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(Au, Ag)/$Al_{0.08}In_{0.08}Ga_{0.84}N$/ (Au, Ag) Metal-semiconductor-metal (MSM) Photodetectors

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Abstract

Metal-semiconductor-metal (MSM) photodetectors (PDs) based on gold and silver (Au, Ag)/Al0.08In0.08Ga0.84N (commercial sample)/ (Au, Ag) have been fabricated and characterized. The effect of annealing temperature of As deposit, 400, 500, and 600 0C for 30 min on the topography and electrical properties of Au contact on Al0.08In0.08Ga0.84N thin film have been characterized and optimized using Current-Voltage (I-V) characteristic. Schottky barrier height (SBH) and ideality factor (n) of Au/ $Al_{0.08}In_{0.08}Ga_{0.84}N$ interface were 1.223 eV and 1.773 at 50 0C annealing temperature for 30 min respectively, and it is found that contact has a high-quality surface. Also, with the same procedure, the effect of annealing time of 15, 30, 45 minutes, and 1 hour have been studied and optimized. The results revealed that the best annealing time is 30 min which has the highest SBH. Au contact compared with Ag contact used to first time as best our knowledge with the optimal condition to select the best metal for MSM photodetectors (PDs). The ideal characterization of Au, Ag/AlInGaN/Au, Ag MSMPDs on Si substrate depend on responsivities of 0.201 and 0.153 A W-1, quantum efficiencies of 71% and 57%, and NEPs of 3.55×10-4 and 1.45×10-3W-1, respectively have been also studied compared. The height SBH and QE for the samples grown on Si was at Au contact which proposed to use in such optoelectronic devices.

Introduction

Although GaN has many advantages in many optoelectronic devices application however Quaternary (AlInGaN) thin films consider as promising material and it attracted much research interest because they allow almost independent control of the lattice mismatch and band off stein AlInGaN-based heterostructures. it has an attractive topic to be used in many applications for any scientific research, such as optoelectronic devices operate in a wide range of the electromagnetic spectrum. it is a benefit due to the high- quality structures and strong ultraviolet emission at RT, it also allows more freedom and independent control regarding energy gap and lattices constant [1,2]. Metal-semiconductor-metal (MSM) has been suggested in this work because of its performance. It is formed from two schottky contacts like fingers that deposit on the top of the surface as shown in Figure (1) [3].

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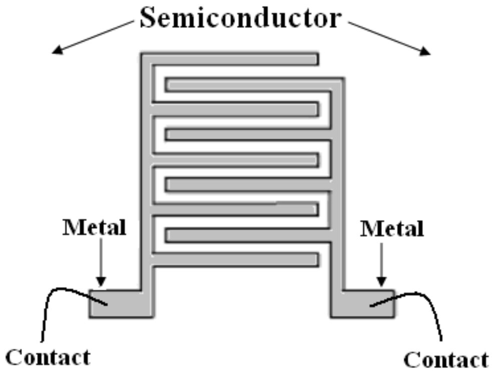

Figure 1 MSM PD structure (top view).

Gold (Au) and silver (Ag) are supposed as ideal Schottky contact for GaN due to its barrier highest (SBH) values [4]. Current-Voltage (I-V) measurements use to determine SBH depend on thermionic emission at V>3kT as following [5]:

$$I = I_0 exp[qV/(nkT)] \quad (1)$$

$$I_0 = AA^{**}T^2 \exp[-q\phi_B/kT] \quad (2)$$

where q, is the electron charge, V is the applied voltage, n represents the ideal factor, k represented the Boltzmann's constant, I_0 represented the saturation current, ΦB represented the barrier height, T represented the absolute temperature, A represented the area of the Schottky contact and A** represented the Richardson coefficient. The theoretical value of A** calculated as shown below:

$$A^{**} = 4\pi \mathrm{m}*\mathrm{q}k^2/h^3 \quad (3)$$

(3) Where m* represented the effective electron mass and h represented the Planck's constant or AlInGaN. The literature on the effective mass of the electron in AlInGaN had not mentioned in the literature before, therefore the effective mass of AlxInyGa1-x-yN with different x, y has calculated depending on the theoretical value of AlN which m*=0.4m_0 (m0 is electron rest mass), of InN which m*=0.11m_0 and of GaN which m*=0.2 m_0 [6].
I-V characteristics for such devices analyzed at reverse bias using the equation as following [7]:

$$I = I_0\ exp(qv/nKT)[1 - exp(-qv/k\mathrm{T})] \quad (4)$$

Thus, Eq. 4 can be re-written in the form [7]

$$I\ exp\ (qv/kT)/exp\ (qv/kT) - 1\ = I_0\ \ exp\ (qv/nkT) \quad (5)$$

Based on Eq. (5), the plot of ln [I exp (qV/kT)/ exp (qV/kT)-1] against V will give a straight line.
In this paper the performance of Au, Ag/ Al0.08In0.08Ga0.84N/Au, Ag MSM PDs depend on SBH, n, Responsivity, quantum efficiency, and NEP have been examined.

Experimental Work

The commercial samples of n- $Al_{0.08}In_{0.08}Ga_{0.84}N$ grown by using molecular beam epitaxy (MBE) on a silicon substrate were employed. The Radio Corporation of America (RCA) cleaning at room temperature was carried out before any fabrication process to remove any contaminations on the wafers. The procedure includes using NH4OH:H2O=1:20 solutions for 10 minutes, then washed with deionized water. Subsequently, the samples were dipped into HF:H2O=1:50 for 10 seconds then, washed again with deionized water. The cleaned samples were then chemically etched in boiling aqua regia of HCl: HNO3=3:1 for 10 minutes to reduce the amount of oxygen (O) and carbon (C) contamination of the Al0.08In0.08Ga0.84N and Si surface. Wafers were then blown dry with compressed air after cleaning. Quaternary $Al_{0.08}In_{0.08}Ga_{0.84}N$ sample must be prepared before depositing the metal contacts and then fabricating the devices.
Silver (Ag) and gold (Au) metal contacts have been deposited on $Al_{0.08}In_{0.08}Ga_{0.84}N$ film as Schottky contacts because of its high work function which equal to 5.4 eV. Au (99.9 purity) Schottky contact deposited on $Al_{0.08}In_{0.08}Ga_{0.84}N$ films grown on Si substrate was fabricated using a metal mask of 250 nm by A500 DC sputtering system while Ag contact was fabricated using the screen print method which considers as a first time as best our knowledge with the optimal condition to select the best metal for MSM photodetectors (PDs).

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Then, the gold contact with a thickness of 200 nm was reached for different temperatures ranged from 400to 600 ºC with different times of 15,30, 45 minutes, and 1hour to optimize the best condition for the device. The topography of Au schottky contact with different annealing temperatures and various times have been examined and optimized using SEM and AFM spectroscopes I-V characteristic of Au, Ag/n- $Al_{0.08}In_{0.08}Ga_{0.84}N$ /Au, Ag MSM carried out using UIR-210A spectrophotometer range from 200 to 1000 nm wavelengths as shown in Figure .2. Using this setting the photocurrent, dark current and I-V measurements were measured and, ideality factors and SBH were calculated.

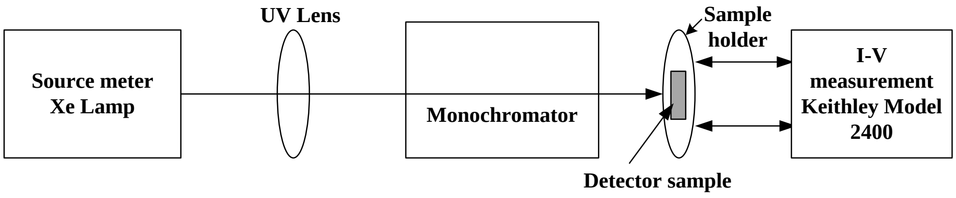

Figure 2 A typical set up of the spectral response measurements of $Al_{0.08}In_{0.08}Ga_{0.84}N$ -based MSM UV PDs

Results and discussion

Au and Ag metals have been used as a Schottky contact in the thin film n- $Al_{0.08}In_{0.08}Ga_{0.84}N$ grown on Si (111) substrate. Effect of annealing temperature of As deposit, 400, 500, and 600 C0 for 30 min on the topography and electrical properties of Au contact have been characterized and optimized.

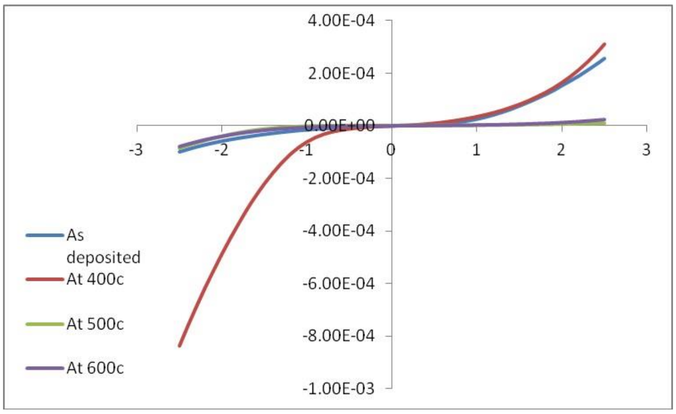

Figure 3 I-V measurements of Au Schottky contact at different annealing temperatures.

I-V characteristics to study the effects of these parameters on electrical properties of films examined by calculated SBH. Figure 3 shows the I-V property of Au/ $Al_{0.08}In_{0.08}Ga_{0.84}N$ Schottky contacts as deposited, 400, 500, 600 ^{0}C for 30 minutes on Si substrates annealing temperature were determined and ideality factors were 1.223 eV and 1.773 of Au/AlInGaN at 50C0 annealing temperature for 30 min. Also, with the same procedure the effect of annealing time of 15,30,45 minutes, and 1hour have been studied and optimized as shown in Figure (4) There results revealed that the best annealing time is 30 min which has the highest SBH.

To be sure that Au contact is the best selection between metals, the comparison with Ag contact has been done with the optimal condition get from the characterization of Au contact. I-V curve of Ag contact deposition AlInGaN prepared by screen print presented in Figure (5).

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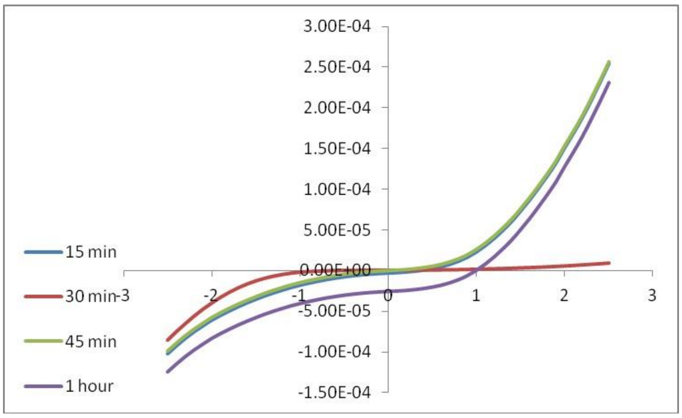

Figure 4 I-V measurements at effect of annealing time of Au Schottky contact deposited on the thin film $Al_{0.08}In_{0.08}Ga_{0.84}N$ grown on then-Si substrates.

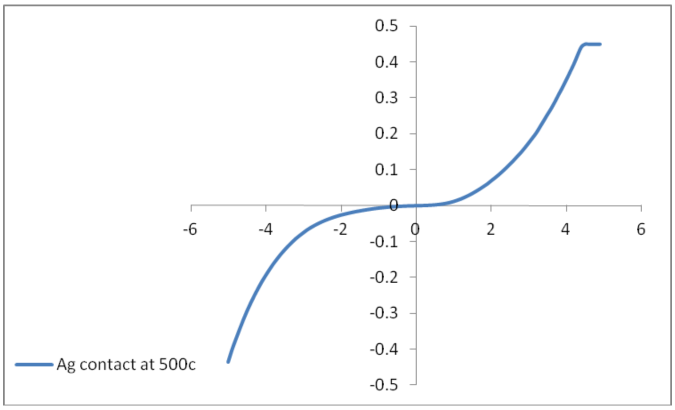

Figure 5: I-V curve of Ag contact at 50 ^{0}C deposit on AlInGaN.

These results of the Au and Ag metal at 500 0C annealing temperature for 30 min showed that the Au metal at 500 C0 annealing temperature for 30 min has the highest SBH and low ideality factor in comparison with Ag metal contact as shown in Table 1.

Table 1 SBH, ideality factor of Schottky contacts of films n- $Al_{0.08}In_{0.08}Ga_{0.84}N$ grown on Si substrate with different temperature.

Electrode	Annealing temperature (^{0}C)	Time (min)	Schottky barrier highest SBH (eV)	Ideality factor (n)
Au	500	30	1.223	1.773
Ag	500	30	1.021	1.883

To confirm the I-V characteristics of the previous results regarding Au contact the topography test have been examined on As deposited, 400, 500, and 600 0C for30 min which including Average diameter, Root mean square, and Roughness Despite, different annealing temperatures have been used, there is no phase change was observed, therefore the optimal annealing temperature is 500°C due to its high RMS which makes more incident beam absorbed inside the layers by increased the quantum confinement probability since its

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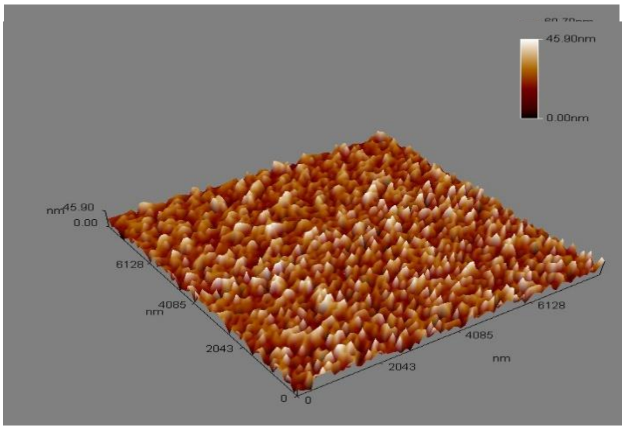
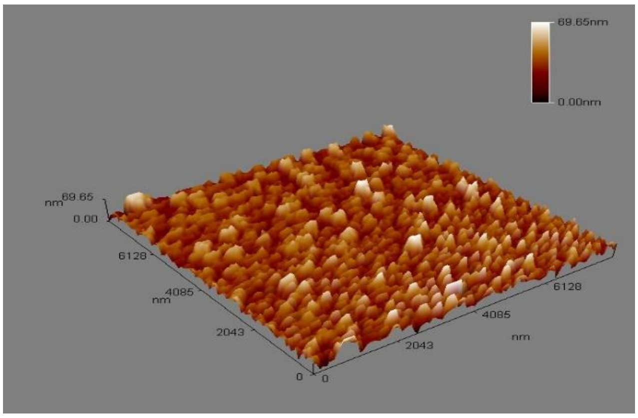
crystalline size is 41 nm depend on Sherrier's formula [8] and bring the quantum effect to appear clearly as shown in Figures 6 and Table (2)

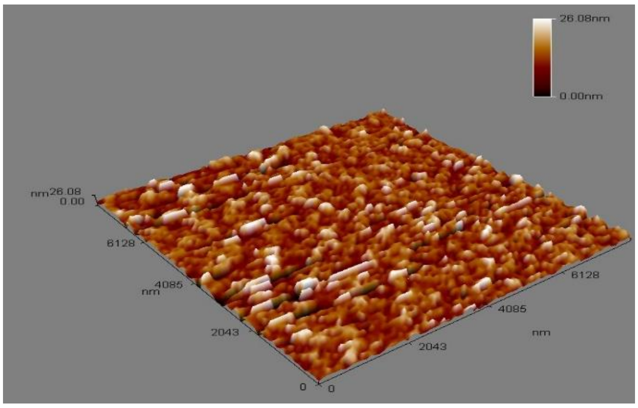
As deposited



At 400 ^{0}C



At 500 ^{0}C



At 600 ^{0}C
Figure 6: AFM measurements of Au Schottky contact at various annealing temperatures.

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Table 2: Average diameter, RMS, and Roughness of the Au contact of $Al_{0.08}In_{0.08}Ga_{0.84}N$ films on Si substrate.

Sample	d(nm)	RMS (nm)	Roughness
As deposited	58.19	2.89	1.7
400	119.09	9.22	7.36
500	91.63	10.3	8.11
600	75.46	4.95	3.79

Figures 7 and 8. Shows the responsivity as a function of the wavelength of the Au and Ag/ $Al_{0.08}In_{0.08}Ga_{0.84}N$ MSM photodetector grown on Si substrate, respectively. Responsivities photodetector is constant over the energy bandgap (UV region from 300 nm to 370 nm) with two orders of magnitude high cut-off drop in wavelength at 360 nm. The responsivities of Au, Ag/ $Al_{0.08}In_{0.08}Ga_{0.84}N$ /Au, Ag MSM photodetectors were 0.201 A W-1 and 0.153 A W-1. In addition, QE of Au, Ag/ $Al_{0.08}In_{0.08}Ga_{0.84}N$ /Au, Ag MSM photodetector son the Si substrate was 71.5% and 57%, respectively.

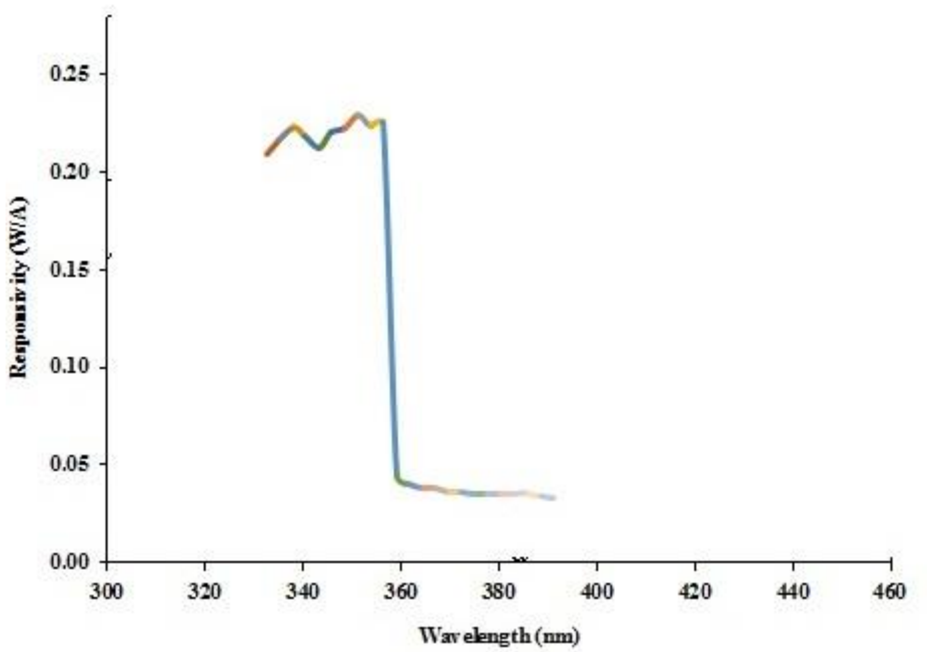

Figure 7: Responsivity of Au / $Al_{0.08}In_{0.08}Ga_{0.84}N$ MSM photodetectors grown on the Si substrate.

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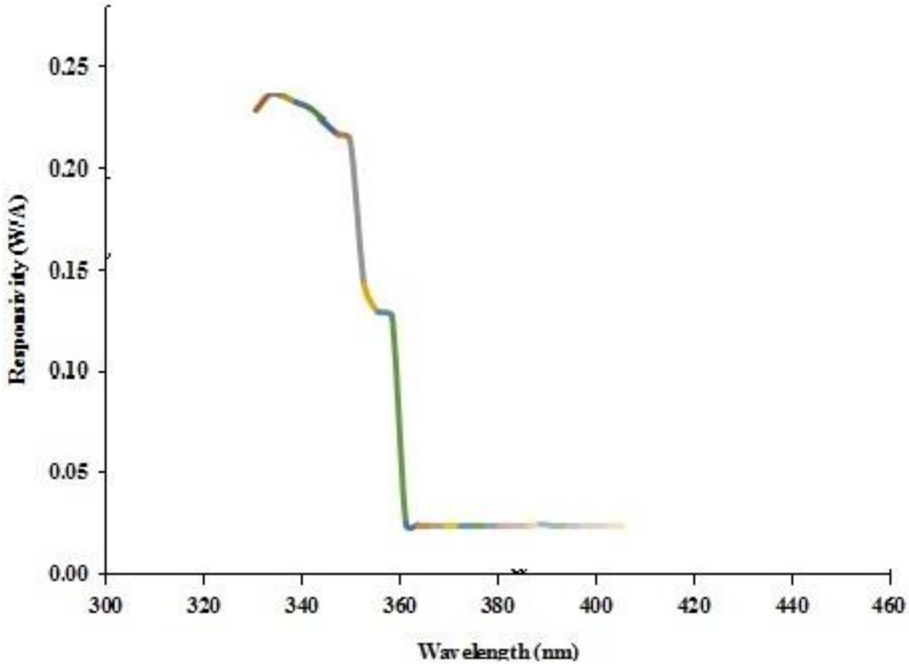

Figure 8 Responsivity of Ag/$Al_{0.08}In_{0.08}Ga_{0.84}N$MSM photodetectors grown on Si substrate.

noise equivalent power (NEP) of Au,Ag/ $Al_{0.08}In_{0.08}Ga_{0.84}N$ /Au,Ag MSM photodetectors were on the Si substrate3.55×10-4 and 1.45×10-3 W-1, respectively, as shown in Figures 7 and 8, calculated that Au metal has the high SBH and high QE of samples grown on Si substrates as summarized in Table3.

Table (3): Dark and illumination current, responsivity, QE, ideality factor and SBH of Au, and Ag/ $Al_{0.08}In_{0.08}Ga_{0.84}N$ MSM photodetectors grown on the Si substrate.

Electrode	Id(A)	Iph(A)	R(AW^{-1})	η%	n	SBH(eV)
Au	$6.87*10^{-5}$	$7.14*10^{-5}$	0.201	71.5	1.773	1.223
Ag	$2.20*10^{-4}$	$2.22*10^{-4}$	0.153	57	1.883	21.2

Conclusion

High work function metals Au successfully used as Schottky contact on n-Al0.08In0.08Ga0.84N thin film which grown on Si (111) substrate. The effect of annealing temperature of 500℃ for 30 min. The electrical characteristics of these effected as well were examined through I-V measurements and their SBH values were computed. The SBH value can be deduced directly from the I-V curves, the computations of SBH and ideality factor (n) at the Au/ Al0.08In0.08Ga0.84N interface for the sample annealed at 500 ºC. Au contact have a higher barrier height when the annealing was performed at 500 °C for 30 minutes which yielded around 1.223 eV.
The ideal characterization of Au /AlInGaN/Au MSM PD Si substrate based on responsivity of 0.201 A W-1, quantum efficiencies of 71.5% .
Au metal has the highest SBH, the highest QE and a low dark current for the samples grown on Si substrates.

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