İLERİ MÜHENDİSLİK ÇALIŞMALARI VE TEKNOLOJİLERİ DERGİSİ

Ag/Aniline blue/n-Si Type Schottky Diode with Organic Dye Interlayers Investigation of Electrical and Photovoltaic Properties

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Abstract

In this study; Polished part n-Si semiconductor together with a donor concentration of $3x10^{17}$ /cm, 200 µm thick, was used. After proper chemical cleaning, an Al ohmic contact was made to the lower face of the semiconductor crystal. After the aniline blue dye was coated with methanol and acetone solution on the upper side, the lower surface of the organic layer was contacted. The electrical and interfacial properties of the manufactured Ag/Aniline blue/n-Si/Al Schottky diode, current-voltage (IV) measurement at room temperature under dark and light, and capacitance (CV) and conductance in the frequency range of 100-900 kHz in 100 kHz steps -Voltage (GV) properties were investigated. Some parameters such as barrier height (ϕ_B) and series resistance (Rs) were obtained from the modified Norde function and Cheung functions using straight feed I-V data. The interface state density (Nss) of the diode was also calculated. In addition, Data obtained as a result of I-V measurements, diode has a good straightening feature.

Keywords: n-type Si, Aniline blue, Schottky diode, Al, Ag.

Organik Boya Ara Katmanlı Ag/Anilin mavisi/n-Si Tipi Schottky Diyot Elektrik ve Fotovoltaik Özelliklerin Araştırılması

Özet

Bu çalışmada, parlatılmış kısım n-Si yarı iletken, 3x1017 /cm donör konsantrasyonu ile birlikte, 200 µm kalınlık kullanılmıştır. Uygun kimyasal temizlemeden sonra, yarı iletken kristalin alt yüzüne bir Al ohm teması yapıldı. Anilin mavisi boyası, üst tarafta metanol ve aseton çözeltisi ile kaplandıktan sonra, organik katmanın alt yüzeyi temas ettirildi. Üretilen Ag/Anilin mavisi/n-Si/Al Schottky diyotunun elektriksel ve arayüzey özellikleri, karanlık ve aydınlıkta oda sıcaklığında akım-voltaj (IV) ölçümü ve 100- frekans aralığında kapasitans (CV) ve iletkenlik 100 kHz'lik adımlarla 900 kHz -Gerilim (GV) özellikleri incelenmiştir. Bariyer yüksekliği (ϕB) ve seri direnç (Rs) gibi bazı parametreler, düz besleme I-V verileri kullanılarak değiştirilmiş Norde fonksiyonu ve Cheung fonksiyonlarından elde edildi. Diyotun arayüz durum yoğunluğu (Nss) da hesaplandı. Ayrıca I-V ölçümleri sonucunda elde edilen veriler, diyotun iyi bir doğrultma özelliğine sahiptir.

Anahtar Kelimeler: n-tipi Si, Anilin mavisi, Schottky diyot, Al, Ag.

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1. INTRODUCTION

The electrical characteristics of the metal-semiconductor (MS) contacts vary depending on the type of interface material used between the metal and the semiconductor. The properties of the material used are important since the interface conditions of metal-semiconductor contacts change many properties of the diode, such as barrier height, ideality factor. Organic semiconductors are considered as the material of the future. Nowadays, many researchers have been working on the use of organic semiconductor materials as interface materials to change the electrical properties of MS structures. Semiconductor materials convert light into current and photodiodes can be obtained as optoelectronic devices. The basis of photodiodes, such as the Schottky diode or n-p joint are semiconductor materials. In recent years, studies focused on the construction of electronic and optoelectronic devices with the formation of organometallic compounds (Sze, 1981). From these applications, dye sensitized solar cells (DSSc) stands out as an alternative to conventional silicon photovoltaic devices. Many solar cells and Schottky diodes, phthalocyanine complexes manufactured using (Rhoderick and William, 1988). Ocak et al. (Ocak et al., 2010) demonstrated the possibility of a new, synthesized Mn hexamide (MnHA) organometallic complex and Schottky diode formation. Thin films of semiconductor organic structure have been useful and very necessary materials for the active operation of electronic and optoelectronic devices. The photovoltaic and electrical properties of MS structures can be changed when an organic layer is added between the metal and the inorganic semiconductor. Obstacle derived from electrical characteristics of Schottky diodes (Ozaydın et al., 2013). The density of the substance providing the interface plays an important role in parameters that determine the properties of the diode, such as height (Φ_b) and the ideality factor (n). Studies in the literature have shown that by increasing the organic thin film on an inorganic semiconductor, the barrier height can be increased or decreased (Oyama et al., 2011).

Çaldıran et al. (Çaldıran et al., 2013) displayed that the Au/Anthracene/n-Si/Al Schottky diode exhibits good rectifier characteristic. They showed the anthracene organic layer increases the influential barrier height of the Au/n-Si/Al diode by creating a physical barrier between Au and n-Si. Orak et al. (Orak and Turut, 2014) investigated the influential of organic layer thickness on electrical and photovoltaic performance by producing organic-inorganic heterojunction. Aydoğan et al. (Aydoğan and Türüt, 2005) obtained a polyaniline/p-Si/Al metal-insulator-semiconductor (MIS) structure by forming a polyaniline layer on the Si by electrochemical polymerization technique.

Reddy et al. (Reddy et al., 2015); They measured the current voltage properties (I-V) of Ru/Ti/n-InP schottky diodes in the temperature range of 200-400 °C and investigated I-V properties to prediction the Schottky barrier parameters. The results showed that as the temperature increases, the barrier height decreases and the ideality factor increases. These data are consistent with Cheung's dV/dln(I) and I. Series resistance values are measured in the range of 16 MΩ - 62 MΩ with enhancement temperature. The nonlinear state at the Richardson constant and Schottky barrier heights was imputed down to the presence of phosphide in the Ru/Ti/n-InP interface.

Güllü et al. (Güllü et al., 2018); They studied the interface, morphological and optical properties of Al/GO/n-InP MIS diode by graphene oxide (GO) intermediate layer between Al/n-InP metal and semiconductor layers. In their study, they measured the barrier height of the reference Al/n-InP diode without GO as 0.43 eV and the barrier height of the Al/GO/n-InP MIS diode with GO interface as 0.85 eV. They investigated that the barrier height of the Al / GO / n-InP diode increased by about 100% relative to the reference Al/n-InP diode.

Yakuphanoglu et al., (Yakupoğlu et al., 2011), obtained the metal structure n-type Si with organic dye. Electronic parameters and photovoltaic properties of Au/Methylene blue/n-Si diodes were measured by current parameters (I-V) and capacitance-conductivity frequency (C-G-f) techniques. They proved the diode exhibited non- optimum attitude due to the presence of organic layer and series resistance. Also; reported that the diode had a photovoltaic attitude with a maximal open circuit voltage of 230 mV and a short circuit current of 20.8 μA in a solar simulator (100 mW/cm^2).

In this work, we researched the electrical and photovoltaic properties of Ag/Aniline blue/n-Si/Al structure less work in the literature. At every stage of this study, the sample was prepared using the ultrasound-assisted technique. Also, after the metal/organic/semiconductor/metal structure is obtained, electrical power in the dark and solar simulator under lighting conditions of 100 mW/cm^2 photovoltaic parameters were obtained.

2. MATERIALS AND METHODS

2.1. Cleaning and Obtaining of Sample

A 200μm thick n-Si crystal with a donor concentration of $3x10^{15}$ /cm^3 and polished on both sides was used. Since both sides of the sample were polished, no mechanical cleaning of the surfaces was required. To remove organic and inorganic impurities on the crystal and Acetone to remove surface roughness and washed in methanol in an ultrasonic-assisted bath for 10 minutes (Kem, 2008; Gezer, 2018). Flowing in 15 MΩ deionized water for 30 minutes then dried with nitrogen gas (Tatar and Urgen, 2013). Al to be used for the ohmic contact has already been cleaned. Later 10^{-5} torr pressure on wafer placed in vacuum unit thermally Al evaporated to a surface. Sample contact taken from vacuum medium is homogeneous and evaporation to penetrate into the semiconductor 5 min at 400 °C in N_2 medium annealing in the annealing furnace was obtained ohmic contact. 1 cm x 1 cm of wafer with omic contact on one side a piece was cut. On the other surface of the n-type Si wafer, the solution formed by adding 0.0015 M alcohol to 3 μL of aniline blue organic dyestuff was dropped. It was allowed to dry at room temperature under N_2 atmosphere for 75 minutes. Then direct current supply (DC) magnetron sputter to make Schottky contact Ag target plate was placed into the system. With the DC Sputter technique, Schottky contacts by a diameter of approximately 1.5 mm were made on the other surface of the Si wafer. As a result, Ag/aniline blue/n-Si/Al (metal/interface/semiconductor/metal) samples were obtained.

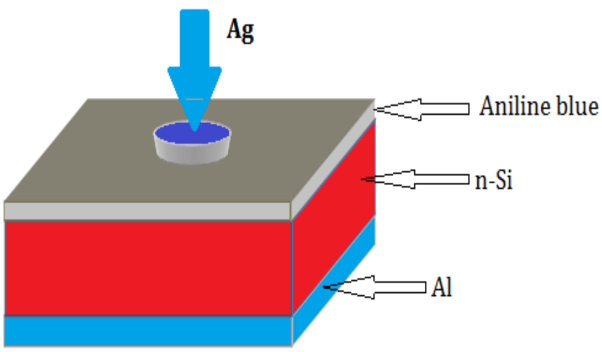

Figure 1. Schematic representation of Ag/Aniline blue/n-Si/Al Schottky diode

The electrical and photovoltaic properties of the obtained Schottky diode (SD) in the dark and in the solar simulator under 100mW/cm^2 light were investigated. Figure 1 shows the Ag/Aniline blue/n-Si/Al semiconductor Schottky diode obtained using the organic interface material. It is given. Aniline blue organic dyestuff molecular the structure is given in Figure 2.

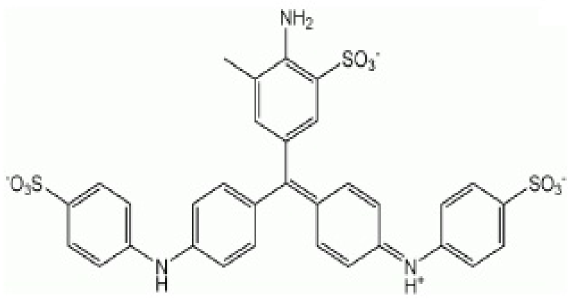

Figure 2. Molecular structure of aniline blue

2.2. Current-Voltage Characteristics

Experimental I-V measurements can be investigated by thermionic emission theory in calculating the ideality factor of the diode (Norde, 1979).

$$I = I_0\left[exp\left(\frac{eV_d}{nkT}\right) - 1\right] \quad (1)$$

After taking ln of both sides in equation (1) according to V if the differential is taken and regulated;

$$n = \frac{q}{kT}\left(\frac{dV}{dlnI}\right) \quad (2)$$

The ideal factor (n) is a dimensionless parameter that shows deviation of the diode from ideal properties. For an ideal diode, this factor should be approximately equal to 1. The linear part of the lnI-V graph gives the saturation current I_0 at the point at which the fit line intersects the vertical axis at V = 0. (1) the saturation current I_0;

$$I_0 = AA^*T^2 exp\left(-\frac{q\emptyset_B}{kT}\right) \quad (3)$$

is defined as. Here, the diode field A is defined as the A* Richardson constant, the temperature as T Kelvin, k the Boltzmann constant, the charge of q electrons, and the barrier height at B zero voltage. When logarithm of both sides of equation 3 is taken and solved with respect to Φ_B;

$$e\emptyset_B = kTln\left(\frac{AA^*T^2}{I_0}\right) \quad (4)$$

obstacle height is achieved.

2.3. Obstacle Height and Series with Norde Model Calculation of Resistance

Norde proposed a new method for calculating obstacle height and calculating series resistance (Bohlin, 1986). The modified Norde function can be written as follows.

$$F(V) = \frac{V_0}{\gamma} - \frac{kT}{q} ln\left(\frac{I(V)}{AA^*T^2}\right) \quad (5)$$

The current-voltage characteristics of Schottky diodes are shown using the function (McLeon, 1986;Zafer, 2006). Where A is the area of the diode, A* is the modified Richardson constant, q is the electronic charge. Considering the minimum point of the function F (V), the barrier height value using the F (V0) value corresponding to the minimum V0 voltage;

$$\emptyset_B = F(V_0) + \frac{V_0}{\gamma} - \frac{q}{kT} \quad (6)$$

obtained in the form. I_0 corresponding to series resistance value V_0 using the value;

$$R_s = kT\left(\frac{\gamma - n}{qI_0}\right) \quad (7)$$

obtained in the form. Where Y is the first integer greater than n. I_0 is the current value where V potential is minimum (Güllü et al., 2010). This model, which is used by Norde, is valid for ideal cases and cases where the series resistance is small, and it is shown that the series resistance and obstacle height values can be calculated by using the generalized Norde model for non-ideal cases (Tunç and Gökçen, 2012).

2.4. Investigation of Photovoltaic Properties

In order to compare the solar cells produced and characterized in laboratories around the world, all measurements should be made under standard test conditions. According to these conditions, the temperature of the measured solar cell should be 25 °C, the measured radiation intensity should be 100 mW/cm^2. Air mass AM is the ratio of the sun's rays to the atmosphere when the sun is in the θ° position while the sun is in the atmosphere when the sun is in the Zenith position. Photovoltaic systems generally vary in current, depending on the voltage applied at different radiation intensities, including darkness. They are characterized by measuring the density (Balkanski and Wallis, 2000).

2.5. Measurement Devices Used in the Study

Keithley 2410 programmable constant current source was used for current-voltage (I-V) measurements. The device in which current-voltage (I-V) measurements are made is shown in Figure 3.

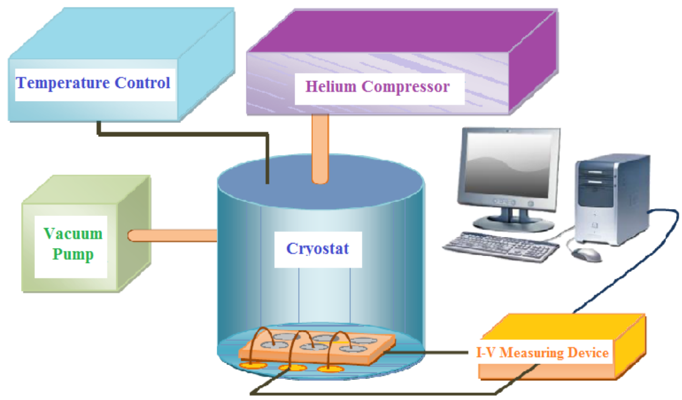

Figure 3. Diagram of the experimental setup used for current-voltage (I-V) measurements

3. RESULTS AND DISCUSSION

3.1. Current-Voltage Characteristics

The values obtained from current-voltage (I-V) measurements and other fixed data are written in (2) and (4) expressions and ideality factors and obstacle height are calculated. In Figure 4, a half-logarithmic current-voltage graph and fit line are given together at room temperature and darkness. For the Ag/Aniline blue/n-Si/Al diode, (2) and (4), the ideality factor was 3,433 and the barrier height was calculated as 0,574 eV (Altındal et al., 2014).

The lower the series resistances of the metal-semiconductor rectifier contacts, the linear the current-voltage characteristics, and the higher the diode quality. Ag/Aniline blue/n-Si/Al Schottky diode series resistance at room temperature and obstacle height values were calculated using Norde Functions.

Figure 4 shows the I-V graphs of Ag/n-Si/Al diodes and Ag/Aniline blue/n-Si/Al diodes used in the study. The n ideality factor calculated for the reference Ag/n-Si/Al diode was n = 1.17 and the barrier height ϕ_B = 0.51 eV (Çetinkaya et al., 2013). When Cheung functions were used, the ideality factor of the studied Ag/Aniline blue/n-Si diode was measured as n = 3,461 and barrier barrier = 0.586 eV. The barrier barrier according to Norde functions was measured as Φ_B=0.769 eV

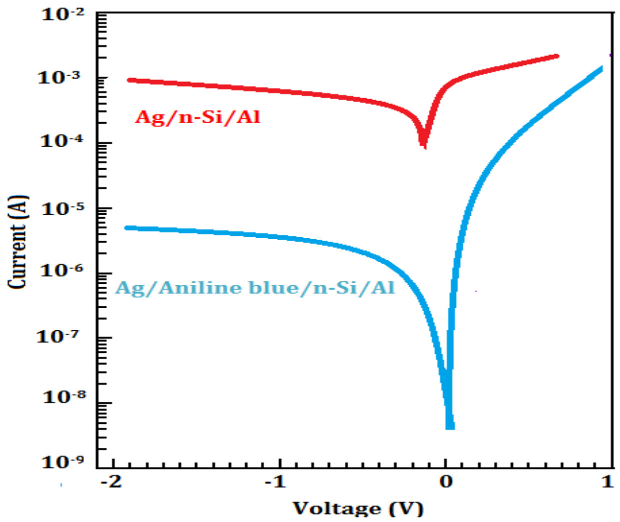

Figure 4. I-V graphs of the Ag/n-Si/Al reference and the organic interface Ag/Aniline blue/n-Si/Al diode without organic interface at room temperature

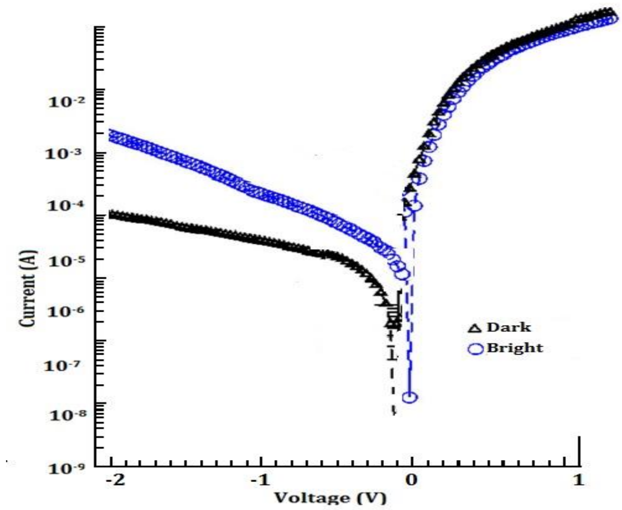

Figure 5. Light and dark medium I-V graphics of Ag/Aniline blue/n-Si/Al diode with organic interface at room temperature (light power 100 mW/cm^2)

3.2. Photovoltaic Measurements

Photovoltaic measurements to AM1.5 air mass filter in the solar simulator with 100 mW/cm^2. Figure 5 shows I-V graphs of Ag/Anilinne blue/n-Si/Al diode under dark and light conditions. It is investigated that the diode feedback voltage and current value under light increase by 10 times. There has been an increase in the current of electrons and void pairs resulting from light. It is seen that light does not have a significant effect on current in forward balm value and as the voltage value increases, it is reached in darkness and linearity in light environment. This situation is realized by series resistance effect in accordance with the literature. From the I-V graph data, it is concluded that the studied Ag/Aniline blue/n-Si/Al diode has a rectifying behavior.

3.3. Temperature-dependent Current-Voltage (I-V) Characteristics

Direct feed current-voltage (I-V) characteristics of prepared metal/organic/semiconductor (Ag/Aniline blue/n-Si/Al) Schottky diodes were examined according to thermo-ionic emission theory (TE) (Gökçen and Alli, 2014). According to this theory, current expression,

$$I = I_0 e^{\left[\left(\frac{qV}{nkT}\right)-1\right]} \quad (8)$$

Here I_0 is the saturation current, which is found in the semi-logarithmic lnI - V graph by fitting the linear part of the curve to the current axis at zero voltage (V = O) and

$$I_0 = AA^* T^2 e^{\left(-\frac{q\Phi_{B0}}{kT}\right)} \quad (9)$$

given with equality. Here, the charge of the electron q, the correct supply voltage applied V, the area of the diode A, the k Boltzmann constant, the effective Richardson constant for A* n-type GaAs (A* = 8.16 A cm^{-2} K^{-2}), barrier Φ_{B0} obstacle height at zero feed, The ideality factor of n diode and T is the temperature in Kelvin. Φ_{Bo} and n values obtained from the semi-logarithmic correct feed lnI - V curves are very tightly dependent on the temperature. While the value of Φ_{Bo} increases with increasing temperature, n value decreases. Temperature variation of zero feed barrier height (Φ_{Bo}) and diode ideality factor (n) are given in Figure 6, respectively. These values for the lowest (70 K) and highest (350 K) temperatures for the obstacle height with the ideal factor, n = 7.28-2.69, and Φ_{Bo} = 0.182-0.801 eV were obtained respectively. The value of the ideality factor is expected to be in the ideal state (n = 1) (Güllü and Turuüt, 2008). However, in practice, this situation is almost never encountered. Because the obstacle height depends on the applied voltage. This dependency leads to a potential drop on the insulating layer, thus the change of the I-V characteristic and the ideality factor to be greater than 1. If the ideal factor is higher than 1, it means that it is difficult to obtain an ideal diode in practice. This increase in the ideality factor can be explained by in homogeneities in organic film thickness, interface conditions, and uneven distribution of interface loads (Kılıçoğlu et al., 2007). In addition, image load reduction and production-recombination processes are among the reasons explaining the greatness of the ideal factor (Ocak et al., 2015).

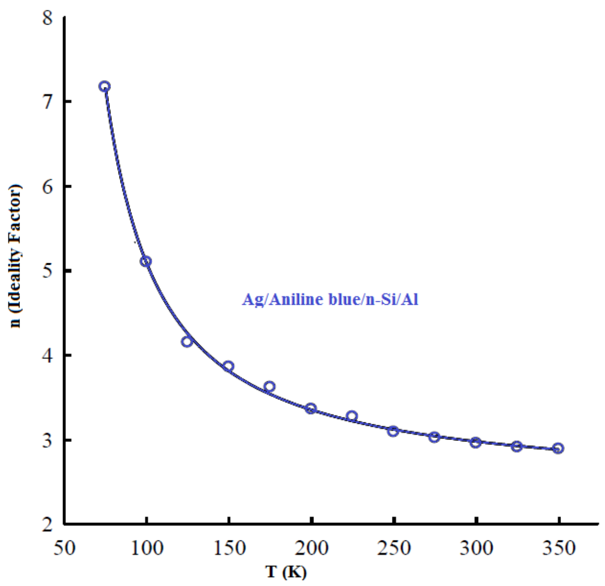

Figure 6. Temperature change graph of the ideal factor of Schottky diode Ag/Aniline blue/n-Si/Al

The fact that the ideal factor is higher than normal means that the current-carrying properties cannot be explained only by the thermo-ionic emission model. In this case, it can be mentioned that there is a secondary mechanism at the interface. Although the organic-inorganic interface is formed in a sharply inactive structure, the organic layer between the metal and the semiconductor appears to cause a important modification in the interface conditions. Therefore, the change in obstacle height can be expressed by the interface dipole through organic layer passivation (Orak et al., 2017).

4. CONCLUSIONS

After obtaining Ag/Aniline blue/n-Si/Al Schottky diode, electrical and photovoltaic properties were investigated in darkness at room temperature (25 °C) and under 100 mW/cm^2 light in solar simulator. Calculated ideality factor and barrier height values Özaydın et al. (Ozaydın et al., 2013; Yakuphanoğlu, 2010) calculated in Cu (II) complex/n-Si heterojunction structures. According to the parameters we produce diode has better straightening feature. From the current-voltage (I-V) graph obtained by dark and light measurements, it was seen that the current intensity was 10 times higher than the dark environment with the effect of light at the feedback voltage. This situation is attributed to the increase of electron and hall pairs in the light Aniline blue paint layer which is placed between the metal-semiconductor surface. I-V measurements obtained from the Cheung function dV/d (lnI) -I serial resistance value Rs = 151,854 Ω, the ideal factor was measured. When Cheung functions were used, the ideality factor of the studied Ag/Aniline blue/n-Si diode was measured as n = 3,461 and barrier barrier = 0.586 eV. These values are in accordance with the literature.

The value of the current was found to be dependent on the Light state, which is attributed to the increase in load intensity at the interface by the light effect. The Ag/Aniline blue/n-Si/Al diode shows photovoltaic properties. It was observed that the light status did not cause a important change in the parameters in the forward feed. It was seen that the current value increased with the effect of light in reverse feed. It was evaluated that the increase in current caused by the increase in electron and gap pairs due to light effect. When the organic interface is used, it is seen that the flow value decreases by 2 order (100 times) in dark environment and reverse feed. This was attributed to increasing the resistance effect of the organic interface.

Capacitance (C) and Conductance (G) measurements were withstand to be mightily interdependent on the pre-voltage and frequency for the Ag/Aniline blue/n-Si/Al structure. At each frequency, the measured capacitance was found to decrease with increasing frequency due to the continuous distribution of interface states in the 100-900 kHz frequency range (Gezer, 2018). Conductance values risinged withrising voltage for each frequency value. It has been found that aniline blue organic compound can be used in semiconductor technology.

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