

Improved Resistivity and Surface Morphology of Laser Treated Cr/Pd Metal Contact Sputter Deposited on Si

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Abstract: In this paper Cr/Pd metal contacts were deposited on Si by using DC magnetron sputtering. The metal contacts were treated using infrared Nd:YAG pulsed laser at different laser pulse energy. The metal contacts were characterized based on electrical, optical and morphology properties by using four-point probes, ultraviolet-visible spectroscopy (UV-Vis) and atomic force microscope (AFM). Measurement obtained from four point probes shown lowest resistivity values for post treatment sample after treated with 25 mJ laser pulsed energy. The measured value is 6.75×10^{-5} Ohm-cm as compared to the as-deposited sample of 1.060×10^{-4} Ohm-cm. The scanned data using UV-Vis shown the characteristics of the thin metal contacts to absorbing light spectrum, whereas reflect light in visible wavelength range. Meanwhile, AFM results confirmed the post-treatment sample has smoother surface as compared to the as-deposited sample.

Keywords: DC Magnetron Sputtering; Nd:YAG pulsed laser; thin film; substrate; resistivity.

1. Introduction

Optoelectronic devices such as light emitting diodes (LED) and solar cells used a semiconductor materials to fulfil the industrial demand. It helps to replace the conventional light bulb. Silicon is one of the semiconductor materials. It is abundant on earth that makes the silicon wafers readily available in large diameter at low-cost. This allow the semiconductor industry to cut the manufacturing cost. In addition, such wafers are compatible with existing processing lines for the six-inch and larger wafer sizes commonly used in the electronics industry [1]. Producing thin films with good material functionality helps industry to produce devices that is reliable and good in performance. The selective substrate to build up the good thin film is crucial. This is due to the well characterized electrical and thermal properties of silicon [2].

Thin films can be produced using several methods such as thermal evaporation, spray pyrolysis, metal organic chemical vapour deposition (MOCVD) and sputtering. Sputtering offer capabilities to produce better quality of thin films at moderate costs and the parameter of deposition can be control. Thermal evaporation even it is offer low

deposition cost, however it creates low quality surface and high thermal heat [3]. Meanwhile, spray pyrolysis produce crack and pores on the sample deposition surface [4]. The metal organic chemical vapour deposition (MOCVD) required high cost to produce the thin films and more complicated deposition process as compared to the sputtering [5].

The type of material chosen to deposit on the substrate plays an important roles. Good material characteristics offer the ability to enhance the devices efficiency. The Cr, Au, and Cu has adhesive properties. Among all three, Cr has greater melting point by 1907°C . Cr also can act as a buffer barrier because it will prevent the metals layer in between upper layer and substrate from mixing [6]. In the other hand, palladium has greater melting point of 1555°C . Pd is in platinum metal group including platinum and rhodium but palladium is generally used as an electrical contacts [7]. This metal produces low-temperature coefficient [8]. When metal and semiconductor is in contact, they can be either Ohmic or Schottky. Ohmic contact offer the ideal type for application in optoelectronics devices due to the low resistance characteristics.

The as-deposited thin films commonly showing amorphous characteristics that

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resulting in higher resistivity Schottky characteristics. Heat treatment including in-situ and post-deposition annealing are commonly used to improve the structural characteristics of deposited thin films. Alternatively, laser beam can be used to treat the films. Laser treatment such as Nd:YAG pulsed laser allows fast heat absorption at specific surface area without affecting the unwanted surfaces of the thin films [9].

This study focus on Cr/Pd deposition on Si substrate by using sputtering technique. The deposited samples were analysed based on its electrical, morphological and optical characteristics by using four-point probe, atomic force microscopy (AFM) and ultraviolet- visible spectroscopy (UV-Vis), respectively.

2. Experimental set up

Firstly, Si substrates were cut into small pieces of $1\text{cm} \times 1\text{cm}$ size. The substrates then were cleaned by heating the samples in acetone solution at 55°C . Cr (5 nm) was deposited on Si followed by Pd (100 nm) by using DC magnetron sputtering. The Cr will act as the buffer layer and also as the strong adhesion on Si substrate. The base pressure during the sputtering process for DC magnetron sputtering system Quorum Q300TD was $\sim 3 \times 10^{-3}$ mbar. The as-deposited sample was treated with Nd:YAG pulsed laser with wavelength of 1064 nm and laser energy was set at 25 mJ per pulse at laser spot size of 0.5mm^2 . Then, the samples were characterized based on electrical properties using four-point probes Model: Lucas Labs Pro4, optical properties using UV-Vis Model: Shimadzu UV-1800 and surface morphological using AFM Model: XE- Park Series.

3. Result and discussion

Table 1 shows the actual data obtained by using four-point probes. Samples treated with laser energy of 25 mJ shows lowest resistivity as compared to the as-deposited samples with resistivity of 6.75×10^{-5} Ohm-cm. Meanwhile, the measured values for the as-deposited sample is 1.060×10^{-4} Ohm-cm. The difference in the measured resistivity values is due to the laser beam absorption by the thin films; actually it will transfer energy in the form of heat. This will cause the surface grains to increase in size.

Moreover, the increase of grain sizes will decrease grain boundary area. Lower grain boundaries will block any scattering of charge carriers thus leads to increasing of the carrier mobility. Additionally, barrier height will also decreases. Thus, lower resistivity reading indicates that the samples itself have lower ability to opposing the current flow. Samples with lower resistivity will allow the flow of electric current. This will increase the electrical conductivity [10]. Meanwhile, another researcher also obtained that the resistivity for post-treatment samples will decrease after being treated [11]–[13].

Table 1 Resistivity, ρ for Cr/Pd metal contacts deposited on silicon.

Laser energy, E (mJ)	Resistivity, $\rho \times 10^{-4}$ (ohm-cm)
0	1.060
25	0.675

The absorption spectrum of Cr/Pd deposited on silicon is shown in Fig. 1(a). The wavelengths chosen are in visible range of 400 nm to 700 nm. A clear observation when the absorption spectrum for post-treatment sample decreases rapidly until the cut off wavelength at 475 nm. Then, the absorption spectrum starts to increase. This is due to the electronic excitation in the thin film. The situation when the spectra of absorbance in thin film increases due to the presence of free electron density. When the electron is excited to the conduction band, inverse bremsstrahlung occur, the electron absorbs energy from the laser irradiation. The electron gain kinetic energy thus producing secondary electron and collides with the lattice atom. The collision enables ionization of them [14]. Vice versa, for the as-deposited sample, the absorption spectrum continues to decrease until the end. Between two types of sample presents industrial demanding sample that had lower in the absorption. Excessive of absorption will cause a decrease in efficiency of the device. By referring to Fig. 1(b) and Fig. 1(c) the post-treatment samples for reflectance graph starts to increase from 400 nm to 700 nm but at transmittance graph, the spectra decreases. In addition, the as-deposited sample is vice versa to the post-treatment sample. The spectra of as-deposited samples decrease in reflectance graph and increase in transmittance graph

Fig. 1(c) shows the transmittance spectrum for post-treatment sample and as-deposited samples. The data obtained from the transmittance spectrum can be used to calculate optical band gap (E_g). Band gap is the minimum energy required for the electron to jump from valence band to conduction band. The transmittance shows that the post-treatment sample decreases rapidly when increasing the wavelength. Whereas, for the as-deposited sample, it rapidly increased by increasing the values of wavelength.

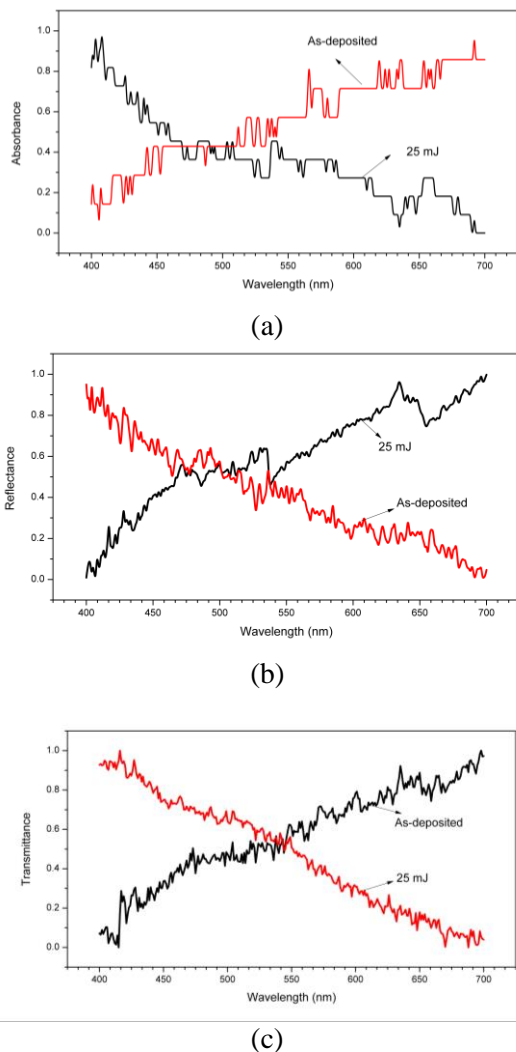


Fig. 1 UV-Vis Spectrum for (a) absorbance; (b) reflectance; (c) transmittance.

The optical band gap energy can be calculated from Eq. 1 and Eq. 2. The values of optical band gap E_g can be estimated by plotting the $(\alpha h\nu)^2$ against $h\nu$ as shown in Fig. 2. From the graph, $m = 1/2$ is more suitable since it shows the best linear curve. The optical band gap is found to be 2.2 eV for Cr/Pd thin film deposited

on Si for the post-treatment sample. Meanwhile 2.4 eV for the as-deposited sample. The changes of the band gap such that the value decreases after treated with laser energy indicate that the increasing of Pd crystallite nanostructure [15].

$$\alpha = \frac{2.3026 \log \frac{1}{T}}{t} \quad (1)$$

Where α is absorption coefficient, T is values of normalized transmittance and t is thickness of thin film.

$$\alpha h\nu = A(h\nu - E_g)^m \quad (2)$$

Where h is planks constant 6.626×10^{-34} Js, N is frequency of incident photon and m is integer.

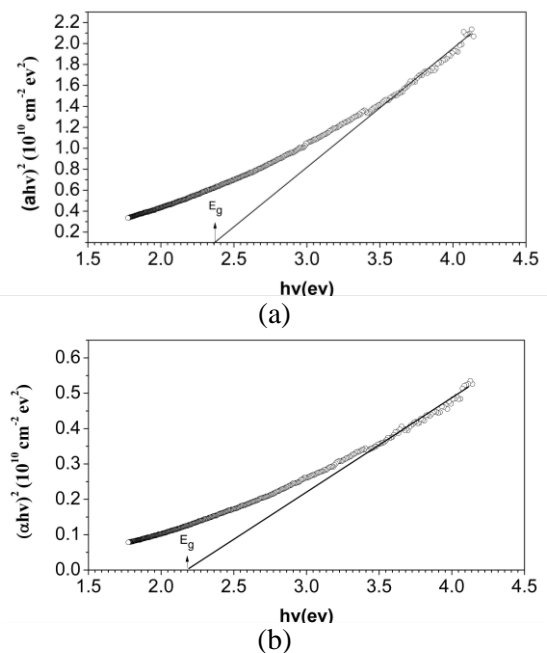


Fig. 2 Plot of photon energy with transition of $m = 1/2$ for (a) As-deposited sample (b) Post-treatment sample.

Fig. 3 revealed the AFM images for thin films of Cr/Pd deposited on silicon for the as-deposited and post-treatment sample. The post-treatment sample that treated with 25 mJ laser energy is smoother as compared to the as-deposited based on the surface area where the grains uniformly distributed. It is obvious for these two treated samples, there are white spots present on the surface that represent valleys. This is due to the increase in height at the surface boundaries [16]. There are black spots present on the as-deposited samples that

indicated more depth area. Table 2 represents the summary of AFM analysis for each thin film samples. Surface roughness refers to the uneven and irregular of surface morphology and topography. Both R_a and R_q refer the irregularities of the surface morphology. The differences between them is that R_q are more sensitive to peak and valley as presented on the samples [17]. Other valuable data is the R_{ku} , it will display the sharpness of the roughness sample profiles. The values greater than 3 indicated more peak and valley [18]. Based on Table 3, post-treatment sample had lower R_q compared to as-deposited sample with 0.873 nm. It is desirable to produce smooth surface since rougher surface causing to decrease any active interaction. The smooth surface of post-treatment sample has better electrical conductivity as compared to the as-deposited sample.

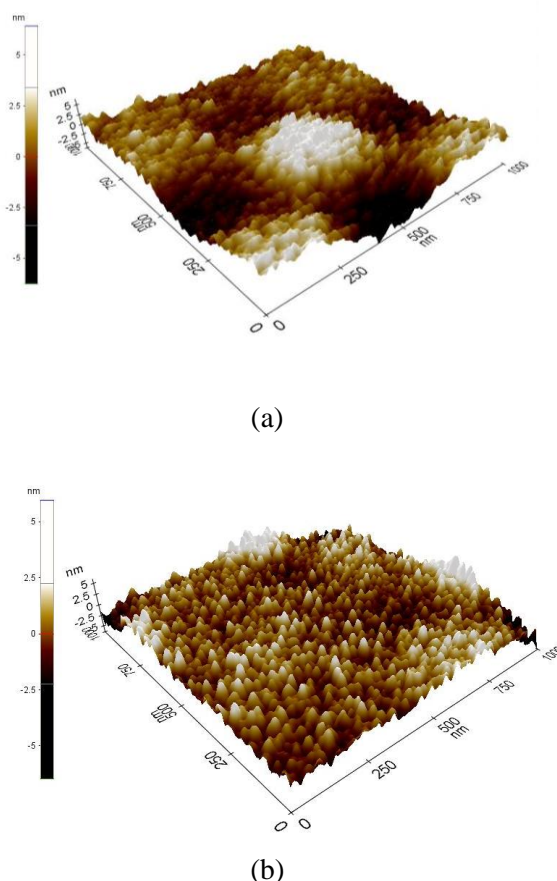


Fig. 3 Surface morphological for thin films samples (a) As-deposited sample and (b) Post-treatment sample.

Table 2 Surface characteristics scanned by AFM.

Sample	Average Roughness, R_a (nm)	RMS Roughness, R_q (nm)	Kurtosis, R_{ku}
As-Deposited	1.329	1.730	3.421
25 mJ	0.873	1.145	4.437

4. Conclusions

The resistivity values for silicon samples decreases after treated with 25 mJ laser energy from 1.06×10^{-4} Ohm-cm to 6.75×10^{-5} Ohm-cm. Laser energy has the ability to deliver energy to the samples without affecting the other area. The lower the values of resistivity indicates greater electrical conductivity. By using laser energy, thermal heat can propagate to the samples and reduce any distortion. Laser energy also has the ability to reorganize the crystal structure. UV-Vis measured the absorbance, reflectance and transmittance spectra showing diverse spectrum for the wavelength range from 400 nm to 700 nm for as-deposited and post-treatment sample. The AFM results proved surface morphological for post-treatment sample treated with 25 mJ laser energy had smooth surface compared to as-deposited samples and contributes to lower resistivity.

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