

EFFECTS OF METAL NANO COATINGS ON EMITTANCE, REFLECTANCE AND TRANSMITTANCE AND COMPARISON WITH NON METAL NANO COATINGS

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ABSTRACT

Thin-film interference occurs when incident light waves reflected by the upper and lower boundaries of a thin film interfere with one another to form a new wave. Studying this new wave can reveal information about the surfaces from which its components reflected, including the thickness of the film or the effective refractive index of the film medium. In this research thin film multilayer has been investigated. The transfer matrix method is applied to calculate the radiative properties of multilayer structures. This method considers wave interferences in each layer. The empirical expression for the optical constants of lightly doped silicon is used. Metal coating compared with non metal coatings. With silver thin film coating can achieve 0.985 of reflectance. It is very good reflector coating. The industrial that need high reflecting can use silver thin film coating. Results show that non metal coatings such as silicon dioxide and silicon nitride act as anti-reflector, but metal coatings such as silver, gold and copper increase reflectance.

Keywords: Metal Coatings, Non Metal Coatings, Emittance, Reflectance, Transmittance, Nano Scale

INTRODUCTION

A thin film is a layer of material ranging from fractions of a nanometer (monolayer) to several micrometers in thickness. Electronic semiconductor devices and optical coatings are the main applications benefiting from thin-film construction. A familiar application of thin films is the household mirror, which typically has a thin metal coating on the back of a sheet of glass to form a reflective interface. The process of silvering was once commonly used to produce mirrors. A very-thin-film coating (less than about 50 nanometers thick) is used to produce two-way mirrors. The performance of optical coatings (e.g., antireflective, or AR, coatings) are typically enhanced when the thin-film coating consists of multiple layers having varying thicknesses and refractive indices. Similarly, a periodic structure of alternating thin films of different materials may collectively form a so-called superlattice which exploits the phenomenon of quantum confinement by restricting electronic phenomena to two-dimensions.

Thin-film interference occurs when incident light waves reflected by the upper and lower boundaries of a thin film interfere with one another to form a new wave. Studying this new wave can reveal information about the surfaces from which its components reflected, including the thickness of the film or the effective refractive index of the film medium. Thin films have many commercial applications including anti-reflection coatings, mirrors, and optical filters (Oloomi *et al.*, 2009).

The studied examples using silicon wafer and either silicon dioxide or silicon nitride coating demonstrate the strong influence of coating and coating thickness on the radiative properties. This study helps gain a better understanding of the radiative properties of semitransparent wafers with different coatings and will have an impact not only on semiconductor processing but also on thin film solar cells. Fu studied radiative properties of NIMs by using three multilayer structures with NIM layer (Oloomi *et al.*, 2009). Silicon is the semiconductor that plays a vital role in integrated circuits and MEMS/NEMS. This work interested in silicon, because of its various applications. During the past two decades, there have been tremendous developments in near-field imaging and local probing techniques. Examples are the Scanning Tunneling Microscopy (STM), Atomic Force Microscopy (AFM), Near-field Scanning Optical

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Microscopy (NSOM), Photon Scanning Tunneling Microscopy (PSTM), and Scanning Thermal Microscopy (SThM). Spectral and directional control of thermal radiation is a challenging yet important task for a number of applications, such as thermophotovoltaic (TPV) energy conversion, solar energy utilization, space thermal management, and high-efficiency incandescent lamps.

Temperature measurements and control are critically important for continuous improvement of RTP (Oloomi et al., 2008; Oloomi et al., 2010a). Since the heating source is at a much higher temperature than that of the silicon wafer, radiative energy exchange is the dominant mode of heat transfer. Hence, understanding the radiative properties of silicon and other relevant materials is essential for the analysis of the thermal transport processes. Furthermore, since many RTP furnaces use noncontact lightpipe thermometers, accurate determination of the wafer emittance is necessary for correlating the radiance temperature to the true wafer temperature (Oloomi et al., 2010b; Oloomi et al., 2010c). For lightly doped silicon, silicon dioxide coating has higher reflectance than silicon nitride coating for visible wavelengths. In visible wavelengths the reflectance increases as the temperature increases due to decreasing emittance; but in infrared wavelengths, the reflectance and transmittance decrease as the temperature increases (Oloomi et al., 2010d).

This Paper, predict the directional, spectral, and temperature dependence of the radiative properties for the multilayer structures consisting of silicon and related materials such as silicon dioxide, silicon nitride, gold, silver and copper.

Modeling the Radiative Properties of Multilayer

Coherent Formulation (Timans et al., 2000; Zhang et al., 2003)

When the thickness of each layer is comparable or less than the wavelength of electromagnetic waves, the wave interference effects inside each layer become important to correctly predict the radiative properties of multilayer structure of thin films. The transfer-matrix method provides a convenient way to calculate the radiative properties of multilayer structures of thin films.

By assuming that the electric field in the j th medium is a summation of forward and backward waves in the z -direction, the electric field in each layer can be expressed by (Timans et al., 2000; Zhang et al., 2003)

$$E_j = \begin{cases} A_1 e^{iq_{1z}z} + B_1 e^{-q_{1z}z} \Big] e^{(iq_x x - i\omega t)}, & j = 1 \\ \left[A_j e^{iq_{jz}(z-z_{j-1})} + B_j e^{-q_{jz}(z-z_{j-1})} \right] e^{(iq_x x - i\omega t)}, & j = 2, 3, \dots, N \end{cases} \quad (1)$$

Where A_j and B_j are the amplitudes of forward and backward waves in the j th layer. Detailed descriptions of how to solve for A_j and B_j is given in (Timans et al., 2000; Zhang et al., 2003) consequently, the radiative properties of the N -layer system are given by

$$\rho = \frac{B_1 B_1^*}{A_1^2}, \tau = \frac{\text{Re}(\tilde{n}_N \cos \tilde{\theta}_N) A_N A_N^*}{n_1 \cos \theta_1 A_1^2}, \varepsilon = 1 - \rho - \tau \quad (2)$$

Optical Constants

The optical constants, including the refractive index (n) and the extinction coefficient (κ), of a material are complicated functions of the wavelength and temperature.

The Refractive Index of Silicon

Jellison and Modine (1994) measured the ratio of the Fresnel reflection coefficients of silicon wafers in both polarization states with a two-channel spectroscopic ellipsometer in the temperature range from 25°C to 490 °C. The Jellison and Modine (J-M) expression of the refractive index for wavelength between 0.4 μm and 0.84 μm is given by

$$n_{JM}(\lambda, T) = n_0(\lambda) + \beta(\lambda)T \quad (3)$$

$$n_0 = \sqrt{4.565 + \frac{97.3}{3.648^2 - (1.24/\lambda)^2}} \quad (4)$$

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$$\beta(\lambda) = -1.864 \times 10^{-4} + \frac{5.394 \times 10^{-3}}{3.648^2 - (1.24 / \lambda)^2} \tag{5}$$

where $\lambda[\mu\text{m}]$ is the wavelength in vacuum and $T [^\circ\text{C}]$ is the temperature.

The refractive index of silicon that covers the wavelength region between 1.2 μm and 14 μm and the temperature range up to 480 $^\circ\text{C}$ is (Timans *et al.*, 2000; Zhang *et al.*, 2003):

$$n_L(\lambda, T) = \sqrt{\varepsilon_r(T) + \frac{g(T)\eta(T)}{\lambda^2}} \tag{6}$$

$$\varepsilon_r(T) = 11.631 + 1.0268 \times 10^{-3}T + 1.0384 \times 10^{-6}T^2 - 8.1347 \times 10^{-10}T^3 \tag{7}$$

$$g(T) = 1.0204 + 4.8011 \times 10^{-4}T + 7.3835 \times 10^{-8}T^2 \tag{8}$$

$$\eta(T) = \exp(1.786 \times 10^{-4} - 8.526 \times 10^{-6}T - 4.685 \times 10^{-9}T^2 + 1.363 \times 10^{-12}T^3) \tag{9}$$

The Extinction Coefficient of Silicon

The J-M expression of the extinction coefficient, covering the wavelength range from 0.4 μm to 0.84 μm , is given as (Jellison *et al.*, 1994):

$$k_{JM}(\lambda, T) = k_0(\lambda) \exp\left[\frac{T}{369.9 - \exp(-12.92 + 6.831/\lambda)}\right] \tag{10}$$

$$k_0(\lambda) = -0.0805 + \exp\left[-3.1893 + \frac{7.946}{3.648^2 - (1.24/\lambda)^2}\right] \tag{11}$$

In the longer wavelength region, Timans (Timans *et al.*, 2000) measured the emission spectra of several silicon wafers and deduced the absorption coefficient in the wavelength region from 1.1 μm to 1.6 μm , in the temperature range between 330 $^\circ\text{C}$ and 800 $^\circ\text{C}$.

$$\alpha(\lambda, T) = \alpha_{BG}(\lambda, T) + \alpha_{FC}(\lambda, T) \tag{12}$$

$$\alpha_{BG}(\lambda, T) = \sum_{i=1}^4 \alpha_{a,i}(\lambda, T) + \sum_{i=1}^2 \alpha_{e,i}(\lambda, T) \tag{13}$$

Notice that silicon is an indirect-gap semiconductor and the absorption process is accompanied by either the absorption of a phonon, denoted by $\alpha_{a,i}(\lambda, T)$, or the emission of a phonon, denoted by $\alpha_{e,i}(\lambda, T)$. Detailed expressions for $\alpha_{a,i}(\lambda, T)$ and $\alpha_{e,i}(\lambda, T)$ can be found in Timans (Timans *et al.*, 2000).

The optical constants of silicon dioxide, silicon nitride, gold, silver and copper are mainly based on the data collected in Palik’s handbook (Palik, 2008).

RESULTS AND DISCUSSION

Results

Optical techniques and radiative processes play important roles in current industry and daily life. Examples are advanced lighting and display, materials and surface characterization, real time processing monitoring and control, laser manufacturing, rapid thermal processing (RTP), communication, data storage and reading, radiation detection, biomedical imaging and treatment, ground and space solar energy utilization, direct energy conversion, etc. High emittance is needed for suitable thermal balance of the thin-film solar cells for space applications. Optical coatings that provide high emittance must be formed on the solar cells to overcome that problem by increasing number of thin film layers. Radiative properties are complex function of wavelength. Increasing number of thin film layers lead to more complexity and dependency on wavelength regard to wavelength interferences (Oloomi *et al.*, 2010c). If thickness of non metal coating increases, reflectance of multilayer decreases and transmittance increases. Gold thin film coating increases reflectance. The reflectance of multilayer coated with gold increases by increasing the thickness of coating. Industrial requirements are supported by selecting coating’s material and thickness (Oloomi *et al.*, 2010d). This work uses transfer matrix method for calculating the radiative

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properties of semiconductor materials related to the recent technological advancements that are playing a vital role in the integrated-circuit manufacturing, optoelectronics, and radiative energy conversion devices.

Figure 1 compares the emittance of donor doped silicon with concentration of $1 \times 10^{18} \text{ cm}^{-3}$ coated by silicon dioxide in the different temperatures with the results in (Ravindra *et al.*, 2011). The silicon thickness is $700 \mu\text{m}$ and the thickness of the dioxide silicon is 65.3 nm and the electromagnetic wave is incident at $\theta = 0^\circ$. The calculated results are in good agreement with those of Ravindra *et al.*, (2001).

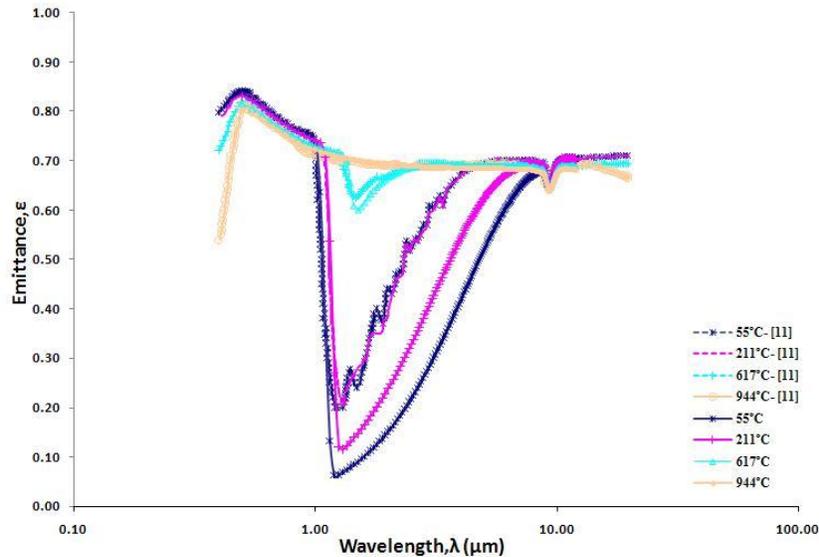


Figure 1: Comparison of Calculated Results with the Results of Ref 11

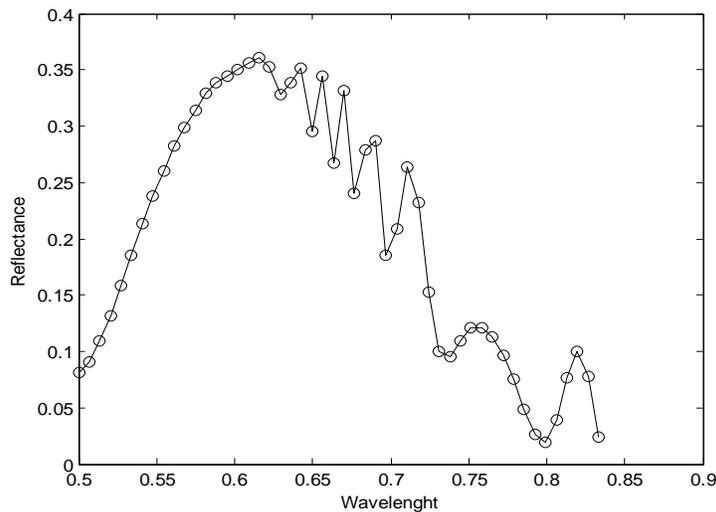


Figure 2: Reflectance of lightly doped silicon wafer coated with a silicon dioxide film on both sides at 25°C

Consider the case in which the silicon wafer is coated with thin film on both sides. One time SiO_2 is used as thin film coating and other time Si_3N_4 is used as thin film coating. The thickness of silicon wafer is $10 \mu\text{m}$. The thickness of SiO_2 and Si_3N_4 is 400 nm . Some results of this study are shown below in figures 2 to 3.

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Any electromagnetic wave consists of an electric field component and a magnetic field component. The electric field component is used to define the plane of polarization because many common electromagnetic-wave detectors respond to the electric forces on electrons in materials, not the magnetic forces. Polarization is a characteristic of all transverse waves. Oscillations which take place in a transverse wave in many different directions is said to be unpolarized. In an unpolarized transverse wave oscillations may take place in any direction at right angles to the direction in which the wave travels. In this paper, the incidence ray considered unpolarized.

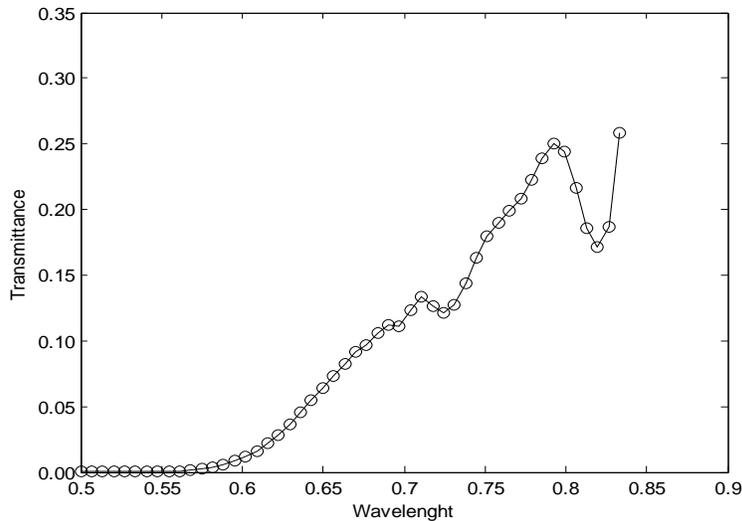


Figure 3: Transmittance of lightly doped silicon wafer coated with a silicon Nitride film on both sides at 25°C

Consider the case in which the silicon wafer is coated with metal thin film on both sides. Gold, Silver and copper are used as thin film coating. The thickness of silicon wafer is $10 \mu m$. The thickness of metal thin film coating is 400 nm. Some results of this study are shown below in figures 4 to 6.

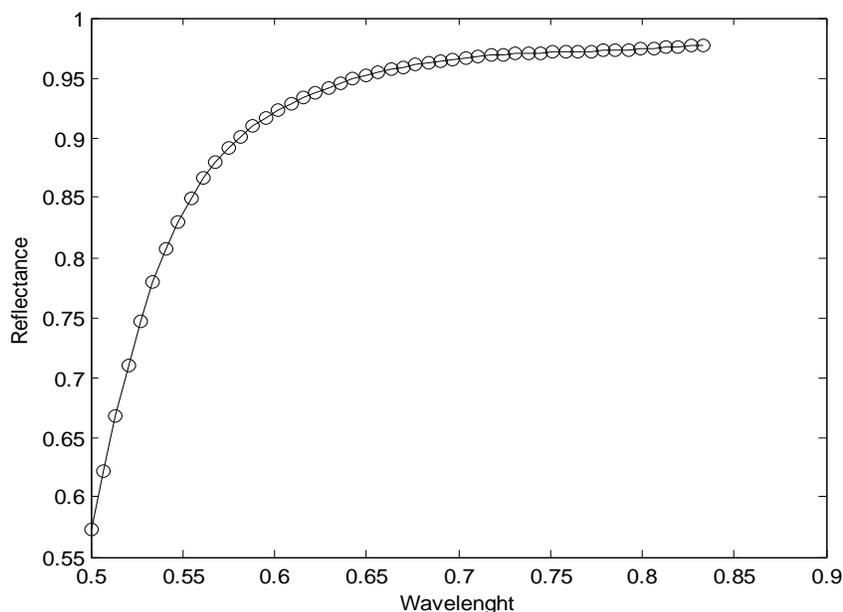


Figure 4: Reflectance of lightly doped silicon wafer coated with gold thin films on both sides at 25°C

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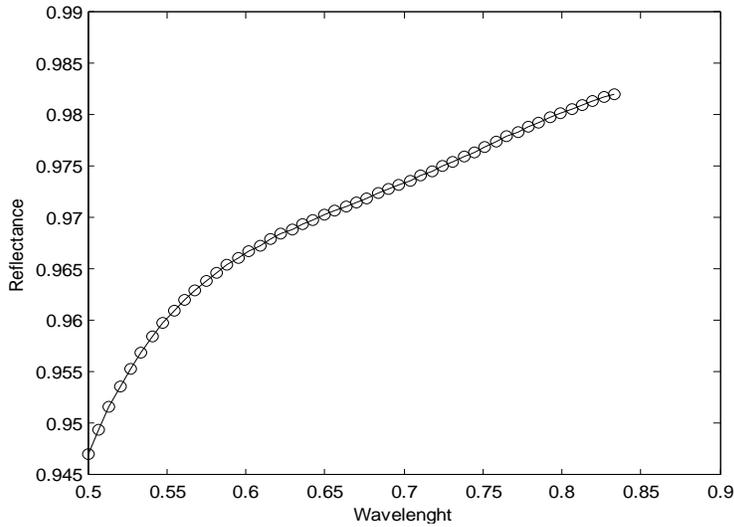


Figure 5: Reflectance of lightly doped silicon wafer coated with silver thin films on both sides at 25°C

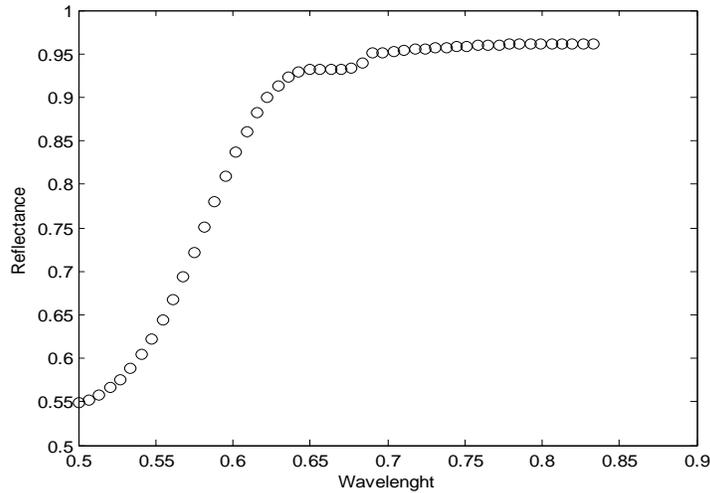


Figure 6: Reflectance of lightly doped silicon wafer coated with copper thin films on both sides at 25°C

Figure 7 shows the reflectance of thick silicon sub layer with 700μm thickness coated by silicon dioxide, silicon nitride and gold thin film coating with 300nm thickness in 1.55μm wavelength and room temperature.

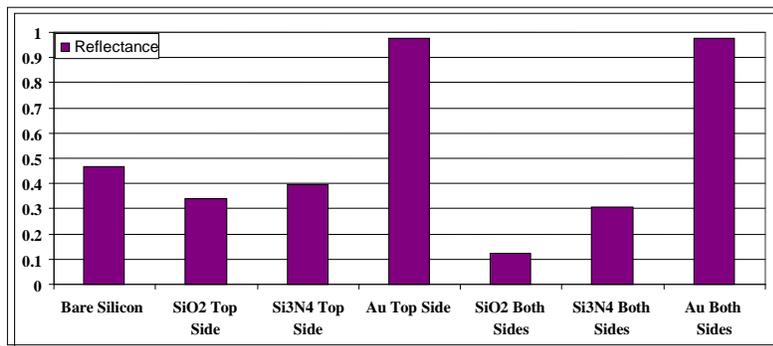


Figure 7: Comparison of Reflectance for Different Thin Film Coatings

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When the metal thin film coatings consist of gold, silver and copper are used, the effects of interferences and fluctuations in the radiative properties are reduced. Silicon dioxide and silicon nitride coating act as anti reflector and these coatings reduce reflectance toward bare silicon. Gold thin film coating increases reflectance. Results also showed that silicone dioxide coating on the upper surface of silicon sub layer leads to 27% reduction reflectance also silicon nitride coating leads to 15% reduction of reflectance but gold coating leads to a rise of 92% of reflectance of silicon sub layer. Industrial requirements are supported by selecting coating's material and thickness.

Conclusion

Results show that silver thin film coating has the highest reflectance of all thin film that used in this study. With silver thin film coating can achieve 0.985 of reflectance. It is very good reflector coating. The industrial that need high reflecting can use silver thin film coating. The non metallic thin film coatings lead to reduction in reflectance and act as anti reflector. The metal thin film coating leads to a noticeable rise in amount of reflectance and metallic thin film coatings can use in industrials which need much reflectance. The silicone dioxide coating on the upper surface of silicon sub layer leads to 27% reduction reflectance also silicon nitride coating leads to 15% reduction of reflectance but gold coating leads to a rise of 92% of reflectance of silicon sub layer. Gold, silver and copper thin film coatings are metal coatings and they increase reflectance.

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