency of matter to change shape, area, and volume in responses to change in temperature. The main objective is to review the thermal expansion of the solid state and its application. This study reviews the thermal expansion of solid state and its applications. The research revues thermal expansion of phases by collecting deferent information from different reference books and also discussed about the next out comes: Thermal expansion of phases is important for building and to bend different material. In this case expansions dap or join on a hot day consecrate in run way Sections in airport expands and this cause cracking to solve this problem. Leave small gap between sections, in anti – scaling values bimetallic strip when the bi metal strip. Is heated they expands more than invar this makes the strip bends with brass on the out sides of the curve, when the bimetal strips heated it curves and breaks contact then temperature reaches a cot value. Thermal expansion of status measurements of temperatures unites of temperature, expansion of solids, and its application. Based on the literature review about thermal expansion of solids: the factors that affecting thermal expansion of solids original length (direct), temperature (direct), material type. Solids in general have the smallest expansively while gases have the greatest expansively and liquids lie in between. Thermal the expansion of phases is important for building and to bend different material. In this case expansion of phases is application to be solid state and its application.

Keywords: Thermal Expansion, Thermometer, Solid Matter, Phase Difference, Gas Expansion

1. Introduction

Thermal expansion is the tendency of matter to change in shape, volume, and area in response to a change in temperature. Temperature is a monotonic function of the average molecular kinetic energy of a substance. When a substance is heated, molecules begin to vibrate and move more, usually creating more distance between themselves. Thermal expansion is linked to a change of temperature. The higher the temperature difference, the more the object will expand. Second, it is dependent on the material. It is clearly related to dilatation with may result from altering other parameters such as pressure, magnetic field, etc. and it level, something about the dependence on volume of the energies of various interaction processes in solid in general, solids expands upon heating, i.e. they exhibit positive coefficients of theta) expansively (CTE). However, a minority of solids show the inverse effect, i.e. of contraction upon heating and thus exhibit negative expansion (NTE) [1].

There has been an increasing amount of interest is solids and their potential application. The underlying mechanisms for NTE have been found to be complex. The reason that most solids have positive CTEs is well understood whit; is due primarily to an increase in the inter atomic bond length, which manifests at the macroscopic level as an overall increase in dimension or Volume [2].

Thermal expansion is the tendency of matter to change shape, area and volume in response to change in temperature. Temperature is mono atone function, of the average molecular kinetic energy of a substance. When substance is heated the kinetic energy of its molecule increases [3].

When people ask about the temperature they ate sally asking how hot or cold something is without thermometer. However most people can do in better then hot or cold or perhaps warm or cool in describing a relative temperature, even throw there are other factors that confuse people about temperature on a basis of the net direction heat low. When we touch an object a property called temperature.

Thermal expansion is generally decreases with increase bound energy which has an effect on the melting point of solids so high melting point are more likely to half lower thermal expansion. Generally liquid expand slightly more thin solids. The thermal expansion of gasses is higher component of that of crystals [1]. At the glass transition temperature, rearrangements that occur in amorphous material lead to character discontinuity allow detection of the glass transition temperature where a super cooled liquid transformers to glass [3].

The coefficient or thermal expansion disease, how the size of an object change which archangel in temperature. Specifically if measures the fractional change in sized per degree change in temperature at constant pressure several type of coefficients half been develop volumetric, area in the liner. Which is used depends on the particular application and which dimensions are considered important. For solids might only be conserved with the change along length or over some area.

The volumetric thermal expansion coefficient is (he tot basic thermal expansion coefficient and the most relevant for fluids. In generally substances. Spaded or contract when the temperatures changes whit expansion occurring in all direction, substances that at the same rate in every direction called isotropic. For isotropic materials the and volumetric thermal expansion ate respectively approximately twice and three times larger than the linear expansion coefficient [4].

1.1. General Objective

The main objective is review the thermal expansion solid and its application.

1.2. Specific Objective

1) To list type of thermal expansion.

2) Explain the thermal expansions of coefficient are solids.

3) To identify the factors affecting thermal expansion.

1.3. Significance of the Project Work

This project thermal expansion of solid and the readers to have insight and give deep understanding of the treatment, waste disposal, cause of increasing solid waste and its contribution to the human health hazardous and environmental related problems. The higher the temperature difference, the more the object will expand.

2. Thermal Expansion of Solid

Thermal expansion depends on: material, size and temperature change [6]. Thermal expansion of state is the increase or decrease of the size (length area or volume) of body due to a change in temperature. Thermal expansion is large for gases, in relatively small, but not negligible for liquids and solids. Thermal expansion of stale is also (he tendency of matter to change its shape area and volume in response to change in temperature most materials expand when they are heated and contract when they are cooled [7].

2.1. Measurement of Temperature

Temperature is a measure of the degree of hotness and coldness of substances while heat is a form energy that transferred from one object to another. Heat is flow energy from hotter region to colder region while temperature indicates the direction of heat flow. Temperature is a basic quantity but heat is a derived physical quantity.

The heat added to a body is the sum of the kinetic energy and potential energy of the particles. That is,

Heat =
$$\sum$$
Kinetic energy + \sum Potential energy

$$Q = \sum KE + \sum U$$

Both heat and temperature are scalar quantities. Heat is measured in joule (J) and temperature is measured in Kelvin (K).

Heat can flow from one region to another in three different ways.

1) Conduction;

2) Convention;

3) Radiation.

Temperature scales are uses in measuring temperature. These are Celsius scale (°C), Kelvin scale (K) and Fahrenheit scale (°F). To design a temperature scale two fixed reference points have to be used. These points are freezing point of water (ice point of temperature) and boiling point of water (steam point temperature). Absolute zero is the temperature at which a substance has no thermal energy. Temperature measures of hotness and coldness of a substance the higher the temperature. The temperature of a substance is a measurement of the average kinetic of the particle within the substance. If the particle in a substance have a hips average kinetic energy than the object is at a higher temperature that is to say if particles on average moving faster than the object is at a higher temperature [5].

The temperature is measured by thermometer, several scales and unit exists for measuring temperature, the most common being the delicious 4 tile is with units called degree centigrade ($^{\circ}$ C), the Fahrenheit height scale with unit called degree Fahrenheit and especially in science the Kelvin scale with units denotes k [7-12].

It is impossible to measure the temperature of a boil accurately by touching or using our sense of perception. an instrument used to measure the temperature is called thermometer. There are many kind of thermometer; a thermometer is specified by choosing a particular thermometric substance and a particular thermometric property of matter is a property that varies predictably with an increase or decrease in temperature [8].

It could be the change of pressure in a gas thermometric, a change in electromotive force in thermocouple, or the change in height of a liquid thermometer.. It is assumed that three is a one to-one relation between the measured valves of the property and the temperature.

Fahrenheit scale: using this scale this scale the normal freezing point of water 32°F and the normal baling point of water is 212°F.

Celsius scale: using Celsius scale normal freezing point of water is 0°C and normal boiling of water is 100°C.

Kelvin: the final temperature unit you may come ay toss is called Kelvin. Note if isn't degrees Kelvin scale has not negative numbers. The low text unperturbed is substance can drop down to'' degree Kelvin or absolute zero [4].

2.2. Converting Unit Temperature

A device used to measure the temperature of a body is known as thermometer. A thermometer may be calibrated to measure temperature in Fahrenheit, Celsius or Kelvin scale. If the upper fixed point and Lower fixed point of two thermometers A and B are given, then the reading of T_A can be changed to the corresponding reading of T_B by the relation given below;

Let us now develop a relationship between any readings in Celsius Scale and the corresponding Fahrenheit, it is obvious that the ratio of the difference in the respective reading of and the intervals of temperature in Celsius scale with the corresponding lower fixed points the difference in the respective reading of and the intervals of temperature in Fahrenheit scale with the corresponding lower fixed points are the same.

Temperature is measure of the average kinetic energy of the particles, heat is the total thermal energy inside the substance (the total kinetics and potential energies added together) on average, 'the particles are moving faster in the spark, however, there far more particles are moving faster in the spark, however, there are more Partech's 1 the water all with a kinetic energy and potential energy. It is important to notice average kinetic energy in any substance some particles will moving faster than others and so this particles will have more kinetic energy than the other [7-9].

2.3. Thermal Expansion

Thermal expansion is the tendency of matter to change its shape, area and volume in response to change the temperature through heat transfer temperature is monotonic function of the average molecules kinetic energy of substance. When substance heated the kinetic materials which contract with increasing temperature are usual, with in limited in size and only occurs within limited temperature ranges. The degree of expansion divided by the change in temperature is called the materials coefficient of thermal expansion. Solid expand when heated its atoms them salves do not expand. But the volume they take up does. When a solid heated its atoms about their fixed points. The relative increase in the size of solids when heated is her metal railway tracks have small gaps to that when the sun heats them the tracks expand in to these gaps and don't buckle solids also undergo thermal expansion. Railroad tracks and bridges, for example, have expansion joints to allow them to freely expand and contract with temperature changes [1].

2.4. Thermal Expansion of Solid

When a solid heated its particles move further apart causing the solid to expand. The amounts of expansion in a solid depend on:

- 1) The nature of the solid;
- 2) The rise of the temperature.
- There are three types of expansion of solid. These are
- a) linear expansion (one dimension expansion).
- b) Area expansion (two dimension expansion).
- c) Volume expansion (three dimension expansion).

The basic properties of thermal expansion; thermal expansion is clearly related to temperature change. The grater the temperature change the more a bimetallic strip will bend.

Second, it depends on the material.

The underlying cause of thermal expansion; an increase temperature implies an increase in the kinetic energy of the individual atoms. In a solid, the in a gas the atoms or molecules are closely packed together, but their kinetic energy (1 the form of small, rapid vibration) pushes neighboring atoms or molecules apart from each other. This neighbor – to neighbor pushing results in a slightly greater distance, on average, between neighbor, and adds up to a larger size for the whole body. For most substances under culinary conditions, there is no preferred direction, and an increase in temperature will increase in temperature will increase the solid's size by a certain fraction in each dimension [10].

- 1) Thermal expansion is the increase, or derivate, of the size (length, area or volume) of a body due to a change in temperature.
- 2) Thermal expansion is large for gases, and relatively small, but not negligible, for liquids and solids.
- 3) The change in size or volume of an object with change in temperature.
- 4) Expansion of solids before and after Appling heat.

When a solid is heated its particles vibrate more rapidly as a result they collide and push each other further apart. When a solid is heated, its molecules gain kinetic energy and vibrate more vigorously. As the vibration become larger, the molecules tiles are pushed farther apart and the solid expands slightly in all directions. Factors that affecting thermal expansion of solids original length (direct), temperature (direct), material type solids in general have the smallest (expensively while gases have the greatest expansively and liquids lie in between. [11, 12].

- List four real life problems due to expansion of material.
- 1) On a hot day concrete runway sections in airport expands and this cause cracking "To solve this problem we leave small gabs between sections.
- 2) On a hot day concrete bridges expand. To solve this problem, we leave small gab at one end and support the other end with rollers.
- 3) Telephone wire contract on cold day lays, Solve this problem, we leave wires slack so that they are free to change length.
- 4) On a hot day railway lines expand to solve this problem,

gaps are left between sections of railway lines to avoid damage of the rails as the expand in hot weather [15].

We have already seen that when a solid is heated its particles moves further apart and hence the solid expands (increases in size). The ball and ring experiment shown in figure is a good demonstration of the expansion of a solid.

The cold metal ball easily passes through the ring, after heating the metal ball expands and it is no longer able to pass through the ring. How much solid expends on heated will depends on the substance how much its temperature increases [12].

2.5. Linear Expansion of Solid

Linear expansion is the increase in length that a heated body makes along a certain line or direction. When a metal rod is heated it expands and increases in length. This expansion is referred to as liner expansion. The diagram in figure below shows rod of length LC (measured in metal) before and alter heating.



Figure 1. The hoop and ball experiment.

According the law of expansion on, the change in length of the rod is directly proportional to both the original length (l_0) and the rise of the temperature (ΔT).

2.6. Linear Expansion of Solid

When a metal rod is hated it expends and increase in length, this expansion is referred to as liner expansion, the diagram in Frig: shows rod of length LC (measured in metal) before and alter heating.



Figure 3. After Heating.

The road's temperature has increase in length on heating the increase in L is difference between the difference between the lengths before heating I and the length after heating 1h.

This cloud be written as I=1h-Ic

So for an j increase in temperature T the fractional increase Length = A II Y he fractional increase in length per unit of temperature (K).

It is found by dividing the fractional increase the temperature AT

A= 1/1 T

Which is the same as a = L/Lc T

A is also known as the same as the coefficient of linear expansion for the solid. It represents the in length n > based of given substance when its temperature it by 1k. it is measured in per k.

When you talk about the expansion of solid in any dimension under the influence o you're talking about liner expansion. Thanks to physics, you can measure how much a solid will expand based on how much its temperature change [10].

The figure shows an image of this phenomenon.



Figure 4. Image of original temperature.





 $Length = L_0 L$

Figure 5. Image of new temperature extension.

Length = $L_0 L$

Linear expansion usually takes place by applying heat y solids. Under thermal expansion a solid object's change in length;

L = is proportional to the change in tempera

T, = you can show this relationship mathematically.

Note: this example us a subscript 0 (Lo, for example), which is common for these kinds of equations.

First Suppose YPU Raise the temperature of an object a small amount:

$$T=T_0+T$$

where T Represents the final Temperature to represents the original temperature.

And T represents the change in Temperature.

The change of temperature results in an expansion in my

linear dimension of when you; you heat a solid, the expands by a few percent and that percentage is proportional to the change in temperature. In general the change in length of a solid is directly proportional to the original length and to the change in temperature and also depends upon the material from which the solid is made L/Lo (the Fraction by which the solid expands).

Table 1. The values for the linear expansion coefficient of some solid are shown in table.

Substance	Linear expansion coefficient (x105/k)
Aluminum	2.3
Copper	1.7
Brass	1.9
Icon	1.1
Concrete	1.2

Table: the linear expansion coefficients of some solids.

This means that an I m iron rod will deepened by 11×10^5 as for every I k rise temperature. With these valves, we can now calculate the in length of material.

2.7. Surface (Area) Expansion of Solids

When metal plate is heated it expands and increases in size. This expansion is called surface or area expansion. If the metal plate of original (A0) is heated to a temperature of (Δ T) then, the increase or change in area (Δ A) of the plate after heating is given by Where, β (beta) is coefficient of surface expansion and is equal to $\beta = 2 \alpha$ The final area of the plate after heating is given by;

1) $\Delta A = A_F - A0$

- $2) A_F = A_0 + \Delta A$
- 3) $A_F = A_0 + A0\beta\Delta T$
- 4) $\Delta A = A_0 \beta \Delta T$
- 5) $A_F = A_0 (1 + \beta \Delta T)$

In the example we have looked at in linear expansion. The sample has been long in comparison to its height and width, so that only significant is in length. In practice many objects are not long and thin and we need to develop a strategy to deal with these objects. We will start by looking at the expansion, in two dimensions of a metal plate [12-15].



After Heating

Before Heating Surface Area=Ac

Surface Area=Ah

Figure 6. Dimensional expansion of an object.

As the plate is heated to causes an increase in temperature T it expand in width and height such that the surface area when heated Ah is longer than the length surface area, AC, so the fractional increase in surface area, B per unit rise in temperature (C° or K) Is given bay

$$B = A/Ac T$$

A=B Ac T

2.8. Volume Expansion of Solids

Volume expansion is take place in three dimensions. Volume expansion is the increase in length, width and height of a substance due to heating. We now need consider the expansion of a solid mm (hive dimensions. When the length breadth and height of the substance all increase on hating, many solids are made up of crystals, regular shapes composed of molecules joined to one another as though on springs. A spring that is pulled back, just before it is released, is an example of feudal energy, or energy that an object possesses by virtue of its position. For a crystalline Saul at room temperature, potential energy and spacing between molecules are relatively low temperature increases as the potential energy in the solid [1-4].

In fact, the responses of solids to changes in temperature tend to be more dramatic, at least when they are seen in daily life, than are the behaviors of liquids or gases under conditions of thermal expansion. Of course, solids actually respond less change in temperature than fluids do; but 1 h since they are solids; people expect their counters to the din movable. Thus, when the volume of a solid changes as a result of an increase in thermal Knot, the outcome is more noteworthy [11].

In general, objects expand in all directions as temperature increase. In the drawing, the original boundaries of the object are shown with soul lines, and the expanded boundaries with dashed lines. (a) Area increases because both length and width increase. The area of a circular plug also increase (b) if the plug is removed, the hole it leaves becomes larger with increasing temperature, just as if the expanding plug were still mi place (c) volume also increases, because all three dimensions increases.



Figure 7. Thermal Expansion in Three Dimensions.

As the temperature of the cube increases from T_0 to T_f it expands in all sides and its volume changes from VO to V f hence $\Delta V = Vf - V0$

According to the law of expansion the change in volume of substances depend on the original volume and the rise of temperature. Mathematically

 $\Delta V \sim V0\Delta T$ $\Delta V = V0 \Xi \Delta T$ $\Delta V = V0 \Xi \Delta T$ $\gamma = 3\sigma$

Where, (gamma) is called coefficient volume expansion and equal to,

1) $\Delta V = V 0 \gamma \Delta T$

2) $\Delta V = Vf \cdot V0$ 3) $Vf \cdot V0 = V0\gamma \Delta T$ 4) $Vf = V0 + V0\gamma \Delta T$

2.9. The Application of Thermal, Expansion of Phase

Thermal expansion widely uses in the following

- 1) Bimetallic strips.
- 2) Bimetallic strip as a switch and Thermostat.
- *Bimetallic strips*

Bimetallic strip is a strip made of two different metals bonded together along their length.

For example if iron and brass bonded together, the coefficient of linear expansion of iron expands more than the iron and the strip bend.

Note that the bimetallic strip bends towards the metal which expands less when heated and bends toward the metal which contrast most when cooled.

$$V_f = V_0 (1 + \gamma \Delta T)$$

Thermal expansion of phases is important for building and to bend different material. In this case expansions dap or join on a hot day consecrate in run way Sections in airport expands and this cause cracking to solve this problem. Leave small gap between sections, in anti – scaling values bimetallic strip when the bi metal strip. Is heated they expands more than invar this makes the strip bends with brass on the out sides of the curve, when the bimetal strips heated it curves and breaks contact then temperature reaches a cot value. Thus switching of the current to the system under control.

Industrial Application of Thermal Expansion:

The application of phases is important or phase it industry are as flows:

For electric ions. Fish tanks, fire alarms car flashers, expansions of holes or mounting trains tires during flight, frozen pipers burst and turn over lake of water is spring. Thermometer most thermometer contain liquid, or (usually alcohol or mercury) this liquid is concerned to flow in one direction only (along the tuber) due to change in volume that are caused because of temperature change.

3. Summary

The temperature of a substance is the indication the average of the particles. Thermal expansion is the tendency of matter to change in shape, area and volume in response to change in temperature through heat transfer. When the kinetic energy of an opposing molecule increases. Thus the molecules begin moving thought usually maintain "a great average separation. All three state of matter [solid, liquid and give] expand when heated. The atom them salves do not expand but the volume they take 'the thermal expansion of solid can be explained in terms of the increasing instance particles that occurs on warming. When a solid is heated its atoms vibrate faster about that is points. Solids actually respond less to changes in temperature than fluids do; but since (Iv wig solids, people expect their contours to be immovable. The volume of a solid change as we testily of an increase in thermal energy, the outcome is more change depends on three dimensions are length, width and height of the objects. We can use this to find by how much the volatile of sample expands the ability of the expansion of different state, gases expand more than liquid and also liquid expands more than solids. Generally, when the temperature of the materials thee and (hose materials is expands in different ways. Gas expands more than both solids and liquids for a given rise in temperature.

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Phonon Effect with Short Drain and Source in Nanowires DGMOSFET SI

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Abstract: Temperature dependence of the drain current of a MOSFET plays a crucial role in the device performance and power dissipation has become a major obstacle in performance scaling of modern integrated circuits, and has spurred the search for devices operating at lower voltage swing. In this paper, we propose the application of a symmetric Double Gate (SDG) in a Tunnel Field Effect Transistor (TFET) to simultaneously optimize the on-current, the off-current and the threshold voltage, and also improve the average subthreshold slope, the nature of the output characteristics and the immunity against the DIBL effects. We demonstrate that if appropriate work-functions are chosen for the gate materials on the source side and the drain side, the tunnel field effect transistor shows a significantly improved performance. We apply the technique of SDG in a Strained Double Gate Tunnel Field Effect Transistor with an Oxide gate dielectric to show an overall improvement in the characteristics of the device along with achieving a good on-current and an excellent average subthreshold slope. The results show that the SDG technique can be applied to TFETs with different channel materials, channel lengths, gate-oxide materials, gate-oxide thicknesses and power supply levels to achieve significant gains in the overall device characteristics. The on-current of these devices is mainly limited by the tunneling barrier properties, and phonon scattering has only a moderate effect.

Keywords: Variability, Microelectronics, Silicon, Nanowire, NEGF, MOSFET, Phonon

1. Introduction

Short-Channel Effects (SCEs) and series source/drain resistance are great challenges in the migration of processing technology to deep sub-100nm regime.

Ultra thin body (UTB) multi-gates MOSFET with source/drain engineering is suggested [11] as an emerging technology to be studied by the International Technology Roadmap for Semiconductors (ITRS) [5].

SCEs has made the scaling of conventional MOSFET structure difficult. As the channel potential of the MOSFET is controlled by all the terminals, drain controllability will increase and gate controllability will decrease when the channel length (L) is scaled down, which will intensify the SCEs [6]. The SCEs may cause large off-current through drain induced barrier low (DIBL) effect. When the SCEs are serious, the drain can turn on the channel even if the gate is biased in the off region, which is so-called "punch-through".

Reducing the gate oxide thickness and increasing the doping concentration used to be the conventional solutions for SCEs control in the past generations [3]. Reducing the gate oxide thickness will directly increase the gate to channel coupling ratio while increasing the doping concentration can reduce off-current and prevent "punch-through".

However, these methods are becoming less effective for two main reasons. Firstly, the equivalent oxide thickness (EOT) of the gate oxide-nitride layer nowadays is less than 1.2nm, which is as thick as only a few atom layers [2]. Further scaling the EOT of the gate dielectric will cause large gate leakage current [1]. Secondly, increasing doping concentration will cause many side effects such as doping fluctuation, lower mobility and higher Source/Drain capacitance [7]. As the degree of doping fluctuations increases at small dimensions, the threshold voltage (VT) variations will be unacceptable for circuit applications if high doping concentration is employed. According to the gate and channel numbers, Multi-Gate structures can be divided into Double gate (DG), Tri-Gate, Pi-Gate and Quadruple-Gate structure [4].



Figure 1. Structure of double gate and Electric field lines originating from the drain for DG MOSFET. IN DGMOSFET, in contrast, lines are terminated on either top or bottom gate.

Although the DG MOSFET is easier to be scaled down, it is much difficult to fabricate a gate under single crystal channel. Selective Epitaxial with Lateral Over-growth (SELO) is an example for planar DG fabrication [13].

Due to the great challenges facing the scalability of bulk MOSFETs, industrial and academic efforts are now being exerted to find a replacement [12]. There are two main directions, adopting new transistor structures or adopting new materials. New transistor structures seek to improve the electrostatics of the MOSFET (i.e. to increase the gate voltage control on the transistor) to reduce the SCEs [10]. Among these structures is the Double-Gate (DG) MOSFET. The DG FET shown in Figure 1 was proposed in 1984 [8]. It was shown that one can improve the immunity to SCEs using a top as well as a bottom gate. The usage of two gates, instead of one, showed excellent gate control on the channel potential [9]. Moreover, the usage of two gates increase the device current capability due to larger gate capacitance per unit area.

In contrast, when another gate is added at the bottom, as shown in Figure 1, the electric field lines will properly be terminated at either the top or bottom gate. Thus the drain control on the channel potential is reduced leading to more immunity to DIBL.

Phonon Dispersion Model

The present work treats all phonon scattering events inelastically, hence the electrons exchange the correct amount of energy (corresponding to the absorption or emission of a phonon) with each scattering event [1]. Particular attention is paid to the treatment of inelastic acoustic phonon scattering, to properly account for energy dissipation at low temperatures and low electric fields. Treating the acoustic phonons inelastically is also important for heat generation spectrum calculations [13].

As in the traditional analytic-band approach, scattering with six types of intervalley phonons is incorporated. Intervalley scattering can be of g-type, when electrons scatter between valleys on the same axis, e.g. from <100>to <-100>, or of f-type when the scattering occurs between valleys on perpendicular axes, e.g. from <100>to <010> [5]. The phonons involved in these scattering transitions (three of f-type and three of g-type) can be determined from geometrical argumentsand are labeled in Figure 5.

Intravalley scattering refers to scattering within the same conduction band valley and usually involves only acoustic phonons [8].

Most typical NEGF codes, both analytic- and full-band, treat intravalley scattering with a single kind of acoustic phonon. This simplification is accomplished by grouping the longitudinal acoustic (LA) and transverse acoustic (TA) branches into a dispersionless mode with a single velocity and a single deformation potential [7]. Historically, TA modes have been neglected because their matrix element is zero for intravalley scattering within a band located at the center of the Brillouin zone [13].

This isn't the case for silicon, hence in a more comprehensive approach (where scattering with *all* phonon modes matters) intravalley scattering with TA modes should be considered. Unlike the traditional approach, this work considers scattering with LA and TA modes separately [4]. Each phonon dispersion branch from Figure 5 (including the optical modes) is treated with the isotropic approximation

$$\omega_q = \omega_0 + v_s q + cq^2 \tag{1}$$

where ω_q is the phonon frequency and q the wave vector. For the acoustic phonons, the parameters v and c can be chosen to capture the slope of the dispersion near the Brillouin zone center and the maximum frequency at the zone edge. The choice ofparameters for longitudinal optical (LO) phonons insures that they meet the zone edge LA frequency. For both TA and transverse optical (TO) phonons the zone edge slope, i.e. their group velocity is fit to zero. The continuous (longitudinal) and dashed (transverse) lines in Figure 5 represent these quadratic approximations, and the fitting coefficients. Quartic polynomials would offer a better fit in the <100>crystal direction but no advantage in the other directions, hence the quadratics are entirely sufficient for this isotropic approximation. They track the phonon dispersion data closely, especially in the regions relevant to electron-phonon scattering in silicon: near the Brillouin zone center for long wavelength intravalley acoustic phonons, and near the frequencies corresponding to intervalley f- and gtype phonons [4]. The quadratics are also easy to invert and, where needed, to extract the phonon wave vector as a function of frequency.

The same approach can be used to extend this phonon

dispersion model to other materials or confined dimensions. Changes in the phonon dispersion due to strain or confinement (e.g. in nanostructures) can be easily included. The challenge in this case lies chiefly in determining the correct modified phonon dispersion to use in such circumstances [3].

The electron-phonon scattering rates need to be numerically recomputed with the modified phonon description (as outlined below), which can be done efficiently if the dispersion is written as a set of analytic functions, like the polynomials in this work.

$$G^{<}(i_{1},i_{2},j_{1},j_{2},k_{1},k_{2},E) = \sum_{n,m} G^{<}_{m_{s}}(i_{1},i_{2},n,m,E) \Phi^{n}_{i_{1}}(j_{1},k_{1}) \Phi^{m^{*}}_{i_{2}}(j_{2},k_{2})$$
(2)

correlation function reads:

2. Physical Models

where $\{\Phi_i^n\}_{n=1,2,...,N_yN_z}$ is the orthonormal set of eigenfunctions solution of the 2-D Schrodinger problem for the *i*th slice of the device, $G_{m_s}^{<}$ is the mode-space counter part of the real-space Green's function and Ny(Nz) indicates the number of discretization nodes along the y(z) confinement direction. The solution in the transverse plane is obtained assuming close boundary conditions with vanishing wave functions at the gateoxide interface [11]. The Green's functions in the mode space are obtained as solution of the two of kinetic equations

$$\begin{bmatrix} E - H_{m_s} - \sum_{m_s} \end{bmatrix} G_{m_s} = I \tag{3}$$
$$G_{m_s}^{<} = G_{m_s} \sum_{m_s}^{<} G_{m_s}^{\dagger}$$

where $\sum_{m_s}^{\leq}$ and \sum_{m_s} are the lesser-than and retarded selfenergies describing the ideal infinite equipotential contacts, H_{m_s} is the mode-space Hamiltonian and I is the identity matrix, for every energy E, and then evaluating the real space electron density through the integral:

$$n_{i,j,k} = \frac{-ig_{\nu}g_s}{\Delta x} \int \frac{dE}{2\pi} G^{<}(\mathbf{i}, \mathbf{i}, \mathbf{j}, \mathbf{j}, \mathbf{k}, \mathbf{k}, E)$$
(4)

Where g_{vs} are the valley and spin degeneration coefficients, respectively [9].

The Poisson equation

$$\nabla \big(\varepsilon(r) \nabla \phi(r) \big) = \rho(r) \tag{5}$$

is solved in the 3-D domain using the box-integration method, where $\varepsilon(r)$ is the position dependent dielectric constant, $\rho(r)$ is total charge density accounting for both electrons and fixed charges, and $\phi(r)$ is the self-consistent electrostatic potential.

3. Electron-Phonon Scattering

Scattering by lattice vibrations (phonons) is one of the most important processes in the transport of carriers through a semiconductor. It is this scattering that limits the velocity of electrons in the applied electric field, and from this point of view transport can be seen as the balance between accelerative forces (the electric field) and dissipative forces (the scattering). The treatment of electron-phonon scattering in NEGF simulations is based on the assumption that lattice

vibrations cause small shifts in the energy bands, and this additional potential U causes the scattering process, with the matrix element

Numerical simulations are performed by self-consistently

solving the 2-D Schrodinger and Poisson equations in the

coherent transport regime in the presence of fixed charge

In order to reduce the numerical burden the coupled mode

space (CMS) approach is used within the NEGF formalism

[4]. According to the CMS approach the discrete electron

centers trapped at the SiO₂/high-kdielectric interface.

$$M(k,k') = \langle k'|U|k\rangle \tag{6}$$

between the initial state k and the final state k'. This matrix element contains the momentum conservation condition, $k' = k \pm q + G$, where q is the phonon wave vector, G is a reciprocal lattice vector, and the upper and lower signs correspond to the absorption and emission of a phonon. The electronic wave functions are typically taken to be Bloch functions that exhibit the periodicity of the lattice. The electron-phonon scattering rate is based on Fermi's Golden Rule, which is derived from first-order time-dependent perturbation theory and gives the transition probability between the two eigenstates

$$P(k,k') = \frac{2\pi}{\hbar} |M(k,k')|^2 \delta \left(E_k - E_{k'} \pm \hbar \omega_q \right)$$
(7)

where the upper and lower signs have the same meaning as in the previous paragraph. It is assumed that the scattering potential is weak, such that it can be treated as a perturbation of the well-defined energy bands, and the δ -function ensures that two collisions do not "overlap" in space or in time, i.e. they are infrequent, or that the scattering time is much shorter than the time between collisions. The total scattering rate out of state k is obtained by integrating over all final states k0 the electron can scatter into. Mathematically, this integration can be carried out over k0 or q with the same result. In those cases in which the matrix element is independent of the phonon wave vector, the matrix element can be removed from the integral, which leaves a total scattering rate directly dependent on the density of states:

$$\Gamma(k) = \frac{2\pi}{\hbar} |M(k)|^2 g_d \left(E_k \pm \hbar \omega_q \right)$$
(8)

where $M(\mathbf{k})$ includes the dependence on the phonon occupation of states, on the wave function overlap integral and on the deformation potential characteristic of the particular phonon involved. 1 The dependence of the total scattering rate on the density of final states has a satisfying interpretation, as it gives us a means for comparing scattering rates in 1-, 2- or 3-dimensional systems. In three dimensions the electron-phonon scattering rate increases roughly as the square root of the electron energy, just like the density of states

$$g_d(E_k) = \frac{(2m_d)^{3/2}}{2\pi^2\hbar^3} \sqrt{E_k(1+\alpha E_k)} (1+2\alpha E_k)$$
(9)

written here in the non-parabolic, analytic band approximation adopted in this work, where $m_d = (m^2 t m l)^{1/3}$ is the electron density of states effective mass.

4. Discussions

Rapid device scaling pushes the dimensions of the field effect transistors to the nanometer regime. In this regime of operation quantum effects play an important role in determining the transistor characteristics. These effects can be accurately predicted only using quantum mechanical based device simulation. Non-equilibrium Green's function formalism (NEGF) provides a rigorous description of quantum transport in nanoscale devices. Computational efficiency is needed to make the device simulation suitable for device design and characteristic prediction. The NEGF method, unfortunately, has the disadvantage of being heavy in computations. The Real-space (RS) representation is the most accurate yet complex representation used in the NEGF. The geometry of fully-depleted double gate (DG) MOSFETs, however, permits the use of a simpler representation, the mode-space (MS) which is computationally efficient.

Electrostatic and carrier transport problems are coupled together. To determine the electrostatic potential by Poisson's equation, we need the carrier distribution. At the same time, the carrier distribution is obtained from transport equations which depend on the electrostatic potential. The solution of the NEGF and Poisson's equation is carried out by the selfconsistent field method. It is an iterative method starts by assuming an initial guess for the potential distribution in the device. According to this potential, the NEGF is used to calculate the electron and hole concentrations in the device. With the electron and hole concentrations are known, Poisson's equation can be solved yielding a new potential distribution. The new potential is compared to the old potential and the solution cycle isrepeated until self consistent solution for the potential is obtained. Selfconsistency criterion is that the difference in potential between two successive iterations drops below a certain tolerance.

In mesoscopic devices electrons may transport from one side of the device to the other side with little or no scattering at all. In this case, the phase of the electrons wave nature plays an important role in the transport process because electrons can interfere instructively or destructively. Thus, we can't describe the transport without including the wave nature of the electrons.

Figure 4 depicts the electron density along the channel of a DG MOSFET calculated by both the semi-classical BTE and the Schrödinger equation. Due to the interference between the incident and reflected electron waves, carrier density oscillations can be seen near the channel barrier edges. At room temperatures, the interference effect is somewhat washed out by the statistics. At low temperatures, however, the oscillation patterns become sharper, indicating strong interference. In this new algorithm, the NEGF simulations do not show any such effect a two-dimensional analytical model for graded channel dual material double gate field effect transistor with oxidespacer has been developed. The potential distribution under oxide spacer regions has been formulated by using conformal mapping technique to consider fringing field effect. The potential profile for channel region has been calculated by solving two-dimensional Poisson's equation and 2-D Schrödinger equation as show in Figure 2.

5. Results

In Figure 2 shows the plot of potential at T=300 K for SI nanowire (D = 3 nm, L = 10 nm) placed on SiO₂ dielectric layer of thickness tox = 1.0 nm at a back-gate voltage of 0 V and a surface donor density of 1×10^{20} cm⁻³. The color scale shows the potential distribution in the nanowire as well as the substrate. The inset on the right is a plot of potential profile in a cross-sectional plane of the nanowire in the middle of the FET channel, indicating the Y distribution of potential with the inset color scale.



Figure 2. Simulated constant potential 2D mesh of channel nMOSFET. The contours are labeled by their band bending w.r.t neutral ni-type regions. The drain is biased at 0.001 V and the gate voltage is slightly below the threshold.

In this section we describe how one can reach the NEGF equations startingfrom the wave-function approach described in the previous section.

This isn't a formal derivation of the non-equilibrium Green's function formalism.

For double gate transistor, the device is fully depleted below threshold voltage, V_{TH} .

As gate voltage is increased, the electron concentration in the channel increases. At threshold voltage, peak electron concentration, n, becomes equal to the doping concentration, N_D . Above threshold voltage, the diameter of this region, where n=N_D, increases as the gate voltage increases.

At flat-band voltage, V_{FB} , he entire cross section of the device becomes neutral. Thus, Double gate transistor follows volume conduction mechanism whereas inversion-mode

MOSFET follows surface conduction mechanism.

Above flat-band voltage, charge carriers are accumulated under oxide-semiconductor interface which is not desirable because it causes surface phonon scattering and also reduces the mobility of the carriers and hence the maximum output current.

The electron concentration contour plots for these different states are shown in Figure 3.



Figure 3. The total 3D electron density, n(x,y), in the on-state. The thin silicon body is volume inverted, and the electron density goes to zero at the top and bottom oxide/silicon interface (1.0nm). Quantum effects due to confinement are accurately captured by n.



Figure 4. The electron density along the channel of a DG-SOI MOSFET calculated by both the quantum transport model for different value of VG.



Figure 5. The I_{DS} vs. V_{GS} characteristics for the model device from both the quantum (blue line) and phonon effect (red line) ballistic transport models. The ballistic off-current is higher from the quantum model due to source-to-channel tunneling.

Figure 5 shows drain current vs. gate voltage characteristic curves for inversion-mode MOSFET (N+NiN+). For inversion-mode MOSFET, below flat-band voltage, V_{FB} , the body is Ni-type neutral and the device is in off-state. As the gate voltage is increased, the intrinsic are pushed away from oxide-semiconductor interface and a negative space charge region or depletion region is created. Thus, above flat-band voltage and below threshold voltage, V_{TH} , the body is fully or partially depleted and the device is off. Above threshold voltage, more negative charges are accumulated, an n-type layer is formed, a channel is created between source and drain and the device becomes turned on.

In Figure 6, Figure 7, Figure 8 There is no presence for the coupling term below the subband energy. This is identified by the blue region below the solid line.

This happens simply because there are no states at this region. Above the subband energy, there is an observed oscillation in the coupling terms versus the longitudinal energy and the position along the x -direction. These oscillations are identified in the graph by the alternation of bright and dark regions. We relate this oscillation to the well known quantum interference effect.

Interference occurs between the electron waves incident and reflected from the energy barrier; the reflected wave interferes constructively or destructively with the incident wave. At high temperature, the quantum interference effect may not be observed in the electron density because it is washed out by the statistics, however, it can be observed at low temperature.

The quantum interference effect can be observed in the local density of states (LDOS) before applying the statistics. For example, the 1st mode 2D LDOS at Tsi=3nm in the off-state is shown in Figures 6, 7, 8. The interference pattern is clear especially for the drain region. In that region, the energy barrier is relatively large and most of the incident wave from the drain contact is reflected blue.



Figure 6. The 1st mode 2D LDOS as a function of Energieand x at T Si = 3 nmin the off-state. The scale on the right side of the graph gives the value of the coupling term versus the intensity where brighter regions mean larger value of the coupling term.

It is seen that the coupling effect between the two modes has larger values above the top of the energy barrier compared with the rest of the device.



Figure 7. The 2nd mode 2D LDOS as a function of Energieand x at T Si = 3 nm in the off-state. The scale on the right side of the graph gives the value of the coupling term versus the intensity where brighter regions meanlarger value of the coupling term.

Also some oscillations can be identified where dark and bright regions alternate. These oscillations are quantum interference effect. However, it is difficult to explain the oscillation pattern because it is generated from the interaction of two modes, and not from a single mode with itself as in Figures 6, 7, 8. A similar behavior was obtained for the higher order coupling terms.

The threshold voltage of a DG MOSFET is defined as the gate voltage when the electron densities in the front or the back channel, formed near front or back Si/SiO_2 interfaces, respectively, equals the doping density of the channel.



Figure 8. The 3rd mode 2D LDOS as a function of Energieand x at T Si = 3 nmin the off-state. The scale on the right side of the graph gives the value of the coupling term versus the intensity where brighter regions meanlarger value of the coupling term.

It should be noted that the minima of front or back surface potential determines the threshold voltage of DG MOSFET.

Moreover, the conventional way of using the surface band bending equal to 2qIB, where IB=ln(NA/ni)kT/q, to define the thresholdcondition becomes irrelevant. An alternative is to define the threshold voltage as the gate voltage at which the sheet density of inversion carriers reaches a value of QTH adequate to identify the turn-on condition. Such a definition is equivalent to the constant-current V_{TH} simulate widely used both in experiments and simulations.

Figure 9 shows the variation of threshold voltage for silicon-film thicknesses (tsi) of 3 nm and SiO_2 layer

thickness (tox) of 1 nm, with the effective channel length ranging from technology nodes 10 nm.



Figure 9. Plot of calculated threshold voltage and threshold sensitivity to body thickness variation as a function of the gate voltage.



Figure 10. Typical as-simulate split $C-V_G$ characteristics for double gate DG MOSFET with 10nm length channel SiO₂/1nm double gate stack for ballistic (blue line) and phonon (red line).

Simulation results of double gate MOSFET for gate capacitance (GC) at different gate voltages and oxide thickness at a constant drain voltage of 10mV is shown in Figure 10. It can be observed from the Figure that in double gate MOSFET as theoxide thickness goes down from 1.5 nm to 0.7 nm the quantum capacitance (QC) increases significantly as the gatevoltage increases from 0.5 V and above. This increment in quantum capacitance is observed up to a gate voltage of 10 mV.



Figure 11. Typical as-simulate split C-Ninv characteristics for double gate DG MOSFET with 10nm length channel $SiO_2/1nm$ double gate stack for ballistic (blue line) and phonon (red line).

Figure 11 shows the Ninv representation of quantum capacitance against gate voltage. It can also be observed from the simulation that at a very low gate voltage such as at 0 V and 1.0 V the value of quantum capacitance is same for all oxide thicknesses considered here.

6. Conclusion

Recent analysis has shown a strong correlation between intrinsic transistor delay, source injection velocity, and lowfield carrier mobility.

In addition, the band structure of silicon results in low transport effective mass and high inversion charge density for electrons on (100)-oriented substrates. As a result, two different Green's functions exist, the retarded and the advanced Green's function.

The electrical characteristics and intrinsic performance of double gate nanowire MOSFETs, simulated using a CMOS compatible top-down approach, were investigated in this paper. The double gate device architecture benefits from excellent gate control, cut-off behavior and immunity to short channel effects compared to planar MOSFETs. However, degraded transport is often observed for both types of carriers due to non-ideal sidewalls with phonon. To overcome this problem, two types of process-based performance boosters, applicable on suspended Si nanowires, were developed in this paper: a novel uniaxial strain engineering method for n-MOSFETs and hydrogen thermal annealing process for ni-MOSFETs. The impact of these performance boosters on the transport properties of double gate nanowire MOSFETs with various channel dimensions were studied in detail.

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Polyelektrolite Solutions and Molecular Descriptions of Biopolymer Macroions

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Abstract: Molecular mass characteristics of samples of ionic biopolymers, including chitosan and fibroin, the manifestation of physical conditions depending on the concentration of macroions, and hydrodynamic, rheological methods were used in the implementation of these studies. These processes depend on the fact that ionic polymers exhibit viscosity in relation to their molecular mass and are sensitive to the effects of the electric field at the expense of ionogenic groups. In order to determine this, the results of studies on the molecular characteristics of basic polymer objects were discussed. When polyelectrolytes are affected by external forces, including mechanical or electrical stresses, gradient fields are created, and macroions move along the lines of force of these fields. Such fields are observed, for example, when a liquid flows from a capillary under mechanical pressure, when the liquid is turned into a stable laminar flow using a rotor, or when ions and macroions move towards the poles (electrodes) during electrophoresis and electrolysis. In general, in the gradient field created under the influence of mechanical influence, the macroions move along the lines of force in rotation and advance, while in the gradient field created under the influence of mechanical stresses for the anote or cathode as anions or cations. The reason for the choice of poles is the sensitivity of anions or cations to the effect of an electric field.

Keywords: Macroion, Fibroin, Chitosan, Viscosity, Solution, Macromolecules

1. Introduction

Today, it is important to obtain ionic biopolymers for specific purposes, including surfactants, the solution of which can be achieved by in-depth study of the movement of macroions and ions in the electric field. The implementation of electrochemical reduction of biopolymers requires the preparation of their polyelectrolyte solutions and the study of the ability of ionic macromolecules to move as giant macroions under the influence of an electric field. These processes depend on the fact that ionic polymers exhibit viscosity in relation to their molecular mass and are sensitive to the effects of the electric field at the expense of ionogenic groups. Ionogenic biopolymers, including chitosan and fibroin as macroions, have the ability to move and electrochemically recover in solution under the influence of an electric field, as well as the formation of micro- and nanoparticles on its basis.

Viscosity of a polymer solution depends on concentration and size (i.e., molecular weight) of the dissolved polymer. By measuring the solution viscosity, an idea about molecular weight could be obtained [1]. Rheological techniques and methods have been used for many decades to describe polymers. Rheology, originally developed and used in synthetic polymers, later aroused great interest in the field of natural (bio) polymers [2]. The electrostatic, entropic and surface interactions between a macroion (nanoparticle or biomolecule), surrounding ions and water molecules play a fundamental role in the behavior and function of colloidal systems [3]. Chitosan based polyelectrolyte complexes favourable physicochemical exhibit properties with preservation of chitosan's biocompatible characteristics [4]. They are reported to promote rapid dermal regeneration and accelerate wound healing. A number of dressing materials based on chitin and chitosan have been developed for the treatment of wounds [5].

2. Experimental Part

Because the chitosan (ChZ) sample selected as the object of study was obtained by rheometry, i.e., deacetylation of chitin in the cutting area, it has a narrow polydispersity index (P = 1.25) and a high deacetylation rate (SDA = 0.75). A relatively convenient viscose method was selected to determine its molecular mass (M). For this purpose, a dilute solution of ChZ (C = 0.2 g / dl) in a 2% solution of acetic acid in water used as the main solvent, ie 2% CH₂COOH [6]. The studies were carried out on the Ubbelode viscometer on the principle of discretely diluting the solution at a temperature of 25°C ($C \rightarrow 0$) and measuring the viscosity (η_c/C) given. The results are shown in Figure 1, a - in the form of a graph of the connection of (η_c/C) to C. In this case, a decrease in concentration (C) results in an increase in (η_c / C) viscosity , i.e., the Haggins formula $\eta_c/C = [\eta] + k[\eta]^2 C$ [7] observed the effect of a polyelectrolytic concentration anomaly without maintaining a linear relationship. This is due to the increase in the viscosity of macromolecules due to the increased interaction of active functional NH₂ groups with the dilution of the solution, ie partial adjustment of the conformation - a relatively large volume as a result of polyelectrolytic swelling, increased viscosity. Such a polyelectrolytic effect indicates that the chitosan molecule exhibits physical states depending on its concentration as a macroion. Such an effect indicates that chitosan is sensitive to the effects of the electric field, and its consideration plays an important role in the implementation of the electrolysis process.

For the study, a powder sample of fibroin (FB) pre-washed from natural silk fiber, washed from oil and minerals, dissolved in CaCl₂ (50%), dialyzed and precipitated in an amorphous state was used [6]. It is convenient to use an amorphous fibron solution containing formic acid (HCOOH) for electrochemical reduction experiments, but in this solvent the process of acid hydrolysis is observed [12]. Therefore, the use of its dilute solution, including HCOOH-H₂O (1: 1), had no additional effect, and moreover, the conformation of fibroin is highly dependent on the pH of the medium. Its isoelectric point (IEN) [8], in which experiments were performed using the Ionomer-75 device and it was found that the IEN was around 3.8–4.5.

3. Results and Discussion

Chitosanni Haggins [7] allows to determine its molecular mass by maintaining viscometric measurements, while maintaining a straight line connection, ie eliminating the polyelectrolyte effect. To do this, it is necessary to eliminate the polyelectrolyte effect of the solution, for which it is necessary to add 2% sodium chloride salt to the solvent in accordance with [9], ie 2% CH₃COOH - 2% NaCl system as a solvent. The result of this study is shown in Figure 1. The connection graph is a straight line corresponding to Haggins's formula, in which extrapolation to $C \rightarrow 0$ was found to be a characteristic viscosity index of $\eta_c/C = [\eta]$ from the condition $[\eta] = 2,00 \ dl \ /g$.



Figure 1. Binding graph of the given viscosity to concentration ($\eta c/C$) (*C*): *a*-ChZ-2% CH₃COOH; *b*- ChZ -2% CH₃COOH-2% NaCl.

Using the quantity of $[\eta]$, the Mark-Kunn-Howing equation [10] and found that the average molecular mass of chitosan was $M_{\eta} \approx ([\eta]/4,97 \cdot 10^{-5})^{1/0,77} = 130000$.

A dilute solution of fibroin (C = 0,3 g/dl) was prepared and the polyelectrolyte properties were investigated by viscometry at 25°C. However, a 2.5 M LiCl-DMFA solvent for which the coefficients of the Mark-Kun-Howing equation [13] were found was used to determine the molecular mass. The results of the study are shown in Figure 2 below.



Figure 2. Graph of binding of the given viscosity to concentration $(\eta c / C)$ (C): a - FB-HCOOH: H_2O (1: 1); b - FB -2.5 MLiCl-DMFA.

In this figure, the graph of the FB-HCOOH: H_2O (1: 1) solution is curvilinear and is characterized by a polyelectrolyte concentration anomaly. Hence, the observation that the interaction of the main functional groups of FB (NH₂COOH) with the dilution of the solution changes unevenly leads to the conclusion that macromolecules as macroions actively interact with the acidic environment surrounding them [11].

The next FB -2.5 MLiCl-DMFA solution bond graph is linear and conforms to Haggins 'law. Extrapolated [14] from it to $C \rightarrow 0$ and found that the descriptive viscosity of the $\eta_c/C = [\eta]$ condition was $[\eta] = 1,2 \text{ dl/g}$. Mark – Kunn-Howing [15] equation using FB to calculate the mean molecular mass $M_\eta \approx ([\eta]/1, 23 \cdot 10^{-5})^{1/0,91} = 295000$.

The determined molecular masses of the samples were

divided by the masses of elementary units (M_o) , and the number of elementary units (n), that is, the degree of polymerization (PD), was found (Table 1). Considering that

chitosan has one NH_2 -amine group and fibroin has one NH_2 and one COOH-carboxyl group, it follows that there are 680 amine and 885 carboxyl groups in XZ and 885 in FB.

Table 1. Examples of ionogenic groups and electrochemical equivalent.

Sample	η	M _η	Mo	N	Ionogen g	roup	Electrochemical equivalent, k, mg/C
ChZ	2,0	130000	161	807	NH ₂	680	0,16
FB	1,2	295000	345	782	NH_2	885	0,16
					COOH	885	0,46

The presence of so many ionogenic groups in a polymer macromolecule is a full reason to consider it as a macroion in a polyelectrolyte solution. One of the important parameters of ionogenic polymers is their electrochemical equivalent, which is calculated according to Faraday's law (F = 96485 C/mol) depending on the molar mass and valency (z) of the ionogenic group.

The results obtained for the ionogenic group of samples are included in Table 1. This case, in general, the parameters defined in this paragraph indicate that macromolecules can move, that is, shift and electrochemically recover under the influence of an electric field, depending on their ionogenic groups.

4. Conclusion

Based on the molecular mass characteristics of objects, ionogenic groups, properties of biopolymers as macroions in gradient areas, effective viscosity, macroions and their behavior in acidic environments, experimental studies have shown that, rheological studies revealed that the molecular masses ($M_{FB} = 295000$, $M_{ChZ} = 130000$). On the basis of the conducted studies, the molecular mass characteristics of the ionogenic research objects, groups and their electrochemical equivalent, the displacement properties of biopolymers as macroions in gradient fields, their effective viscosity were determined and entered as a scientific conclusion, and the practical significance and the behavior of macroions in the polymer solution in the electric field were described.

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Geospatial Analysis of Solar Energy Potentials in Niger State, Nigeria

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Abstract: Solar energy has been identified as the largest renewable resource on earth, and it is more evenly distributed in Sunbelt locations than wind or biomass use. In this paper, geospatial methods were used to examine solar energy potentials in Niger State Northcentral Nigeria. Observed insolation data from Nigeria meteorological station was used over the study period 1988–2018. A Digital Elevation Map (DEM) and solar radiation of the area were used as input parameters. Slope and slope aspect were calculated using the DEM. Slope, slope aspect, and solar radiations of the study area were reclassified and weighted using a Hierarchical Analytical Process (AHP). The variability analysis was done using a standardized variable index. It was observed that the months of February, March, and April were the highest with average solar radiation of $6kWh/m^2/day$, while July and August, on average, had the lowest solar radiation of $4.4kWh/m^2/day$. The results showed the areas with moderate solar energy potential; good solar energy potential and very good solar energy potential. It was revealed that the amount of available solar power in Niger is 414.651×10^6 MWh. The study has demonstrated the potential of geospatial technology in the analysis of solar energy potentials, making it suitable for the investigation of other renewable energies. The results also identified the enormous availability of solar energy potentials in the state as well as the most suitable site for solar energy farms.

Keywords: Solar Radiation, Solar Energy Potentials, Geospatial Methods, DEM, AHP

1. Introduction

All over the world, energy is critical for economic and socio-development activities. There are different types of renewable and non-renewable energy which are obtained from various sources. Most African countries, especially those in the process of development, are not able to produce enough energy, despite the potential of the continent. This insufficiency of energy causes the poverty and under development activities for less privileged peoples.

The objective of the energy system is to provide energy services which begin with the extraction of primary energy, which is then converted into energy carriers suitable for various end-uses. These energy carriers are used in energy end-use technologies to provide the desired energy services [1]. It is widely recognized that solar energy is the most reliable renewable energy source [2]. Solar power is more dependable than wind energy and is not as affected by changes in the climate across the year [3]. However, a large amount of data is needed to design and create solar energy systems, including information on the monthly average of solar radiation on the Earth's surface [4]. Unfortunately, there is a lack of this kind of information on renewable energies, especially in Africa [5]. As a result, the utilization of solar power as a substitute power source is very poor, leaving millions of African people without access to electricity.

In terms of solar energy development and usage, countries of Africa vary significantly. For example, in Morocco in 2013, the world's largest solar power plant was built. Aswan City in Egypt recently built forty solar power stations with the ability to generate 2000 megawatts of power. Tanzania and Kenya have gone far ahead of Nigeria in terms of solar energy development and use. Despite the fact that solar is now a viable source of power in Nigeria, most studies have concentrated on Southern Nigeria, in spite of the fact that Northern Nigeria has even more potential solar energy that can be utilized to partially address the country's original power problem. To study the potential solar energy in Northcentral Nigeria, in spite of the fact that Northern Nigeria has even more potential solar energy that can be utilized to partially address the country's original power issue.

Finding a long-term solution to Nigeria's energy shortage is possible by tapping into the country's abundant solar energy resources. Nigeria's energy mix is not getting any more energy, so finding a long-term solution is crucial. Solar energy is now considered to be the most effective alternative energy resource [6]. There are other alternative energy sources in Nigeria, but solar energy is now the most effective one. Nigeria has an average daily solar radiation of about 5.25 kWh/m²/day, which varies between 3.5 and 9.0 kWh/m²/day at coastal as well as northern locations. This indicates that Nigeria has the greatest opportunity to harness its renewable energy potentials by employing effective strategies to harness renewable energy at a reasonable cost and minimise dependence on fossil fuels [7].

In developing nations where the number of radiation data collection stations is limited and direct measurements of solar radiation aren't sufficient, global solar radiation and sunshine duration can be estimated or deduced according to Rehman, S & Ghori, S. G. [4]. Radiation data can be calculated from other meteorological information in addition to real measured data to provide the required data content for a location or region [8]. This requires empirical modelling.

Several studies have been done to assess the solar energy potentials for various locations in northwestern Nigeria. The studies, include Sambo, A. S. [9] in Kano; AbdulAzeez, M. A. [10] in Gusau. Gana and Akpootu employed Angstrom model for predicting global solar radiation in kebbi State [11, 12]. These studies employed various statistical techniques to model solar radiation directly from solar data, or, indirectly from other climatic variables.

There are no many research conducted at regional and local scales in East Africa related to solar radiation features. However, spatial and temporal variability in global, diffuse, and horizontal direct irradiance and sunshine duration has been examined at eight stations in South Africa and two stations in Namibia, where the time series range between 21 and 41 years. Global and direct irradiance and sunshine duration decrease from Northwest to Southeast, whereas diffuse irradiance increases toward the East [13]. A study was conducted in Kenya in 2013 to investigate the potential of solar energy as a local source of clean and renewable resource for Nakuru city. Nakuru is a moderately high solar energy potential region. The study concluded that Nakuru is rich with abundant solar energy resources, favorable for tapping at both small and medium scale levels [14].

A tool that uses geographical techniques to manage and

analyse geographic data in Geographic Information System (GIS) is gaining in popularity as a territorial planning tool and as a choice of optimal sites for a range of activities and installations [8, 15]. Juhi, J. [16] in a study conducted, used GIS to create thematic maps of monthly global horizontal irradiance (GHI) in Uttarakhand by mapping them district by district. The solar potential analysis discovered the maximum and minimum monthly GHI in every district of Uttarakhand. The map was created in Map Info and linked to the databases for the individual district. Asakereh *et al.* [17] utilised Fuzzy Analytical Hierarchy Process (Fuzzy AHP) and GIS to find the best locations for solar energy farms in Shodirwan region of Iran. GIS interpolation revealed that the annual solar insolation in Shodirwan was the most appropriate.

GIS models were used to map potential harvesting solar energy sites in Niger State and determine prospective energy potential areas based on this research. In addition, the major factors influencing solar radiation in the study area were identified.

2. Study Area

Niger State is a state in the Northcentral region of Nigeria and the largest state in terms of land mass in the country, with the capital in Minna. The area is found to between latitude 10°00'N and longitude 6°00'E of the Greenwich meridian. It is bounded by the states of Kebbi and Zamfara to the North, Kaduna to the North and Northeast, Kogi to the Southeast, and Kwara to the South. The Federal Capital Territory (FCT), Abuja is on Eastern border, and the Republic of Benin is its Western border (See Figure 1).

3. Materials and Methods

3.1. Types and Sources of Data

- 1. The data used for this research was collected by Nigerian Meteorological Agency (NIMET) weather stations at Nigerian airports. Until now, data was recorded using Gunn-Bellani pyranometers at NIMET weather stations, but currently Solarimeter is used to measure solar radiation in Watt per metre square (W/m²) and Campbell-strokes sunshine recorders to log sunshine duration in hours. Thirty years, daily solar radiation data in millijoules per metre square (MJ/m²/day) was provided by NIMET. The data was converted into kilowatt hour per metre square per day (kWh/m²/day) using the International Energy Agency (IEA) General Converter for Energy. This was because solar radiation values are normally presented in kWh/m²/day, which is the amount of sunlight that strikes a square metre of Earth's surface in one day.
- 2. The temporal scope covers 30 year period (1988-2018).

3.2. Methods of Data Analysis

1. The study area's solar energy potential was affected by slope, elevation, slope angle, and slope aspect. The input

variables were solar radiation, elevation, slope, and slope aspect. A multi-criteria analysis was executed to create a pairwise comparison map. Weighted overlaying was used in the ArcGIS 10.3 spatial analyst extension to produce a stability distributed network. To generate a stability distributed network, a method was adapted from Sadeghi, M. & Karimi, M. [18] assessed suitable locations for solar farms and wind turbines in Tehran to increase power transmission in the area. A tabular report displays the mean, minimum, and greatest solar radiation values in the study area. This is a popular technique that is successfully used across the world.

2. Variability Analysis of solar Irradiance.

The standardised variable index (I) was created by McKee *et al.* [19] and can be found in many articles [20, 21]. It was used to determine the degree of discrimination between high

and low values of each climate parameter. It can be found by the following equation:

$$I(i) = \frac{X_i - \overline{X}_m}{\sigma} \tag{1}$$

where $X_{i,i}$ is the value for the considered years or months *i*; \overline{X}_m is the mean for the considered years or months *m*; σ is the standard deviation for the considered years and months.

To sum up, in this experiment, it was concluded that a month and year are normal if their standardized variable index is between -0.5 and +0.5. If their index is greater than +0.5, they are said to be excessive, and if their index is less than -0.5, they are considered deficient. This interval is not very wide but can be used to distinguish between years and months that are deficit or surplus [21].



Figure 1. The Sudy Area.

4. Results and Discussion

4.1. Seasonal Solar Energy Potentials in Niger State

Figure 2 presents the monthly solar irradiance structures and respective standardised solar irradiance at Niger State over the period of 1988-2018. The analysis of figure 2a depicts a bimodal seasonal cycle with peak value attained in February, March, and April. The month of August shows the lowest mean value of solar radiation, while the month of March shows the highest mean value of solar radiation as shown in Figure 2a.

Figure 2b presents the monthly standardised solar

The analysis of this figure shows that four months (July, August and September) are in deficit of solar irradiance. The month with the lowest index value of -2.00 is August. The analysis shows also that three months (February, March and April) are in excess of solar irradiance. Normal months are January, May and December. The Month with highest index value of solar irradiance is March with 1.23.

irradiance in Niger State over the study period.

The estimated monthly standardised variable index for Niger State is 5.43 kWh m⁻² d⁻¹, based on the monthly mean solar irradiance of 5.43 kWh m⁻² d⁻¹. The monthly standard deviation is 0.62. This information indicates that the months with the highest solar irradiance are likely to be the dry season months, resulting in an excess of solar energy. Indeed, due to the scarcity

of water in the dry season, crop production is constrained.

4.2. Spatial and Temporal Extent of Solar Energy Potential in Niger State

From Table 1, we can see that the highest monthly mean solar radiation values of $6.19 \text{ kWh/m}^2/\text{day}$, $6.10 \text{ kWh/m}^2/\text{day}$ and $5.94 \text{ kWh/m}^2/\text{day}$ were recorded in March, April, and February, respectively. The longer days and shorter nights in the sahelian region of Nigeria account for the maximum insolation received during these months. Cloud attenuation reduction during these months results in higher insolation, which is received over the study area.

Results from the study also showed that the minimum monthly mean solar radiation values of 4.49kWh/m²/day and

4.20kWh/m²/day were recorded in Niger state in July and August, as presented in Table 1.

However, the study found that lower insolation levels are due to the presence of clouds, which significantly reduce the intensity of solar radiation reaching the Earth's surface in July and August. The minimum insolation recorded in both months is also attributed to the rainy season. Ojosu, J. O. [22] found similar results in Nigeria, where the rainy season records low solar radiation levels in July and August.

The study also found that harnessing solar energy in February, March and April is peak time in the area. However, there are other months of the year that offer good times for doing so, which vary with locations.



Figure 2. a. Monthly Insolation Pattern (Niger State); b. Monthly Standardised Insolation.

Table 1. Solar Radiation Values in Niger State (kWh/m²/day).

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Mean	5.67	5.94	6.19	6.10	5.58	5.10	4.59	4.20	4.84	5.43	5.84	5.66
Min	5.37	5.02	5.45	5.67	5.17	4.73	4.52	3.79	4.49	5.53	5.47	5.19
Max	5.41	5.76	6.26	6.13	5.71	5.43	4.70	3.95	5.03	5.67	5.60	5.40

4.3. Available Solar Power in Niger State

To determine the available solar power in an area, you will need to know the average solar radiation received and the cross-sectional area of the location. This is illustrated below:

Since Niger state's cross-sectional area =76,363 km²;

and the average solar radiation in Niger State= 5.43 kWh/m²/day;

Cross sectional area X the average power intercepted at any time (Electropaedia, 2016).

Thus, the average power intercepted at any time in the state = $76,363 \times 25.43$

=76,363 X 5.43 = 414651.09 X 10^6 = 414.651 X 10^9 kWh = 414.651 X 10^6 MWh

= 35,653,568.40 tonne of oil equivalent.

4.4. Solar Energy Potential Sites in Niger State

Figure 3 below shows the spatial variation of solar energy

potentials in Niger State highlighting the areas with very high, moderate and low solar energy potentials in the state.

Areas with very high solar energy potentials are: Agwara, Agaie, Bida, Edati, Gbako, Katcha, Kontagora, Lapai, Lavun, Mashegu and Mokwa Local Government Areas (LGAs). These are the most suitable potential sites for exploiting solar energy in the state. Areas with high potentials are: Bosso, Borgu, Chanchaga, Gurara, Paikoro, Suleja and Tafa LGAs.

Areas with moderate solar energy potentials are: Magama, Munya, Rijau, Rafi, Shiroro and Wushishi Local Government Areas. Areas with low potentials is Mariga LGA.

Descriptions of location qualities that should be considered when identifying suitable locations for PV and concentrating solar power projects are given in [23]. The amount of direct, horizontal solar radiation at a site should be $\geq 5 \text{ kWh/m}^2/\text{day to}$ be of real interest. Many locations in Niger state could be utilised in this way.



5. Conclusion

Studying the potential of solar energy in Niger State, this research used geospatial techniques. The result discovered an immense solar energy potentials in the state and the most suitable locations for solar energy installations were identified. It was found that despite Niger State being characterised by high solar energy potentials, spatial variations in the amount of utilisable solar potentials exist across the study area, resulting in moderate, good and very good solar energy potentials. To investigate the factors behind the spatial variation in solar energy potentials, further research is required.



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