FABRICATION AND CHARACTERIZATION OF Au/CARMINE/N-GaAs SCHOTTKY DIODE BY SPIN COATING TECHNIQUE

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Carmine thin films were obtained on both quartz glass and n-GaAs semiconductor using spin coating. Scanning electron microscopy (SEM) shows that the thin film has a uniform surface and the average grain size is 30.717 nm. Surface roughness was determined from atomic force microscopy (AFM). To determine transmission (T), reflection (R) and absorption (α) behavior, allowed direct band gap value (Eg), refractive index (n), extinction coefficient (k), dielectric coefficients (ε_1- ε_2) of the thin film, optic spectrometry was employed. The allowed direct band gap value of the carmine thin film is found as 3.94 eV. The current-voltage (*I-V*) curves of the *Au/Carmine/n-GaAs* Schottky barrier diodes (SBDs) were measured at room temperature. The characteristic parameters of the *Au/n-GaAs* and *Au/Carmine/n-GaAs* diodes such as effective barrier height (Φ_{b0}), ideality factor (n), and series resistance (R_S) were obtained from the *I-V* measurements. *I-V* characteristic parameters of the devices were analyzed via using with the standard thermionic emission (TE) theory at very low forward bias voltage regime. The ideality factory and effective barrier height values were found in the range of 1.359-2.090 and 0.858-1.001 eV for modified SBDs, respectively. Furthermore, Cheung functions were also used to evaluate the characteristic parameters of the SBDs. The obtained diode parameters from *I-V* with Cheung functions were compared

(Received January 1, 2019; Accepted September 2, 2019)

Keywords: Carmine, Schottky diode, I-V, Serial resistance, Organic interlayer

1. Introduction

Organic materials have important properties like processability and flexibility. These properties can be used in electronic and optical devices to lead novel technologies. There are a variety of organic materials in nature. Some of them have been used in devices such as graphene, Rhodamine B, aniline green, Methylene Blue, new fuchsin, Carmine [1-6]. Among the wide variety of those, carmine with molecular formula 7 – beta – D – Glucopyranosyl – 3,5,6,8 – tetrahydroxy – 1 – methyl - 9,10 – dioxo – anthracene – 2 – carboxylic acid ($C_{22}H_{20}O_{13}$) can be investigated and thought to make a solar cell, sensor, Schottky diode etc. According to literature investigated, Aydoğan and coworkers [6] fabricated Au/Carmine/n-Si Schottky diodes and determined contact parameters. The Schottky diodes are one of the important devices in the semiconductor device technology. While Schottky diode is fabricated, one of the organic or inorganic substance silicon (Si) or gallium arsenide (GaAs) etc. are generally used as interface layer and substrate, respectively. It is known that the properties of the interface layer have very effected on the properties of the Schottky diodes [7-9]. GaAs have unique structural, chemical and electrical, properties such as mechanical stability, higher electron mobility, chemical inertness and a high breakdown voltage [10, 11]. Hence, GaAs is an important semiconductor for electronic devices such as Schottky diodes (SDs).

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In the present work, we focus on the optical, structural and electrical properties of the carmine thin film. We have obtained a detailed analysis of the *I–V* characteristics of *Au/Carmine/n-GaAs* Schottky diode. Up to our knowledge, the properties of carmine thin film and the *I–V* characteristics of *Au/Carmine/n-GaAs* Schottky diode has not been previously examined.

2. Experimental procedures

Carmine thin films were fabricated using a spin-coating. Quartz glass substrate was cleaned with successive with acetone, methanol, ethanol and deionized water of 18 MΩ using an ultrasonic bath. 0.05 g of carmine precursor was solved 3 ml of NH_3:H_2O (1:4) (molarity was 68 mM). Then, to measure optical properties of the carmine thin film, of the carmine solution was drop on quartz glass cleaned and spin coated at 600 rpm for 10 s and then 2500 rpm for 30 s. To dry the wet carmine thin film, the structure was baked for 1 min at 50° C. The *Au/Carmine/n-GaAs* Schottky barrier diodes were prepared by using only one side polished n-type GaAs wafer with tellurium doped (Freiberger Compound Materials). The substrate was first degreased in acetone, methanol, ethanol and finally with deionized water of 18 MΩ using an ultrasonic bath. The substrate surfaces to prepare a nearly oxide-free surfaces were etched in HCl:H_2O (1:10) for 30 s and then followed by a rinsed in deionized water. Next step GaAs substrates dipped into the H_2SO_4:HCl (3:1) piranha solution. The substrate has been dried with high-purity nitrogen (4N5) and immediately carried into the evaporation chamber to form Ohmic contact after the etching process. The Ohmic back contact was made by thermally evaporating AuGe (%18 wt.) on the non-polished side of the substrate in a vacuum coating unit of 1,5 x 10^{-6} Torr and then *n-GaAs/AuGe* structure was thermally annealed at 275 ˚ C for 4 min in a quartz tube furnace with flowing N_2. Then the sample was inserted into the spin coating unit (SÜSS MicroTec Lithography GmbH model) and the carmine interfacial layer was formed on the front surface (polished side) of the *n-GaAs* by dropping 0.1ml carmine solution and spin coated at 600 rpm for 10 s and then 2500 rpm for 30 s. The Schottky contacts were formed by thermal evaporation of high purity Au (%99.995) dots with diameter of 1.0 mm. In this way the *Au/Carmine/n-GaAs/AuGe* SBDs was obtained. Surface and cross-section morphology of the carmine thin film were analyzed by scanning electron microscope (SEM, Zeiss EVO LS 10). Atomic force microscopy (AFM, VEECO Multimode 8) was employed over an area of 5x5 μm^2. The transmission spectrum of the carmine thin film was obtained using with a double beam spectrometer (PerkinElmer UV/vis Lambda 25 spectrophotometer) at 290–1100 nm and at room temperature. The I-V characteristic of the *Au/Carmine/n-GaAs/AuGe* SBDs were measured by using an HP 4140B Picoammeter, in the dark and at room temperature.

3. Results and discussion

3.1. Structural properties

The surface morphology, shape, and size of the grain, the thickness of carmine thin film fabricated by the spin coater method was determined from Scanning electron microscopy (SEM). Fig. 1 clearly shows that the film composed of large number of small uniform spherical grains. The information about average grain size was determined by analyzing the SEM images using ImageJ software. According to this analyze, the average grain size is 30.717 nm. The inset image in Fig. 1 demonstrates the film thickness determined from cross-sectional SEM image as 88.48 nm.

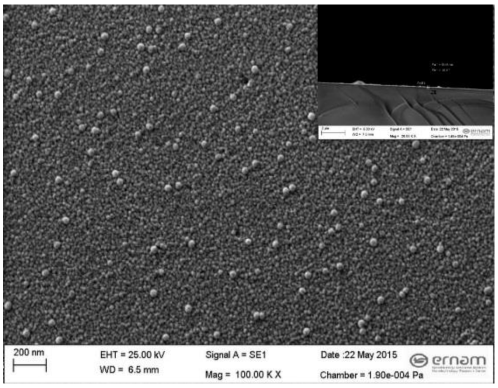

Fig. 1. Surface and cross-sectional SEM images of the carmine thin film.

In addition, the surface topography and roughness of carmine thin film have been investigated using atomic force microscopy (AFM). The determined root-mean-square (RMS) or roughness for carmine thin film is 1.095 nm (Fig.2).

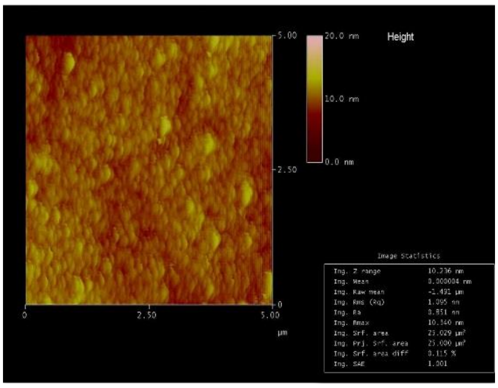

Fig. 2. AFM image of the carmine thin film.

3.2. Optical properties

The transmission (*T*), reflection (*R*) and absorption (*A*) spectra of the carmine thin films in the wavelength range 290–1100 nm were depicted in Fig. 3. Generally, the carmine thin film has high transmission in the UV-Vis area (average 90%). However, the spectra of *T*, *R*, and *A* have changed because of an absorption band with direct peaks centered at 522 nm and 560 nm in the visible spectral range.

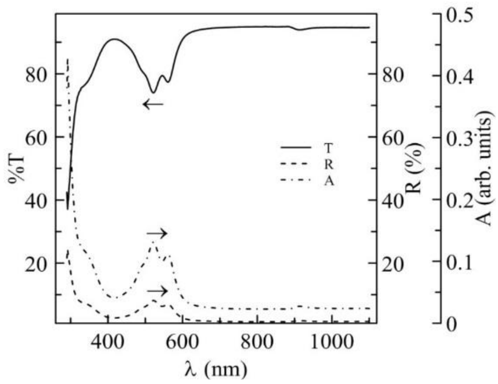

Fig. 3. Transmittance, reflectance and absorbance spectra of the carmine thin film.

The absorption band gap or the allowed direct band gap value of the thin film was estimated using the Tauc relation [12]. In Fig. 4, the corresponding direct optical band gap (E_g) of the carmine film was determined by plotting a graph $(\alpha h\nu)^2$ versus ($h\nu$). In Fig. 4, E_g is found to be 3.94 eV.

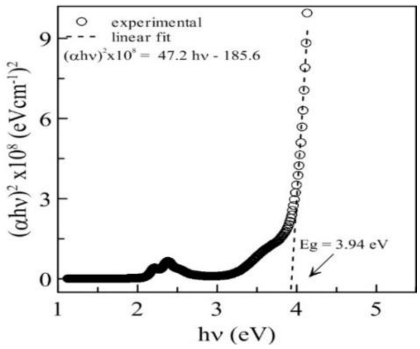

Fig. 4 *Plots of $(\alpha h\upsilon)^2$ versus $h\upsilon$ for the carmine thin film.*

α and R are connected with k and n[12]. The k value is 0.141 at 522 nm while n value is 1.784 at 523 nm for the carmine thin films (Fig. 5).

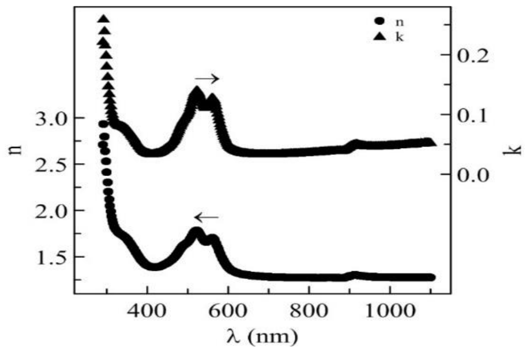

Fig. 5. Plots of extinction coefficient (k) and refraction index (n) for carmine thin film.

The values of n and k can be employed to determine the real (ε_1) and imaginary parts (ε_2) of the dielectric [12]. The plotting of dielectric coefficients with wavelength for the carmine thin film was shown in Fig. 6 (a) and (b).

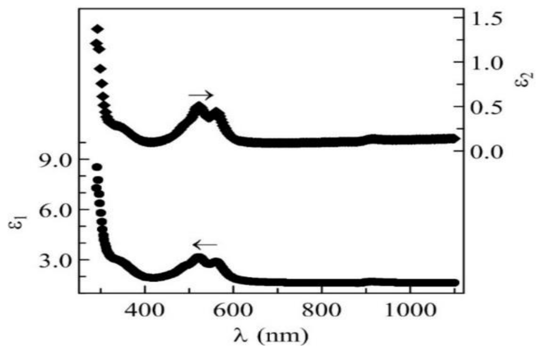

Fig. 6. Plots of the real part (ε_1) and imaginary part (ε_2) of the dielectric constant for carmine thin film.

3.3. Electrical properties

The experimental semi-logarithmic plots of forward and reverse currents of the *Au/Carmine/n-GaAs/AuGe* and *Au/n-GaAs/AuGe* reference SBDs were shown in Fig. 7, at room temperature. These plots can be used to obtain the characteristic diode parameters (*eg.* ideality factor (n), barrier height (Φ_{b0}) and series resistance (R_S)) of devices.

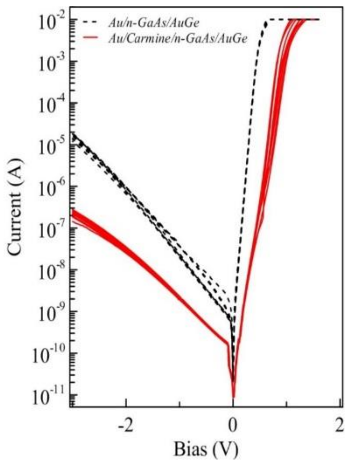

Fig. 7. The experimental semi- log forward and reverse bias I-V characteristics of the ten Au/n-GaAs/AuGe and ten Au/Carmine/n-GaAs/AuGe SBDs at room temperature.

The rectifying *I-V* plots suggest that *Au/Carmine/n-GaAs-* Schottky diodes are formed at the interfaces. Current conduction mechanism, in such a heterojunction diode, is usually follows the thermionic emission [13-15]. The experimentally obtained characteristic parameters of the *Au/Carmine/n-GaAs* and *Au/n-GaAs* reference SBDs were given in Table 1. The ideality factor n values of the *Au/Carmine/n-GaAs* SBDs were obtained from the linear part of the forward biased *I-V* plots (Fig. 7). This linear parts of *I-V* plots includes the effect of the interfacial parameters rather than that of the series resistance [14].

Even if they are identically prepared, the effective barrier height and ideality factor values for the diodes varied from diode to diode. When considering all of the *Au/n-GaAs* reference SBDs, according to the the result of statistical analysis mean value of Φ_{bo} was a 0.782 eV and standard deviation was 4 meV at the 300 K measurements. Similarly; for *Au/Carmine/n-GaAs* SBDs, the mean value of Φ_{bo} was 0.954 eV and standard deviation was 40.4 meV at the 300 K measurements (Table 1.). The value of the barrier height of SBD modified with carmine is higher than the reference diodes [16], so modification of diodes with the carmine organic interlayer increased the barrier heights around the %22. This Schottky diode has a comparable barrier height value with some similar organic interfacial layered Schottky diodes. Such as, Wenjie et al. [17] presented a barrier height of 0.95 eV in the *Au/octanedithiol/n-GaAs*, Aydın et al. [18] obtained a *Au/PEDOT/Au-GaAs* Schottky diode with a barrier of 0.69 eV.

The ideality factor determined from the slope of the linear regions of the forward bias *I-V* plots varied from 1.359 to 2.090 for *Au/Carmine/n-GaAs* reference SBDs. The mean value of ideality factor was 1.641 and standard deviation was 0.222 (Table 1.). For *Au/Carmine/n-GaAs* diode, some values of n do not fall within the reasonable value range between the one and two, so there is a relatively small deviation from the ideality behavior and n>2 condition implies that the thermionic emission may not be a main current transport mechanism. This results are sign of the existence of traps in the organic material. Traps called localized states are created by disorders, defects, impurities, etc. The capture/release nature of traps of charge carriers, has a very important role in the charge conduction process of organic compounds. For the reverse leakage current significantly decreased with the organic modification. *Au/Carmine/n-GaAs* diodes mean correction factors was a 1.072×10^{6} while reference diodes mean correction factors was only a 6.361×10^{4} at ±1.5 V. Cheung functions [19] were also used to evaluate the characteristic parameters of the SBDs.

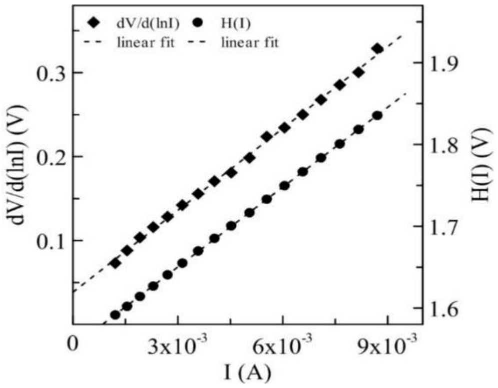

Fig. 8. The plots of dV/dlnI vs I and H(I) vs I obtained from forward bias I-V characteristics for one of ten Au/Carmine/n-GaAs Schottky barrier diodes.

The *dV/dlnI* versus *I* (♦) and *H(I)* versus *I* (●) plots of one of the *Au/Carmine/n-GaAs* SBDs were shown in Fig. 8. The characteristic parameters of the SBDs were evaluated from Cheung functions were given in Table 1. The values of *n* and *Rs* were obtained as 1.446 ± 0.249 and 28.290 ± 11.721 Ω from the intercepts and slopes of *dV/d(InI)-I* plots, respectively. The values of Φ_b and were obtained as 1.034 ± 0.126 eV and 28.082 ± 11.810 Ω from the intercepts and slopes of *H (I) –I* plots, respectively.

Table 1. The values of characteristic diode parameters of ten Au/n-GaAs/AuGe and ten Au/Carmine/n-GaAs/AuGe SBDs at room temperature.

Sample	**n**	**Φ_b (eV)**	**I_0 ($x10^{-10}$A)**	**Cheung**			
				n	**R_S (Ω)**	**Φ_b (eV)**	**R_S (Ω)**
Au/n-GaAs	1.115±0.009	0.782±0.004	4.340±6.058	1.106±0.077	16.612±1.833	0.787±0.030	16.555±1.878
Au/Carmine/n-GaAs	1.641±0.222	0.954±0.040	2.832±6.737	1.446±0.249	28.290±11.721	1.034±0.126	28.082±11.810

4. Conclusions

In this paper, the carmine thin film was deposited on quartz glass and n-GaAs using a spin coating technique. Its structural, optical and electrical properties were investigated. According to microscopy images thin film was having a uniform surface and, the particle size and surface roughness was 30.717 nm and 1.095 nm, respectively. From the optical data taken spectrometer, it is found that the carmine thin film has high transmission (90%) in a wide area (400-1100 nm) and the direct optical band gap is 3.94 eV. It is worth pointing out that the carmine thin film having high transmission can be employed transition layer in the solar cell. The *Au /n-GaAs* SBDs *I-V* characteristics with and without the carmine thin film layer were studied.

The control/improvement of the barrier height of the *Au/n-GaAs* SBD was achieved by using an organic thin film. The values of Φ_{bo} and ideality factor *n* were found as 0.782±0.004 eV and 1.115±0.009 for the reference *Au/n-GaAs* device; 0.954±0.040 eV and 1.641±0.222 for the *Au/Carmine/n-GaAs* device. It was seen that the mean barrier height of the *Au/n-GaAs* SBD was increased 172 meV by means of the organic thin layer. The increment in barrier height of *Au/n-GaAs* SBD is explained by changings in the space charge region of GaAs, due to the carmine thin film. Furthermore, it was also seen from the results obtained that the interface state density in the *Au/n-GaAs* SBD was reduced by the introduction of the carmine interlayer. According to these results, the diode parameters of SBDs was changed from one diode to another, which are prepared at the same process. This fluctation was closely related with the inhomogeneity of the barrier formed between metal and semiconductor.

Acknowledgments

This work was supported by the Scientific Research Projects Unit of Erciyes University under the grant of FBA-09-1073 EÜBAP. The authors would like to thank Erciyes University for their financial support.

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