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A New Approximation On The Well-Known Interfacial State Density Of Schottky Diodes With Contacted Interfaces Of Different Materials

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By modifying the interface of the diode with the composition of [Alumina] and [Alumina + GO] (PdNi/Al_2O_3%75+GO%25/n-Si/AlMn), three Schottky diodes were produced along with the reference diode. Some electrical properties at room temperature have been investigated. The basic electrical parameters of the diodes were calculated by applying forward and reverse bias in the dark. The effect of different interface materials on the interfacial state density of diodes was studied. New N_{ss} graphs were obtained by adding the Schottky barrier lowering value to the traditional interface state density equation. Thus, a new N_{SS} perspective has been brought to the literature.

Keywords: *Al_2O_3, Alümina, Graphene, Interface State Density, MS Contact, Schottky Diode, Thin Film*

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1. Introduction

Today, metal-metal and metal-semiconductor materials are heavily used in the production of electronic devices as solutions and alloys due to technological needs. Metal-semiconductor materials in which diodes are used are Schottky diodes, which are one of the basic elements of electronics and are obtained by evaporation of metal on the semiconductor. These production processes have been described in many articles, and the parameters of the diodes have also been calculated. In addition to the basic Schottky diode parameters, there are also derived parameters that need to be calculated. Ideality factor (IF) (n_{IV})[1], barrier height (Φ_{BH}) [1], [2], [3], Cheung functions (Ch1, Ch2) [4], [5], saturation current (I_o), built-in potential (V_{bi}) [6], [7], donor density (N_D) [3], [8], zero-voltage depletion length (W_0 or L_0), interfacial thickness (δ_{it}) [7], [9], interface state density (N_{SS}) [7],[10] and effective Fermi level (E_F) is known as Schottky parameters [7], [11]. In this study, these variables will also be investigated under forward and reverse bias. First, current-voltage (I-V) and capacitance-voltage (C-V) data will be used, and then other parameters will be calculated using derived data.

2. Experimental Details

2.1. Schottky Diode Production Stage and Method

Silicone parts and contact materials to be used in the test are cleaned by standard cleaning method. All test stages are carried out in accordance with the clean room method [12]. After cleaning üç n-type silicon parts with an area of approximately (7 mm x 7 mm) 49 mm^2, the ohmic contact stage is started.

Al%75Mn%25 (constantan) alloy will be used for ohmic contact. A new tungsten boat, pre-cleaned and burned, is attached to the vacuum device, Al%75Mn%25 metals are placed in it (see Table 1). n-Si fractures are taken to the vacuum device and waited until the vacuum reaches a pressure of 5.5x10^{-5} Torr. The Edwards A306/500 evaporator is supplied with current very quickly. The vacuum device is brought to normal atmospheric pressure. The fractures are annealed in a quartz oven at 460 °C in nitrogen environment for 3 minutes, and ohmic contact is made. Tungsten was put into boat aluminum oxide (alumel as powder) (Al_2O_3 (100%)). It is deposited on the shiny surface of silicone. It was called the D2 diode. Similarly, aluminum oxide and graphene oxide (as powder from supplied international Co.) [13], [14], [15] (Al_2O_3 + GO (100% + 25% by mass) were put into tungsten vats (see Table 1). It accumulated on the shiny surface of silicone. It was called the D3 diode. Finally, the diode D1, D2, D3 was put into the vacuum machine, and tungsten was put into the rough mass (Pd75% Ni25%). The vacuum and evaporation process was carried out. Schottky Diodes with different interfaces were obtained. All diodes were carried out with a sieve with a diameter of 0.8 mm with preliminary contact points. The data were obtained in the dark and at room temperature. Finally, I-V and C-V data were obtained. The aim of this study is to investigate the change in the electrical parameters of three different Schottky diodes with altered interface material. In addition to the basic parameters, the traditional interface state density will also be examined. In the literature, there is a large number of traditional state density equations and graphs, just for plain feeding. As a novelty of this study, the traditional state density was reconstructed by the authors by examining it from a new perspective, adding the effective band energy net potential expression and adding the Schottky barrier lowering value. Very interesting interface state density graphs have been reached.

Table 1. Copper-nickel percentages of diodes

Diode No	Front Contact	Interface Material	Back Contact
XX%	Pd75% Ni25%	100%	Al75% Mn25%
D1	PdNi	-	AlMn
D2	PdNi	Al_2O_3 (100%)	AlMn
D3	PdNi	Al_2O_3 + GO (100%+25%)	AlMn

2.2. Ideality Factor

The IF is the essential parameter of a diode. The Schottky diode's current-voltage curves obey to the thermionic current equation [6]. Both case of forward bias, the thermionic current equation is as that:

$$I = \underbrace{AR_n^* T^2 \exp\left(-\frac{e\Phi_{BH}}{kT}\right)}_{I_0}\left[\exp\left(\frac{e(V - IR_s)}{nkT}\right) - 1\right] \quad (1)$$

where; n is the ideality factor, V is voltage, e is the electron charge, R_s is the series resistance, k is the Boltzmann constant, T is the temperature in Kelvin and I_0 is the saturation current. Additionally, R^*_n is the Richardson constant (120 A/cm^2 K^2 for n-type Si) , A is the active diode area, sieve dot radius is 0.4 mm, and Φ_{BH} is the effective barrier height. IF (n) has no dimension and is identified from the slope of the linear of the curve in the case of the forward bias and reverse bias [11], [16]. The n_{FB} and n_{RB} were obtained from the next equation:

$$\frac{1}{n} = \frac{kT}{e}\frac{d(\ln I)}{dV} = tg\,\alpha \quad ; \quad n = \frac{e}{kT}\frac{dV}{d(\ln I)} \quad (2)$$

The values of ideality factor were obtained from I-V. C_s-V and Ch2 functions given in Table 2 and 3. In the present study, main characteristics were only given as I-V data and all parameters were taken in the forward and reverse direction state.

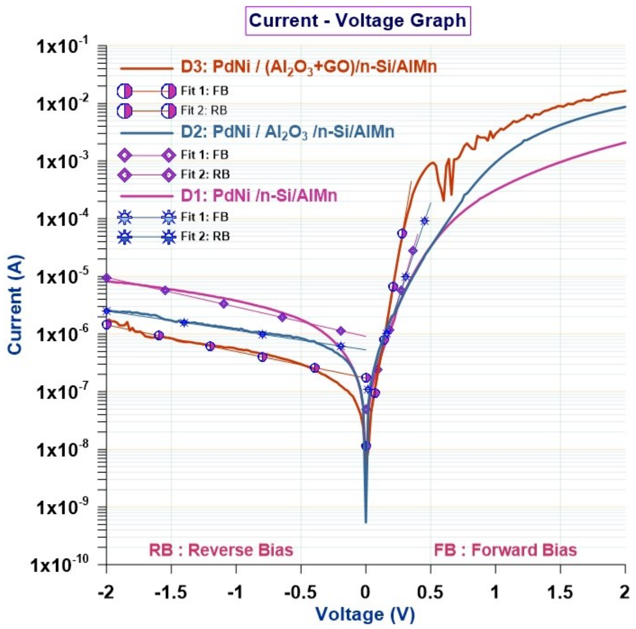

Figure 1: Current versus voltage (lnI-V) and fit lines for three Schottky diodes (D1 is the reference diode).

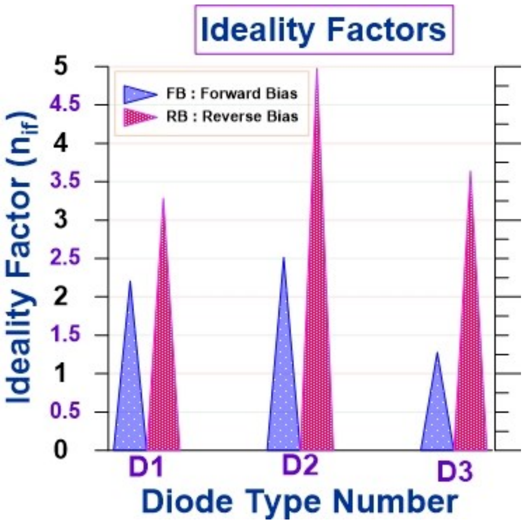

Figure 2: Values of ideality factors belonging to diodes under the forward and reverse bias.

Figure 1 and 2 shows IF versus applied voltage, curves conform with literature. In the case of forward and reverse direction, the slopes of the curve D1 are also shown. Figure 2 shows IF versus diodes of type.

2.3. Barrier Height

The barrier height (BH) determines the basic characteristics of a Schottky diode. The following formula [16-19], is used to calculate BH:

$$\Phi_{BH} = \frac{kT}{e} \ln\left[\frac{AR^{*}T^{2}}{I_{0}}\right] \tag{3}$$

Figure 2 shows BH versus diode type.

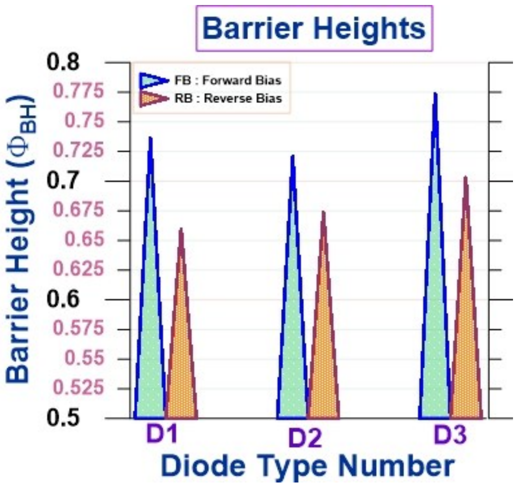

Figure 3: BH (from I-V and C-V data) versus for three Schottky diodes under the forward and reverse bias.

Table 2. Diodes parameters (forward bias)

Diode No	Ideality Factor	Saturation Current	Barrier Height (eV)	Series Resistance Rs (kOhm)
D1	2.207	4.8817759E-8	0.736	4.580
D2	2.516	8.6718989E-8	0.721	3.780
D3	1.280	1.1331373E-8	0.774	0.110

Table 3. Diodes parameters (reverse bias)

Diode No	Ideality Factor x(10)	Saturation Current	Barrier Height (eV)	Series Resistance Rs (kOhm)
D1	3.286	9.12170E-7	0.660	086.7
D2	4.975	5.33497E-7	0.674	575.9
D3	3.642	1.72343E-7	0.703	162.8

2.4. Cheung Functions

The functions of Cheungs' include series resistance and barrier height. The most efficient equation for calculating series resistance is the first equation of Cheungs. IF and BH can also be extracted from I-V data and compared with each other. The Cheung functions are given as [4], [5], [21], [22] :

$$H(I)_{Ch1} = \frac{dV}{d[\ln I]} = IR_s + \frac{n_{IV}kT}{e}, \qquad H(I)_{Ch2} = IR_s + n_{Ch1}\Phi_{BH} \tag{4}$$

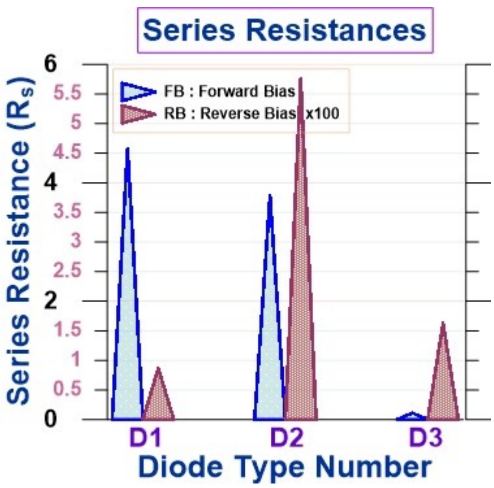

Figure 4: Series resistance versus for three Schottky diodes under the forward and reverse bias.

2.5. C_s-V Graphics

The Cs-V measurements of D1, …, D5 diodes were performed for 235 kHz frequencies at room temperature at dark medium.

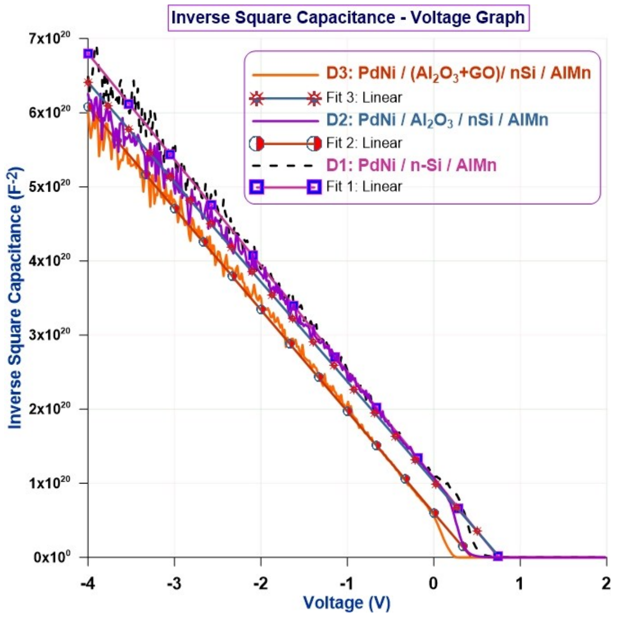

Figure 5: Inverse Square Capacitance-Voltage (C^{-2}-V) fits versus voltage graphs.

From the Cs-V measurements, Cs-2-V fitting line were plotted for Schottky diodes and the donor concentration for each diode by the helping of slope after which donor concentration could be calculated. (Figure 5) [23]. In addition, the built-in potential was obtained from the intercepting points on the V-axis.

Table 4. Other diodes parameters

Diode No	Built-in potential (eV)	Effective Fermi Level (eV)	Donor Concentrasyon x (10^{15} cm^{-3})
D1	0.749	0.549947	0.687
D2	0.762	0.546368	0.731
D3	0.438	0.543529	0.718

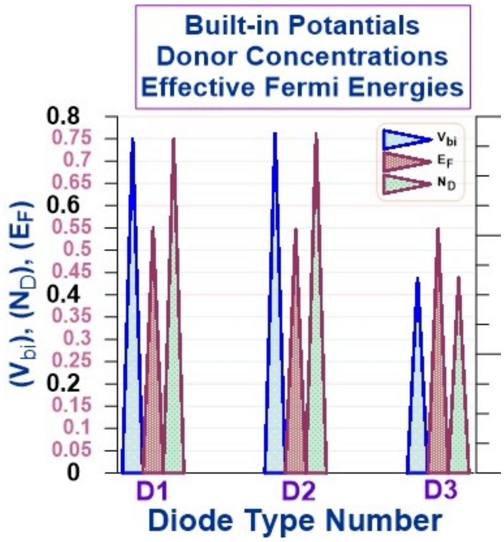

Figure 6: Built-in potential, donor concentration, effective Fermi energy versus for three Schottky diodes under the forward and reverse bias.

3. N_{ss} Graphics : Traditional Approximation

3.1. N_{ss} Graphics : A New Twist On The Traditional Approach

In the literature, the interfacial state density (ISD) is generally not included in calculations under inverse bias and Schottky barrier lowering (SBL) [2], [11], [23] [24].

Now, let's look at the N_{ss} calculations differently and plot the graphs under straight and reverse feed according to the traditional approach. Let's then redraw the Nss graphs by adding the net potential and Schottky barriyer lowering to the effective bandgap energy (EBE).

3.2. N_{ss} Graphics : Traditional Approximation (Well-known)

$$\frac{d\Phi_e}{dV} = \beta_e = 1 - \frac{1}{n_{IF}}, \quad \frac{d\Phi_e}{dV} = \beta_e = 1 - \frac{1}{n_{FB/RB}}, \tag{5}$$

where β_e is the voltage coefficient of Φ_e. The effective barrier height is given as

$$\Phi_e = \Phi_{BH} + \beta_e V \tag{6}$$

In a n-type semiconductor, the energy of the interface states E_s respectively at the bottom of the conduction band at the surface of the semiconductor is shown [23], [25], [26] as

$$\mathbf{E_c - E_{ss} = q\Phi_e - qV = q(\Phi_e - V)} \qquad (7)$$

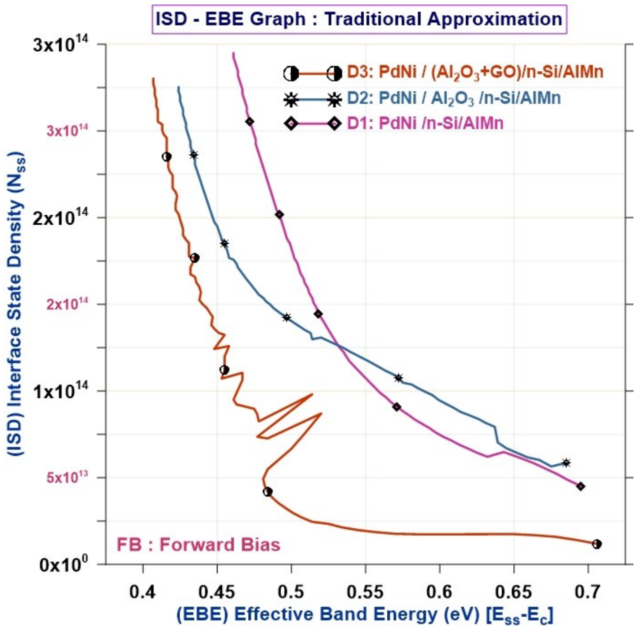

Figure 7: Interface state density according to traditional approximation under the forward bias.

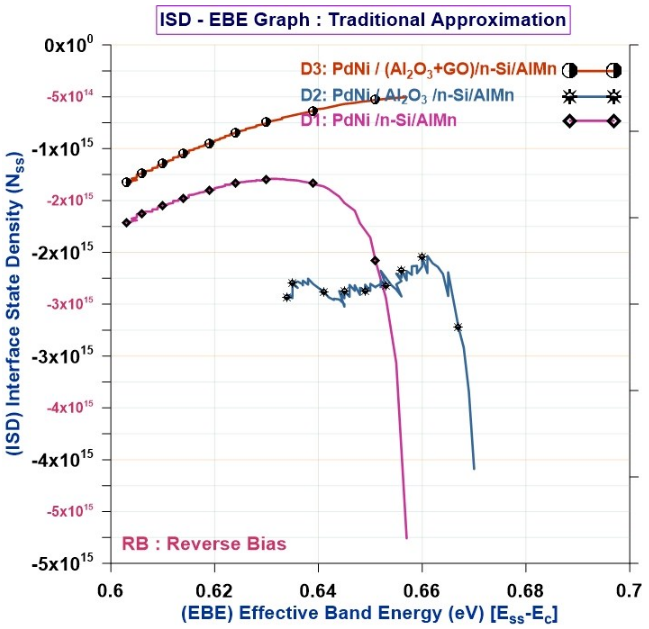

Figure 8: Interface state density according to traditional approximation under reverse bias.

Unlike the literature, we see that N_{ss} can also be calculated under reverse bias (Fig.8).

3.3. N_{ss} Graphics : Traditional Approximation (When the net voltage and Schottky barrier lowering applied)

Equations (7 and 8) are rearranged. The voltage V can be replaced by (V_{bi}-V_a) for forward bias and (V_{bi}+V_a) for reverse bias. Then the barrier height $\Delta\Phi_{BH}$ can be added to Φ_{BH}. SBL is caused by virtual images of the metal's electrons, which affect the total energy. It was first announced by W. Schottky and brought to the literature (Eq.8). So we get Eq.10 and Eq.11.Its formula is as follows [21-23]

$$\mathbf{\Delta\Phi_{BH} = \sqrt{\sqrt{\frac{e^3 N_d (V_{bi} \mp}{8\pi^2(\varepsilon\varepsilon_0)^3}}}} \qquad (8)$$

$$\mathbf{\Phi_e = \left[\Phi_{BHF/R} - \Delta\Phi_{BHF/R}\right] + \beta_e \left(V_{bi} \mp\right.} \qquad (9)$$

$$\mathbf{\Phi_e = \left[\Phi_{BHF/R} - \Delta\Phi_{BHF/R}\right] + \left(1 - \frac{1}{n_{FB/RB}}\right)\left(V_{bi} \mp\right.} \qquad (10)$$

We can call to Eq.(10) "the effective barrier height (EBH)".

$$\mathbf{\Delta E_{css} = E_c - E_{ss} = q\Phi_e - qV =}$$

$$\mathbf{= q\left(\left[\Phi_{BHF/R} - \Delta\Phi_{BHF/R}\right] - \left(\frac{\left(V_{bi} \mp\right.}{n_{FB/RB}}\right)\right)} \qquad (11)$$

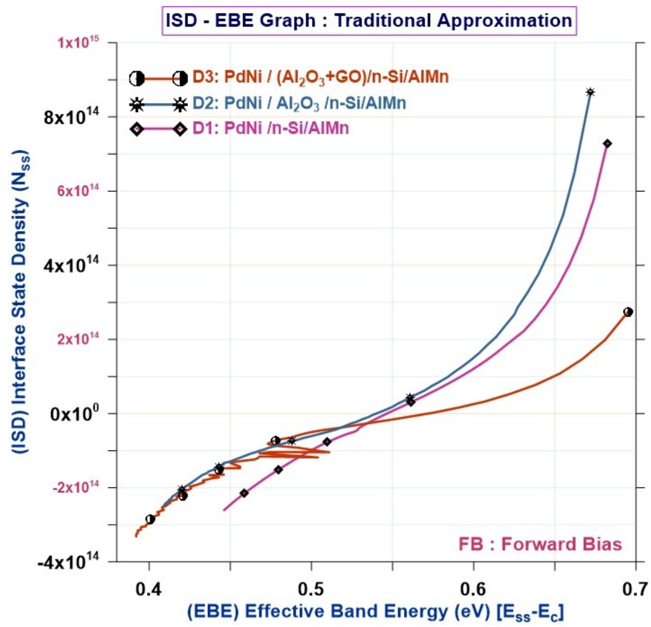

Figure 9: Interface state density according to traditional approximation when the effective voltage applied under the forward bias (according to net potential, V_{net} = V_{bi} - V_a and Schottky barrier lowering).

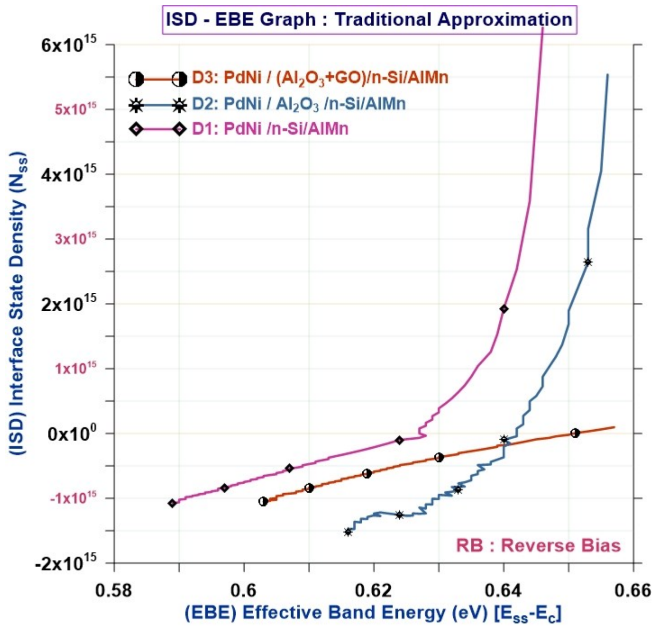

Figure 10: Interface state density according to traditional approximation when the effective voltage applied under the reverse (according to net potential, $V_{net} = V_{bi} - V_a$ and Schottky barrier lowering). We can also call to equation (1) "effective bandgap energy (EBE)". EBE is E_c-E_{ss} is the difference between the bottom of the conduction band and the top of the effective Fermi level (namely, (namely, shifted Fermi level to conduction band bottom). The next plots are drawn as the new N_{ss} versus E_c-E_{ss} for both reverse bias and forward bias (see Figure 9, 10).

4. Conclusion

Consequently, the authors examined correlation in between N_{ss} and E_{css}=E_c-E_{ss}. A new E_{css} = E_c-E_{ss} equation finds out to Equation 11 by based on the traditional equations beings Equation 8 and Equation 10. Figure 9 and 10 show the new ISD or N_{ss} versus E_c-E_{ss} (EBE) plots [11], [26]. Graphs show in both cases of forward bias and reverse bias.

Figure 7 shows that the ISD values were positive in the case of forward deviation, but Figure 8 and Figures 9 and 10 show that they were both positive and negative. This is because Equation 7 turns into Equation 11. When we examine the diodes in terms of interfacial material, we see that the materials directly affect the electrical parameters of the diode. When we compare the D2 and D3 diodes, it is seen that graphene is more dominant at the interface (Figure 10). This also depends on the mixing ratio of alumel and graphene (oxide) [27] (please, refer to Wikipedia for material information). In this study has provided new insights into the interface state density.

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The diodes in this study are original and have not been used in any other publication. The design and writing of the article belong to the corresponding author. The second author has assisted in the production of diodes and the calculation of diode parameters.

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