INSULATION VERIFICATION USING LOW VOLTAGE AND HIGH CURRENT SENSITIVITY

Tonko GARMA – Željka MILANOVIĆ – Ivan MARASOVIĆ

***Abstract**: The classic approach for determining insulating resistance by using commercial testers is not reliable for testing different types of insulation, especially for cables with one conductor and nanoelectronic oxide-based devices (nanotransistors). In this paper an alternative low-voltage method for measuring insulation resistance based on strongly increased current sensitivity is proposed. The proposed method of measuring insulation resistance at low voltages is realized by using a high sensitivity Keithley SMU 2612 unit. The verification of the proposed method is made by measuring insulation resistance of medical Corkscrew Electrode and gate oxide resistance for nano-scaled MOSFET. Finally, results of measuring insulation resistance obtained by commercial testers and proposed method in the verification process are compared.*

Keywords:
– Commercial insulation testers
– Insulation resistance measuring methods
– Low-voltage resistance measuring method
– Nano-transistor gate-oxide resistance

1. INTRODUCTION

The role of insulating materials is to electrically separate two points being kept on different potentials. The presence of potential difference between two points in an electric circuit will result in voltage which will cause the current to flow from a point of higher to a point of lower potential. In case the current flow between these two points is not desirable, we have to separate it by placing insulating inter-material which will disable the electric current. This paper presents an outline of the insulation material theory and classic insulation properties tests contrasting the latter ones with a novel low voltage insulation resistance tests method. The method will be verified in two different applications. The first one will be dealing with the test of insulation resistance of an electroencephalogram electrode (brain probe) where both classic and novel approaches can be used and compared. The second test will be performed on the highly sensitive nanostructured metal-oxide-semiconductor field-effect transistor, where the novel method serves as an approach for testing gate oxide performance. As we shall show later, a conventional solution based on commercially available testers may not be used in nanoelectronics.

2. STATEMENT OF THE PROBLEM

In insulating materials, even for high electric fields, the current is low and based on a migration of rare free electrons, holes and ions as well as free electrified molecules. These facts can be derived from simplified quantum mechanical considerations [1].

The most important property of insulating materials is its resistance. Due to the nature and role of insulators, insulating resistance should be as high as possible, and therefore, in the first approximation the resistance of the properly made insulation is assumed to be infinitely high. Since insulation properties in general case deteriorate with time, it is necessary to perform periodic control measurements in order to maintain the level of safety requested by authorities. Moreover, regular insulation resistance tests should reduce downtime in different systems [3]. The common causes of insulation failures are either exceedingly high or low temperatures, moisture, strong chemical vapours, etc.

Let us assume that the solid state insulating material is exposed to the influence of the static electrical field and placed between two metal electrodes, between which a DC voltage is applied. Insulating materials contain free and bound charge carriers, which results in an interaction between the field and insulator. Bound charge carriers will be shifted while the process of polarization lasts. After omitting details on polarization which are well described in available literature [4], we will focus on the polarization in dielectric materials. This polarization may be described applying Maxwell equations, leading to expression (1):

$$J_d = \frac{\partial D}{\partial t} = \frac{\partial \varepsilon_0 \varepsilon_r E}{\partial t} = \varepsilon_0 \varepsilon_r \frac{\partial E}{\partial t} \quad (1)$$

Here, $\boldsymbol{J_d}$ stands for dielectric shift current density, $\boldsymbol{D}$ is dielectric induction, $\boldsymbol{E}$ the electric field while ε_0 and ε_r are dielectric constants for vacuum and the specific material, respectively. When a more detailed analysis is applied, one cannot neglect the conduction current I_c and corresponding current density $\boldsymbol{J_c}$. There is no ideal insulator, for example even brand new insulation will have some leakage current. Leakage current will increase as the insulation ages. Shift (displacement) current can be divided into capacitive current and absorption current (Figure 1) [3].

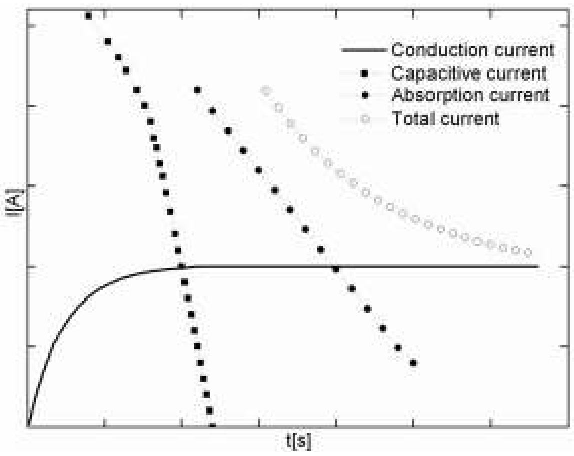

Figure 1. Total current density versus the time for the dielectric material[3]

As it can be concluded analyzing the nature of the total current density, after the polarization process is completed, only the conduction component remains. Considering the time scale, we should point out that the polarization process for most of the dielectric materials lasts less than 1ps [4]. Taking into account only the conduction current, insulation resistance will be given by Ohm's law:

$$R = \frac{U}{I_C} \quad (2)$$

where U stands for the constant DC voltage applied between metal electrodes, as mentioned earlier. On the other hand, conduction current consists of both surface and volume component, $I_c = I_{cs} + I_{cv}$. Details on surface and volume conduction currents can be found elsewhere [5]. The classic approach to determine insulating resistance using the U-I method is depicted in Figure 2.

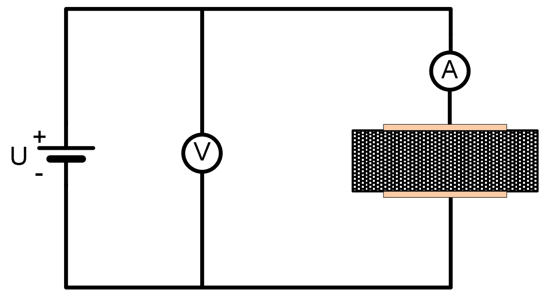

Figure 2. Classic U-I method for measuring volume resistance of the sample

In industrial applications and similar control measurements, for the sake of simplicity and time required to complete measuring procedure, resistance is obtained by direct measurements using insulation testers that display insulation resistance rather than voltage and current separately.

Measurements are done using standardized DC voltages, namely 100, 500, 1000, 2 500, 5 000 and 10 000 V. If intra electrode distance is of order of millimeters, high voltages as ones previously mentioned, will result in extremely high electrostatic fields (order of magnitude MV/m). Classic approaches for insulation tests dictate measurements for different voltages and times. As we have already pointed out, capacitive and absorption current should become negligible as measurements process flows. Due to this, overall current will be reduced only to conduction current, which results in lower current for the same voltage, and which, of course, means higher insulation resistance. Two basic approaches compare insulation resistance after 60 s and 30 s of measurements, as well as after 10 min and 1 min (polarization index). In both cases, to calculate

proper insulation, the result obtained for longer time reading divided with the result obtained for shorter time reading should result in number higher than 1. When measuring insulation for different test voltages, results should be relatively constant or slightly increased, since higher voltage entails more electrons having enough energy to overcome the gap. If current-voltage ratio is relatively linear, resistance should stay within the same order of magnitude [3]. If resistance values decrease when tested at higher voltages, this may be indication of resistance deterioration related to cracking, aging, moisture, etc.
In this paper, we focus on the alternative method for measuring insulation resistance based on strongly increased current sensitivity, enabling formation of substantially high electric fields even for lower voltage levels.

3. NEW METHOD FOR LOW-VOLTAGE MEASURING INSULATION RESISTANCE

With respect to the classic methods of measuring insulation and their disadvantages (primarily the need for high voltage up to 10 000V), we propose a method of measuring insulation resistance at low voltages with very high current sensitivity measurements. Moreover, conventional methods are applied in practice to measure the resistance of insulators with larger dimensions such as insulation resistance of cables or electric motors. Due to larger dimensions of the insulator being tested, the probability of electrical breakdown is increased. The current occurring under the breakdown can be detected and measured. Due to this, the conventional method for measuring insulation resistance can be used in similar cases. The probability of breakdown can be described by electron wave functions and the volume in which the electron can exist [7]

$$P = \Psi \cdot \Psi^{*} dV \tag{3}$$

where $\boldsymbol{\Psi}$ stands for wave function and $\boldsymbol{dV}$ observed volume. According to (3), dielectric with reduced dimensions will result in a reduced probability of breakdown, hence the necessity to provide greater sensitivity for measuring current flowing during the described measurements. Current density in this case can be expressed as follows [7]:

$$J = \frac{\hbar}{2m}\left(\Psi \frac{\partial \Psi^{*}}{\partial x} - \Psi^{*} \frac{\partial \Psi}{\partial x} \right) \tag{4}$$

where $\boldsymbol{\Psi}$ stands for wave function, $\boldsymbol{\hbar}$ reduced Planck constant and $\boldsymbol{m}$ electron mass. With the increased electrical sensitivity this method also involves the lower voltage at which the insulation resistance is measured, therefore, this method is called low-voltage method. To preserve the same range of measuring resistance necessary also for the conventional method, this method however, ensures the measurement of currents in the order of pA. The measurement of these currents requires very sensitive and accurate measuring equipment. At the same time it is important to ensure the protection of the measuring chain from external interference and noise. For greater accuracy of results measurement, the process should be repeated and mean value taken as the relevant measured value. By repeating the measurements process it is possible to determine fluctuations of the insulation resistance at different voltages [9][10]. The analysis of resistance fluctuations can provide information about the structure such as defects density or determination of regime in which dielectric operates.

3.1. Basic idea

The introduction of new methods (based on a measurement unit SMU 2612) is necessary for the measurement of the extremely reduced sample size. Traditional telecommunication and power lines contain two or more parallel conductors. Therefore, measuring insulation resistance is reduced to measuring currents in the dielectric that separates the electrical conductors. In a simplified consideration, in the structure of conductor-dielectric-conductor plate, the capacitor is formed so that the insulation resistance measuring in practice is reduced to testing the quality of the dielectric inside plate capacitor. In the case when the line consists of only one conductor, the second electrode is a probe of the measuring instrument. Since the contact area of the connectors and the dielectric is much lower compared to the case of parallel conductors, the probability of breakdown is much lower. Due to a lower probability of breakdown, current density that might occur (see (3) is also lower and measuring insulation resistance by using commercial insulation resistance testers is not reliable. Another disadvantage of this approach is the impossibility of measurement and detection of damage in insulation in places which are not covered by the measuring instrument probe. Because of these deficiencies in the process of measurement, auxiliary electrode fabricated out of the aluminum foil wrapped around the test insulator was made. The proposed method of measuring insulation resistance at low voltages is realized using a Keithley SMU 2612 unit. The above mentioned device has the ability to work simultaneously as source and measuring device for either current or voltage. Key advantages of this device are, primarily ability to measure current of 1pA range and generate voltage of up to 200V. The method for measuring insulation resistance at low voltages includes voltage from 1 mV to 200V with the measuring current of the order of pA.

Voltage values ranging from 1mV to 100 V are used for the proposed method measurements and 100V to 10kV for the commercial testers. Insulation resistance measurement of the previously described electrode was carried out in two ways:

- Measurement of insulation resistance between the auxiliary electrode and conductor by using the proposed method and commercial instruments. Figure 4 shows the tested electrode with the added auxiliary electrode.
- Measurement of insulation resistance at M = 6 points with 15 cm distance between points without using auxiliary aluminum electrodes (Figure 4). In order to reduce contact resistance measurement probe and the insulation, each measuring point was covered with aluminum foil 1 cm wide, which has increased surface area between the measuring points and probes a reduced contact resistance.

All measurements were made in N = 1000 samples and the obtained value of insulation resistance was considered as a mean value. The value of the whole insulation resistance is defined as the mean value of the resistance measurement points, according to the formula:

$$R_{TOT} = \frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N} r_{i,j} \qquad (5)$$

Novel low voltage method was also applied to test gate oxide resistance of the nano-MOSFET (Figure 5). Since gate oxide must exhibit the barrier properties disabling galvanic bond between gate electrode and nanotransistor body, it may be treated as insulation. Hence, the gate oxide quality can be tested by measuring gate oxide insulation resistance.

3.2. Measurement SETUP

This approach includes measuring the resistance and current with constant voltage value applied on the insulator whose resistance is measured. When configured to source voltage (V-Source) as shown in Figure 3, the SourceMeter instrument functions as a low-impedance voltage source with current limit capability and can measure current (I-Meter) or voltage (V-Meter). Sense circuitry is used to monitor the output voltage continuously and to make adjustments to the V-Source as needed. The V-Meter senses the voltage at the input/output terminals (2-wire local sense) or at the DUT (4-wire remote sense using the sense terminals) and compares it to the programmed voltage level. If the sensed level and the programmed value are not the same, the V-Source is adjusted accordingly. Remote sense eliminates the effect of voltage drops in the test leads, ensuring that the exact programmed voltage appears at the DUT. The voltage error feedback to the V-Source is an analog function. The source error amplifier is used to compensate for IR drop in the test leads [11]. An alternative approach involves measuring the resistance and current with constant voltage value applied on the insulator, the resistance of which is measured.

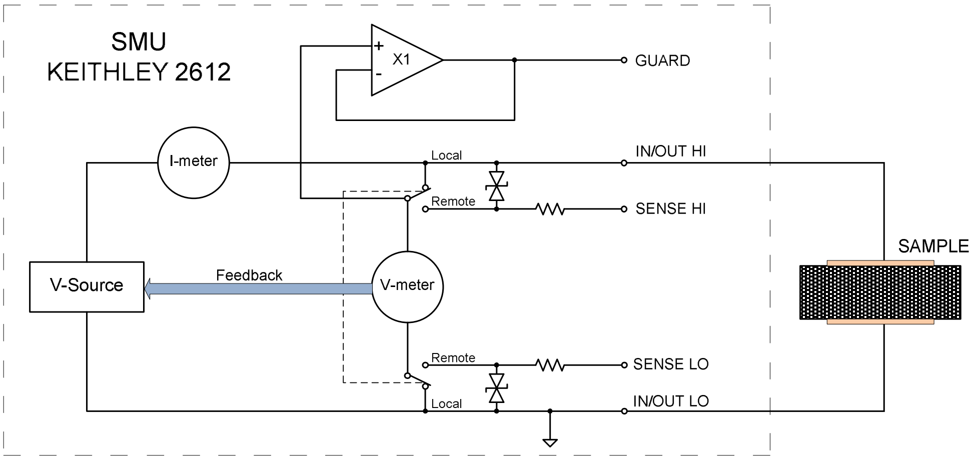

Figure 3. Measurement of insulation resistance at constant voltage

When configured to source current (I-Source), the SourceMeter instrument functions as a high-impedance current source with voltage limit capability and can measure current (I-Meter) or voltage (V-Meter).

3.3. Verification of the proposed method by measuring insulation resistance of medical Corkscrew Electrode

The Corkscrew electrode is a reliable alternative to the disc electrode system. It is easy to insert, requires little preparation and eliminates collodion drying time. It has 1cm hub and is designed to stay fixed in place during surgeries. The needle has 0,60mm in diameter, machine sharpened tip (at 25 degrees angle), and 1,0 m long lead wire. It may be used for both stimulating and recording. [8]. For the safety of both patients and measuring equipment to which the electrode is applied, it is very important that the insulation of the electrode is correct and reliable. The accuracy and reliability of insulation is simply determined by measuring its resistance and the correct interpretation of results. Because of the size and performance of the tested electrodes, it is clear that the traditional methods of measurement cannot reliably determine the insulation resistance (Section 3.1) without adding auxiliary electrode. Therefore, the insulation testing of Corkscrew Electrode is performed by measuring insulation resistance using the proposed method.

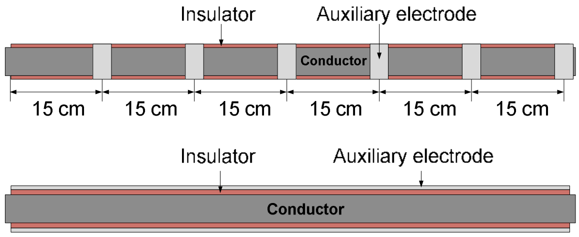

Figure 4. Lateral section of the Corkscrew electrode with measuring points marked (up); Lateral section of the electrode with auxiliary electrode (down).

3.4. Verification of the proposed method by measuring gate oxide resistance for nano-scaled MOSFET

Semiconductor nanowires have attracted significant attention in the last decade for their potential in improving existing or enabling novel devices. An important challenge in the field is to reproducibly control the electronic properties and to fabricate high purity nanowires [6]. Nanowires can be used for the realization of field effect transistors and sensors, whose performance exhibit all the benefits of having high quality nanoscale materials [6]. The nanowires analyzed in this paper are synthesized at Walter Schottky Institute, Technical University of Munich, Germany and are gallium arsenide (GaAs) nanowires grown by Molecular Beam Epitaxy (MBE) and germanium (Ge) nanowires grown by Chemical Vapor Deposition (CVD). What is special about these nanowires is that they are synthesized by avoiding the use of gold in the nucleation and growth process, which should lead into higher purity and improved overall properties. Details on GaAs and Ge nanowire based MOSFETs can be found in [6].Since dimensions of the nanowires and hence nanowire based transistors are extremely small (nanowire diameter is of the order of 100 nm or less), corresponding gate electrodes and oxides are also reduced in dimension. Aforementioned is the reason why classic methods based on commercially available devices may not be used. This fact is coming from the principle of the commercial insulation testers operation, which includes using voltages of the order of 1 kV or more. Voltages of such magnitudes applied across electrodes separated by the distances of the order of 100 nm, see Figure 5, would induce extremely high electric fields resulting in both electrical and thermal destruction of the nanotransistor. Consequently, alternative low-voltage methods are needed for reliable and non-destructive gate oxide resistance tests.

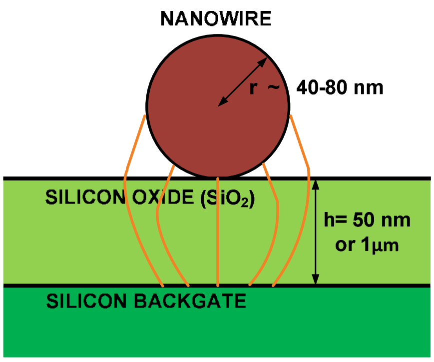

Figure 5. Schematics of the GaAs nanotransistor cross section. Orange lines represent electrical field in back-gate capacitor. Geometrical relations are exaggerated for the sake of clarity

We applied setup based on Keithley 2612 SMU system to bias low voltages (order of 1V) and sense corresponding currents. Results of these verification tests are reported and discussed in section 4.

4. RESULTS AND DISCUSSON

4.1. Corkscrew electrode

Table 1 shows initial results measured on the representative electroencephalogram electrode Corkscrew. These measurements have been performed in the straight forward measuring configuration. As we have already pointed out, geometry of the electrode disables standard measuring protocols. Furthermore, as described in bibliography [3][5], when measuring insulation of the standard symmetric cable, usual field tests as well as laboratory analyses are carried out by applying the bias between the conductors within the cable. Since electrode Corkscrew consists of the only one conductor, test bias has been applied between the first test clip connected to electrode core and the second test clip connected to the insulation. Although straight forward, this method extremely reduced the insulation tunneling probability. Consequently, insulation resistance results obtained using this approach had values in the TΩ range. Table 1 shows an example of the measured insulation resistance obtained with commercially available testers. All results were showing a clear trend indicating that the insulation resistance is out of measuring range, as it can be seen for representative results obtained by reputable insulation tester Megger BM 110. Results measured with other commercially available testers were omitted since they show exactly the same trend. Measurements have been performed on 6 locations placed laterally along the electrode, see Figure 4. All measured values are matching, showing high homogeneity of insulation properties.

Table 1 also shows the result obtained on exactly the same 6 locations along the same representative probe, using novel low voltage and high current sensitivity method, based on Keithley SMU 2612 measuring system. As it can be observed analyzing the table content, SMU 2612 can measure insulation resistance even under described conditions of very low insulation tunneling probability. Unlike classic method where measurements on different positions are displayed together, here we can obtain more precise results and report them separately.

Measurements have been performed using wide range of test voltages. From 1 mV, up to 15 V. In all cases, measured values are laying with measurement range, indicating that this method functions indeed. For same values of test voltages, insulation resistance results are within the same order of magnitude. The general trend is that higher test voltages result in higher insulation resistance. This increase in resistance can be explained simply by analyzing the operation of the device. The proper insulation should have positive resistance, meaning, an increase in voltage will cause an increase in the current. However, if we increase the voltage for the order of the magnitude and resulting current increases, for example, twice, and consequently,

Table 1. Measuring results obtained by commercial tester MEGGER BM110 for upper configuration in Figure 4

Test voltage [V]	**Resistance [GΩ]**(MEGGER BM110)	Test voltage [V]	**Resistance [GΩ]**(New method)					
	P1-P6		P1	P2	P3	P4	P5	P6
500	>51.5	1 mV	0.05	0.11	0.10	0.10	0.37	0.18
1000	>103	10 mV	0.31	0.89	0.23	2.24	1.60	2.21
2500	>256	100 mV	40.61	4.54	8.20	4.97	2.27	4.14
5000	>510	1 V	16.38	111.17	24.00	41.55	92.64	66.87
		5 V	87.69	77.26	69.50	89.27	99.32	51.84
		10 V	97.72	65.71	18.52	101.16	128.44	73.26
		15 V	86.98	82.91	86.64	124.14	75.43	80.08

derived voltage will appear to be higher. In conclusion, insulation, which can lead to different resistances for different test voltages, does not necessarily have to be linear for all test bias intervals. At this point, however, we want to comment measuring configuration. Although being straight forward, this configuration, due to a very small contact surface between the test clip and insulation, has a strongly reduced insulation tunneling probability. Due to this, measuring the insulation resistance becomes challenging and, as we showed, virtually impossible with commercial insulation testers. As it can be seen in Table 1, these testers only show the minimal possible value, not the exact value. Moreover, since there is 15 cm long spacing between 2 measuring points (see Figure 4), this method is not very reliable in terms of proper probe operation. It is not impossible that the insulation damage zone is placed, for instance, in the middle between two measuring points. Although at this point insulation resistance may be well below values in Table 1, this cannot be determined using described method. In order to increase tunneling probability and, consequently, enable measurements with commercially available testers, auxiliary electrode was added by coating the probe with aluminum foil, see Figure 4. This method enabled testing the entire insulation at once, in a way comparable to standard cables with two or more conductors, providing possibility for detection of possible damages. Although an auxiliary electrode changes probe configuration, it enables simpler measuring procedures and comparison of results obtained with conventional testers and new low voltage and high current sensitivity method, based on Keithley SMU 2612 SMU system. As it can be seen from table 2 (left), results obtained from all types of testers (Megger BM11D, Peak Tech 2685 and MA 2075) are placed within the same order of magnitude, no matter which tested voltage was selected. However, comparing results from different testers at the same test voltage, quite high dispersions (2 orders of magnitude) can be detected. Obviously, different producers do not apply the same standards in terms of precision.

This is coming from the fact that instrument sensitivity and precision depend on current detector embedded in insulation tester. The Reader should not be led to wrong conclusion since this fact is not surprising. Insulation resistance measurements in general are not meant to be very precise. Insulation may be considered to be in good condition no matter if value is of the order of 100 MΩ or 10 GΩ. Although these results differ for 3 orders of magnitude, they both mean that insulation is properly made. Since Megger BM11D has the highest current sensitivity among all mentioned testers, we consider those results to be the most reliable.

Table 2 (right) shows results obtained with Keithley 2612 SMU system on the same representative electrode and same measuring configuration using aluminium foil auxiliary electrode. Except for extremely low test voltages (bellow 10 mV), all insulation resistance results are placed within the order of 10 – 100 GΩ, showing quite high homogeneity of results. Moreover, comparing Megger MB11D resultswith Keithley ones, we can

Table 2. Measuring results obtained by different commercial testers (MEGGER BM110, PEAK TECH 2685, MA 2075) for case with auxiliary electrode shown in Figure 4 (bottom configuration) - ***NA- not available***

Test voltage[V]	**Resistance [GΩ]**			**Test voltage[V]**	**Resistance [GΩ]**
	MEGGER BM110	**PEAK TECH 2685**	**MA 2075 (ISKRA)**		**New method**
100	**NA**	**NA**	150 GΩ	1 mV	0.097
500	>51.5 GΩ	**NA**	200 GΩ	10 mV	0.274
1000	>103 GΩ	11.4 GΩ	200 GΩ	100 mV	4.46
2500	73 GΩ	1.32 GΩ	**NA**	1 V	9.79
5000	56 GΩ	2.23 GΩ	**NA**	5 V	55.08
10 000	**NA**	3.3 GΩ	**NA**	10 V	58.25
				100 V	57.24
				200 V	58.78

see they are matching. This comparison is a direct proof of proposed method validity. We have showed that low testing voltage insulation measurements result in valid values in terms of comparison with conventional devices results. To have one more element of consistency, we will be comparing resistance behavior with. high voltage testing. Properly made insulation should not show dramatic changes of insulation resistance (2 or more orders of magnitude) when test voltage gets higher [3]. Both conventional and our low voltage method show this type of behavior, meaning, both methods applied on the same sample show comparable results. Moreover, as we have already pointed out, out of 3 commercial insulation testers, the best one (Megger BM11D) shows the results of the same order of magnitude as ones obtained with new low voltage and high current sensitivity method. The reason why we have introduced the new method arises from practical aspects. Commercially available insulation meters are particularly designed for standard energetic networks. A general rule of thumb is to test the cable with voltage being at least equal to the standard nominal voltage for the network being tested [3]. In the case of standard energetic networks, this is 400 V and that is why insulation meters normally have test voltages of 500V and more. However, our medical electrode operates on much lower voltages, of the order of 1V. Due to this, it was necessary to provide inspecting staff with testing methods which can function under low test bias conditions since our electrode, for example, will never be exposed to 1 kV operating conditions. Comparative tests with conventional devices of different qualities showed high matching results, indicating that our approach actually brings useful values.

4.2. Nanowire based MOSFET (nano MOSFET)

Gate oxide has the vital role in operation of the MOSFET. In a standard MOSFET, a semiconductor is connected to metal source and drain electrodes. These electrodes are used to inject and collect the charge carriers. The conductance of the semiconductor between the source and the drain can be tuned or even switched on and off by a third electrode, gate. Gate is capacitively coupled through a thin dielectric layer. In the case of GaAs and Ge nanowire based MOSFETs, this dielectric layer is made of thermally grown silica (SiO_2) or room conditions grown alumina (Al_2O_3) fabricated out of electron-beam evaporated thin aluminum (Al) films. Details on gate oxide fabrication as well as nano transistor design can be found in [6]. In the case of both a nano MOS transistor and MOSFET in general, and if we employ a p-type transistor body, and apply a positive gate voltage, carriers will be depleted and the conductance reduced. On the other hand, the application of a negative gate voltage leads to an accumulation of carriers thus increasing the conductance [2]. The key element in capacitive coupling between the body and gate is well fabricated dielectric intra-layer. In the case of our nano transistors, the quality of this layer was verified by measuring corresponding resistance.

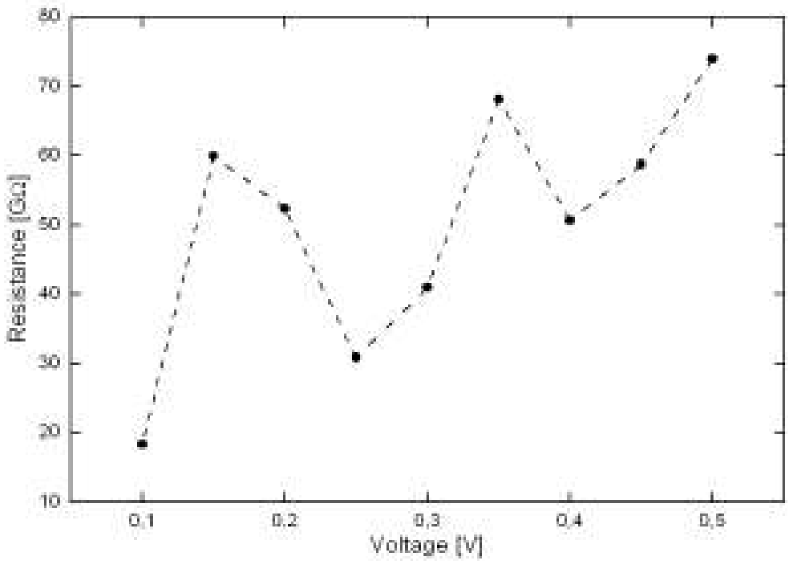

Figure 6. Gate oxide resistance for nano MOSFET

In this particular case, the novel low voltage method is essential. Measuring configuration based on commercial insulation testers and applying voltages of the order of 1 – 10 kV would simply destroy the sample. Let us explain this further. Assuming test voltage of 1 kV, top gate oxide thickness of 10 nm (typical example in the case of our nano transistors) and plate capacitor field line distribution [2], corresponding electrical field generated between the gate and transistor body would have the magnitude of 100 GV/m. This number is much higher than breakdown filed in alumina or silica, 400-900 MV/m, meaning, testing gate insulation with so high voltages would simply burn the gate oxide. That is why the novel low voltage method based on Keithley SMU 2612 system was applied. The test results are shown in Figure 6. Resistance is obtained by standard U-I characterization, where the constant voltage is sourced and corresponding current measured. To reduce the measuring uncertainty, measurements have been performed in 1000 cycles and averaged. As it can be seen by analyzing the magnitudes of the insulation resistance derived from measured current, gate oxide has very high resistance, meaning that the necessary condition for capacitive coupling in the nano transistor is fulfilled. As it can be found in existing bibliography, the quasi-oscillating nature is coming from charging effects, usual in porous thin oxide films [6].

5. CONCLUSION AND OUTLOOK

We proposed a novel method for testing insulation resistance based on low voltage sourcing. The method was verified on electroencephalogram electrode Corkscrew and results compared to results obtained using commercially available insulation testers. This comparison showed acceptable matching between two methods. In this case, low voltage based tests are desirable since mentioned electrode works on voltages of the order of 1 V. Furthermore, additional method verification tests were performed on nanowire based MOSFETs, where gate oxide insulation was tested and proved to be well fabricated. In contrast to the case of Corkscrew electrode, for this particular case, the low voltage method is the only possible solution since the conventional method would result in both electrical and thermal destruction of the nanotransistor. The future work will be orientated towards the application of the same method in constant current measuring configuration, where the current will be sourced and corresponding voltage drop sensed. The comparison between results obtained using this approach and results discussed in this paper will shed new light on the possible use of the proposed method.

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Authors’ address:

Tonko Garma
Walter Schottky Institute, Technical University of Munich
Am Coulombwall 3, 85748 Garching b. Munich, Germany
Željka Milanović
Faculty of Engineering, University of Rijeka
Vukovarska 58, 51000 Rijeka
Ivan Marasović
Faculty of electrical engineering, mechanical engineering and naval architecture, University of Split
Ruđera Boškovića 32, 21000 Split
Tonko.Garma@fesb.hr
Zeljka.Milanovic@riteh.hr
Ivan.Marasovic@fesb.hr