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The effects of thickness and number of silicon thin layers on Reflectance, Transmittance and Emittance

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Abstract: The thin layered cover has an important role on semiconductor industries and micro electro mechanic and Nano electro mechanic equipment's. It's important to know about radiation properties of multi-layered structures like Sillicon and metal coatings like magnesium oxide, dioxide silicon and trioxide aluminum with different parameters to use in small systems. In this article Si is selected as basic material. The effect of thickness and numbers of thin Silicon layers on reflectance, transmittance and emittance of a multi-layered structure consist of silicon main sub-layer with 500 micrometer thicknesses and different Nano coatings like gold, copper, silver and aluminum with 400 nanometer thicknesses on 25 ^{o}C temperature and 0.75 micrometer wave length was obtained. Results shows that as Ag in first layer come with Cu of next layer, it can be said that amount of emittance is increasing to maximum.

Key words: Reflectance; Transmittance; Emittance; Thin Film

1. Introduction

Understanding the radiative properties of semiconductors is essential for the advancement of manufacturing technology, such as rapid thermal processing (Timans, 1996).

Because the major heating source in rapid thermal processing is lamp radiation, knowledge of radiative properties is important for temperature control during the process.

Silicon is semiconductor that plays a vital role in integrated circuits and MEMS/ NEMS (Oloomi et al., 2008).

Semitransparent crystalline silicon solar cells can improve the efficiency of solar power generation (Fath et al., 2002).

Accurate radiometric temperature measurements of silicon wafers and heat transfer analysis of rapid thermal processing furnaces require a thorough understanding of the radiative properties of the silicon wafer, whose surface may be coated with dielectric or absorbing films (Timans, 1996). In fact, surface modification by coatings can significantly affect the radiative properties of a material (Makino, 2002).

For lightly dopped silicon that silicon dioxide coating has higher reflectance than silicon nitride coating for visible wavelengths. In visible wavelengths the reflectance increases as the temperature increases, because of decreasing emittance but in infrared wavelengths the reflectance and transmittance decrease as the temperature increases (Oloomi et al., 2008, 2009).

Silicon dioxide and silicon nitride coating act as anti-reflector and these coatings reduce reflectance toward bare silicon. If thickness of non-metal coating increases, reflectance of multilayer decreases and transmittance increases (Oloomi et al., 2010). In visible wavelengths the reflectance increases as the temperature increases, because of decreasing emittance. As the film thickness increases, the free spectral range decreases, resulting in more oscillations with thicker silicon dioxide film, but interferences in the substrate are generally not observable in incoherent formulation (Oloomi et al., 2010).

Infrared imaging is used extensively for both military and civilian purposes. Military applications include target acquisition, surveillance, night vision and homing and tracking. Non-military uses include thermal efficiency analysis, remote temperature sensing, short-ranged wireless communication, spectroscopy, and weather forecasting.

This work uses transfer-matrix method for calculating the radiative properties. Lightly dopped silicon is used and the coherent formulation is applied.

2. Modeling

2.1. Coherent formulation

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

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convenient way to calculate the radiative properties of multilayer structures of thin films (Fig. 1).

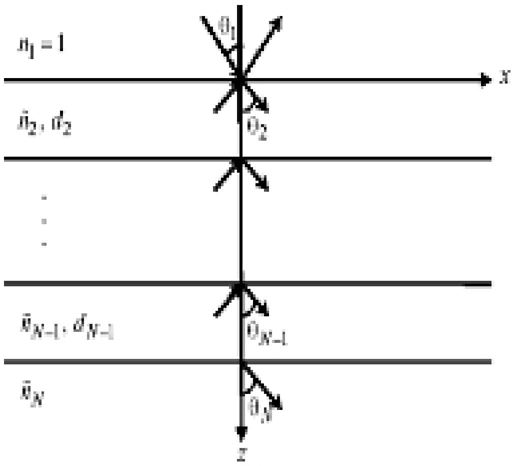

Fig. 1: The geometry for calculating the radiative properties of a multilayer structure

By assuming that the electromagnetic field in the jth medium is a summation of forward and backward waves in the z-direction, the electric field in each layer can be expressed by

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

Where A_j and B_j are the amplitudes of forward and backward waves in the jth layer. Detailed descriptions of how to solve for A_j and B_j is given in (Fu et al., 2003).

2.2. The Drude model for the optical constants of doped silicon

The complex dielectric function is related to the refractive index (n) and the extinction coefficient (κ) by this equation

$$\varepsilon(\omega) = (n + ik)^2 \quad (2)$$

To account for the doping effects, the Drude model is employed, and the dielectric function of both intrinsic and doped silicon is expressed as the following form (Hebb, 1997).

$$\varepsilon(\omega) = \varepsilon_{bl} - \frac{N_e e^2 / \varepsilon_0 m_e^*}{\omega^2 + i\omega/\tau_e} - \frac{N_h e^2 / \varepsilon_0 m_h^*}{\omega^2 + i\omega/\tau_h} \quad (3)$$

Where the first term in the right (ε_{bl}) accounts for contributions by transitions across the band gap and lattice vibrations, the second term is the Drude term for transitions in the conduction band (free electrons), and the last term is the Drude term for transitions in the valence band (free holes). Here, N_e and N_h are the concentrations, m_e^* and m_h^* the effective masses, τ_e and τ_h the scattering times for free electrons and holes, respectively, and e is the electron charge. For simplicity, the effective masses are assumed to be independent of the frequency, dopant concentration, and temperature in the present study, and their values are taken from Ref. (Fu and et al, 2003) as:

$$m_e^* = 0.27 m_0 \quad (4)$$

$$m_h^* = 0.37 m_0 \quad (5)$$

Where m_0 is the electron mass in vacuum? Since ε_{bl} accounts for all contributions other than the free carriers, it can be determined from the refractive index and extinction coefficient of silicon (Timans, 1996) as:

$$\varepsilon_{bl} = (n_{bl} + ik_{bl})^2 \quad (6)$$

When considering the contribution from transitions across the band gap, the modification of the band structure by impurities is neglected and this assumption should not cause significant error (Jellison et al., 1994). In this work, the expression of Jellison and Modine (Jellison et al., 1994) is used to calculate the refractive index n_{bl} in the wavelength region from 0.5 µm to 0.84 µm.

$$n_{bl}(\lambda, T) = n_0(\lambda) + \beta(\lambda)T \quad (7)$$

$$n_0 = \sqrt{4.565 + \frac{97.3}{3.648^2 - (1.24/\lambda)^2}} \quad (8)$$

$$\beta(\lambda) = -1.864 \times 10^{-4} + \frac{5.394 \times 10^{-3}}{3.648^2 - (1.24/\lambda)^2} \quad (9)$$

The extinction coefficient k_{bl} accounts for the band gap absorption as well as the lattice absorption. The band gap absorption occurs when the photon energy is greater than the band gap energy of silicon and results in a large absorption coefficient. The absorption coefficient is related to the extinction coefficient as

$$\alpha = 4\pi k / \lambda \quad (10)$$

k_{bl} can be determined for all temperatures from the equation for absorption coefficients. In this paper the extinction coefficient of silicon is calculated from Jellison and Modine's expression in the wavelength range from 0.4 to 0.9 µm (Jellison and et al, 1994).

$$k_{bl}(\lambda, T) = k_0(\lambda) \exp\left[\frac{T}{369.9 - \exp(-12.92 + 6.831/\lambda)}\right]$$
(11)

$$k_0(\lambda) = -0.0805 + \exp\left[-3.1893 + \frac{7.946}{3.648^2 - (1.24/\lambda)^2}\right]$$
(12)

Once ε_{bl} is determined from the preexisting functional expressions and tabulated data, the remaining parameters are the carrier concentrations and scattering times, which are functions of the temperature and dopant concentration. The calculation of carrier concentrations requires the knowledge of the Fermi energy (E_F). By knowing the Fermi energy, carrier concentrations can be obtained from the following equations (Gaylord et al., 1976).

$$N_e = N_C F_{1/2}\left(\frac{E_F - E_g}{kT}\right) \quad (13)$$

$$N_h = N_V F_{1/2}\left(\frac{-E_F}{kT}\right) \quad (14)$$

3. Results

Fig.2 compare the reflectance and transmittance of thick silicon substrate with $700\ \mu m$ thickness and coated by silicon dioxide thin film with $300nm$ thickness in two different coating cases and two different temperatures with the results in. The Electromagnetic waves are incident at $\theta = 0^\circ$. The calculated results are in good agreement with results in (Lee et al., 2005).

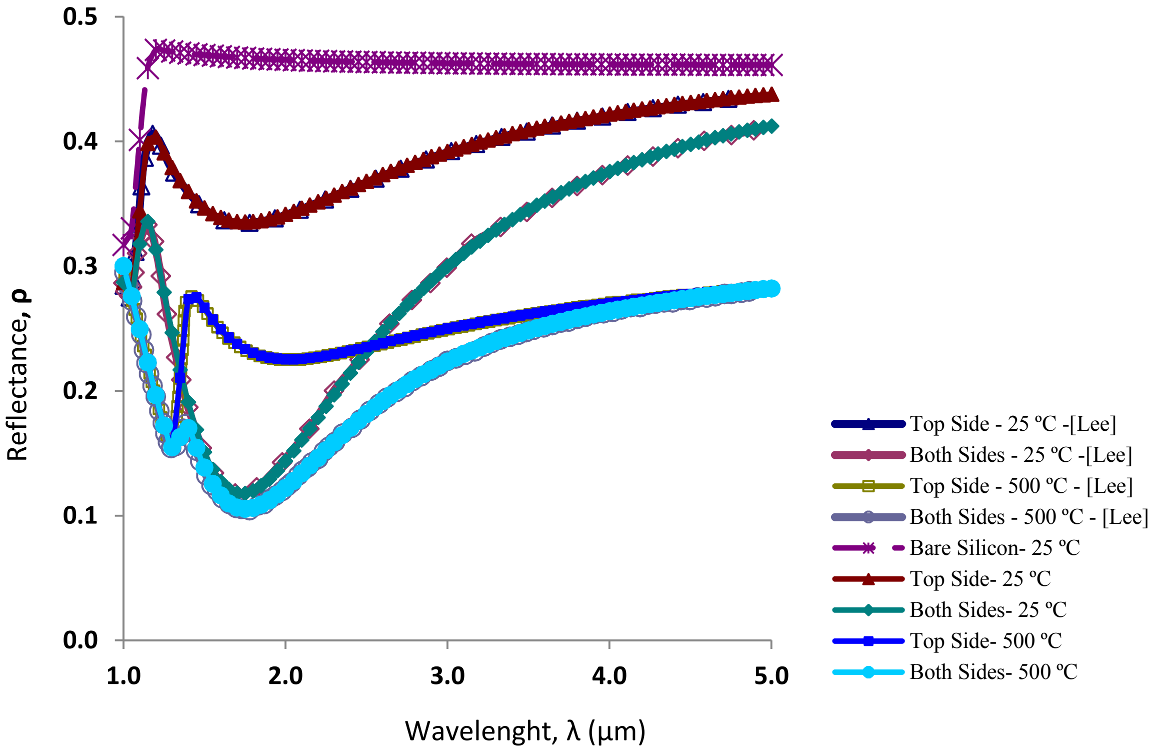

Fig.2: A comparison of the calculated reflectance with results of (Lee and et al, 2005).

Because the refractive index of silicon dioxide (around 1.45) is smaller than that of silicon, the reflectance with a coating is always lower than that of bare silicon (Fig. 2).

In this paper Si is selected as basic material. Then Si is covered with Al, Ag, Cu and Au in different shapes. To simplify, each Nano has a code that are used in next phases of making layers. Table (1) shows all kinds of used Nano coatings with related code.

Table 1: Numbers nano coatings

id	Si	Cu	Au	Ag	Al	Air
id	1	2	3	4	5	6

The effect of thickness and numbers of silicon thin layers on reflectance, transmittance and emittance of a multi-layered structure consist of main sub layer of silicon with 500 micrometer thickness and different Nano coatings such as gold, silver, copper and aluminum with 400 nanometer thickness from two side on 25 ºc and non-polar and an upright radiation angle in 0.72 micrometer wavelength was obtained. Now that Nano coating and their codes are defined, all kinds of layering with these Nano coatings can be done. As it is shown in chart (2), 21 forms of Nano coatings are viewed and the reflectance, transmittance and emittance of them are obtained.

3.2. Study the diagram of reflection at 0.72 micrometer wavelength

It is obvious from Fig. (4) that if Cu and Si be in first layer or last layer, the reflectance will be in its maximum. If Au exists, something different will happen. If Ag be in first layer or last layer, the reflectance will go toward its minimum and when the cover has Si and Au sub layer or both of them, it can be said that the reflectance will reach to its maximum.

Table 2: Reflectance, transmittance and emittance

Reflectance	Transmittance	Emittance	Id
8.97E-01	7.44E-42	1.03E-01	9 5 1 2 9
8.97E-01	1.31E-41	1.03E-01	9 5 1 3 9
9.68E-01	9.76E-27	3.24E-02	9 3 1 3 9
8.64E-01	3.30E-10	1.36E-01	9 4 1 4 9
9.58E-01	2.53E-13	4.22E-02	9 2 1 1 9
9.58E-01	2.92E-27	4.22E-02	9 2 1 2 9
8.97E-01	7.34E-53	1.03E-01	9 5 1 5 9
9.58E-01	8.88E-19	4.22E-02	9 2 1 4 9
9.58E-01	3.85E-40	4.22E-02	9 2 1 5 9
9.68E-01	4.89E-13	3.24E-02	9 3 1 1 9
9.58E-01	5.37E-27	4.22E-02	9 2 1 3 9
9.68E-01	1.63E-18	3.24E-02	9 3 1 4 9
8.64E-01	6.58E-19	1.36E-01	9 4 1 2 9
9.68E-01	5.32E-27	3.24E-02	9 3 1 2 9
8.64E-01	6.63E-32	1.36E-01	9 4 1 5 9
8.64E-01	3.02E-05	1.36E-01	9 4 1 1 9
8.67E-01	3.89E-28	1.33E-01	9 1 1 5 9
8.64E-01	1.22E-18	1.36E-01	9 4 1 3 9
8.97E-01	4.26E-34	1.03E-01	9 5 1 4 9
8.82E-01	4.16E-07	1.18E-01	9 1 1 4 9
8.97E-01	1.31E-26	1.03E-01	9 5 1 1 9

3.1. Study the Diagram of Emittance at 0.72 Micrometer Wavelength

It is obvious from Fig. (3) that when Al and Ag coatings are between layers, the emittance will be in its maximum. Of course it has some forms. In all forms when Au and Cu are between layers, there is minimum transmittance. So when Ag is in first layer and Cu in next layer, it can be concluded that amount of emittance is growing to its maximum.

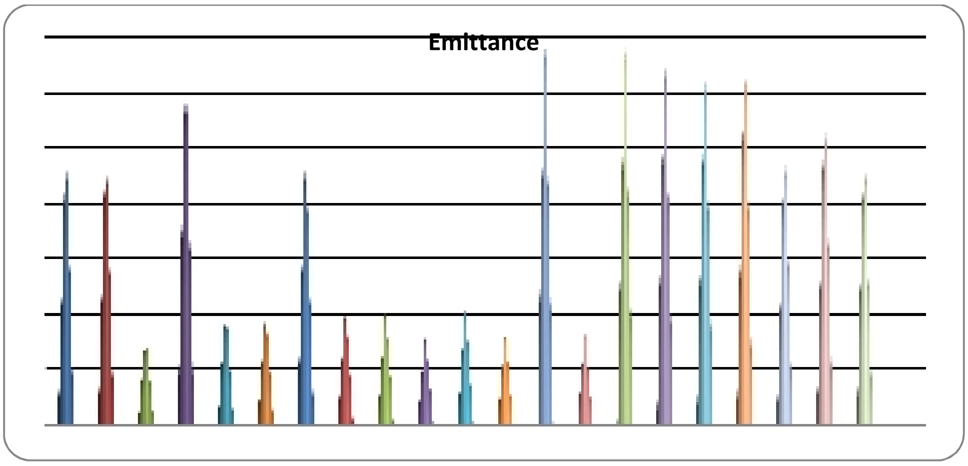

Fig. 3: Diagram of Emittance with 0.72 Micrometer Wavelength

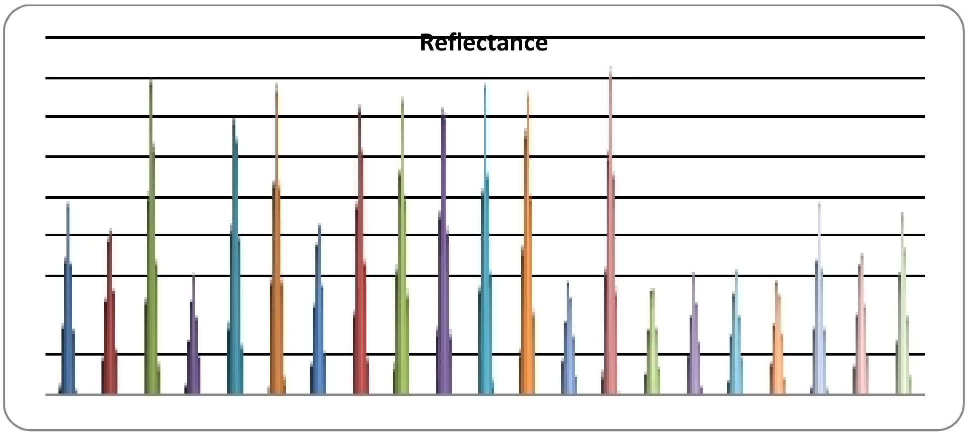

Fig. 4: Diagram of Reflection with 0.72 Micrometer Wavelength

4. Conclusions

With respect to the needs of spatial systems to maximum coefficient in order to control the temperature and to have an efficient performance, the numbers of thin films should increase. Changes of radiation properties is a complex function of wavelength that by increasing the number of layers, this complexity and dependency to wavelength will increase due to wave interferences and also when aluminum cover with main layer of silicon is in up and down side, the reflectance at 0.72 micrometer wavelength is 0.897.

References

Fath, P. Nussbaumer, H. Burkhardt, R. (2002). Industrial manufacturing of semitransparent crystalline silicon power solar cells, Sol Energy Mater Sol Cells, 74:127-31.

Fu, C.J. Zhang, Z.M. Zhu, Q.Z (2003). Optical and thermal radiative properties of semiconductors related to micro/nanotechnology, Advanced in Heat Transfer. 37:179-296.

Gaylord, T.K. Linxwiler, J.N. (1976) .A Method for Calculating Fermi Energy and Carrier Concentrations in Semiconductors, Am. J. Phys, 44: 353-355.

Hebb, J.P. (1997). Pattern Effects in Rapid Thermal Processing, Ph.D. Dissertation, Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, MA.

Jellison, G.E. Modine, F.A (1994). Optical functions of silicon at elevated temperatures, J Appl Phys. 76: 3758-3761.

Lee, B.J. Zhang, Z.M (2005). Modeling radiative properties of silicon with coatings and comparison with reflectance measurements, Journal of Thermo physics and Heat Transfer. 19:558-565.

Makino, T. (2002). Thermal radiation spectroscopy for heat transfer science and for engineering surface diagnosis. In: Taine J editor. Heat transfer. Oxford: Elsevier Science, 1: 55-66.

Oloomi, S.A.A. Saboonchi, A. Sedaghat, A. (2008). Predict Thermal Radiative Properties of Nanoscale Multilayer Structures, the IASTED International Conference on Nanotechnology and Applications, Crete-Greece.

Oloomi, S.A.A. Saboonchi, A. Sedaghat, A. (2010). Comparison Radiative Properties of Thin Semiconductor Films by Coherent and Incoherent Formulation, World Applied Sciences Journal, 9(4): 372-379.

Oloomi, S.A.A. Saboonchi, A. Sedaghat, A. (2010). Effects of Thin Film Thickness on Emittance, Reflectance and Transmittance of Nano Scale Multilayers, International Journal of the Physical Sciences, 5(5): 465-469.

Oloomi, S.A.A. Saboonchi, A. Sedaghat, A. , (2009). Computing Thermal Radiative Properties of Nanoscale Multilayer, World Academy of Science, Engineering and Technology, 37: 929-934.

Timans, P.J. (1996). the thermal radiative properties of semiconductors. Advances in Rapid Thermal and Integrated Processing, Academic Publishers, Dordrecht, Netherlands, 35-102.