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Effects of Donors and Acceptors on Emittance, Reflectance and Transmittance of Nanoscale Semiconductors in Infrared Wavelengths with Incoherent Formulation

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Abstract: Surface modification by coatings can significantly affect the radiative properties of a material. This work uses transfer-matrix method for calculating the radiative properties. Doped silicon is used and the incoherent formulation is applied. Results show that average reflectance changes from 0.2842 to 0.2159 for donor concentrations of 10^{17} cm^{-3} and 10^{19} cm^{-3}, respectively, indicating that average reflectance decreases with increasing concentration. A donor concentration of 10^{19} cm^{-3} yields an average emittance of about 2.47 times higher than that yielded by a concentration level of 10^{17} cm^{-3}. An acceptor concentration of 10^{19} cm^{-3} has an average emittance of about 2.12 higher than that of a concentration equal to 10^{17} cm^{-3}. At infrared wavelengths, lower reflectance occurs at higher concentrations and emittance increases with increasing concentration. Results also show that donors and acceptors act similarly with respect to spectral radiative properties at infrared wavelengths.

Key words: Donors · Acceptors · Nanoscale · Multilayer · Infrared Wavelength · Incoherent Formulation

INTRODUCTION

A great number of the optical components and semiconductors are being covered with thin films, so study of the surfaces which covered by thin films are very important. Coatings act as wavelength selective emitters for radiative energy conversion and thermal radiation detection [1]. 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 [2]. 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 [3].

Infrared imaging is used extensively for both military and civilian purposes. Military applications include target acquisition, surveillance, night vision, 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. Doped silicon is used and the incoherent formulation is applied. The drude model for the optical constants of doped silicon is employed. Phosphorus and boron are default impurities for n-type and p-type, respectively in this work.

MATERIAL AND MATHODS

Incoherent Formulation: When the thickness of silicon substrate is much greater than the coherent length and the considered wavelength falls in the semitransparent region of silicon, interferences in the substrate are generally not observable from the measurements. In this case, the incoherent formulation or geometric optics should be used to predict the radiative properties of the silicon substrate.

Figure 1 shows the geometry of the silicon wafer with thin-film coatings on both sides. The radiative properties of the silicon wafer with thin-film coatings in the semitransparent region can be expressed as [4]:

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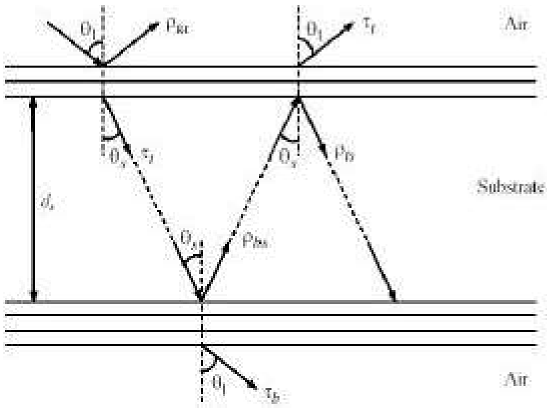

Fig. 1: Schematic of thin-film coatings on both sides of a thick silicon

$$\rho = \rho_{ta} + \frac{\tau_i^2 \tau_t^2 \rho_{bs}}{1 - \tau_i^2 \rho_{ts} \rho_{bs}} \quad (1)$$

$$\tau = \frac{\tau_i \tau_t \tau_b}{1 - \tau_i^2 \rho_{ts} \rho_{bs}} \quad (2)$$

$$\varepsilon = 1 - \rho - \tau \quad (3)$$

Optical Constants: The optical constants of silicon dioxide are mainly based on the data collected in Palik's handbook [5].

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 $\varepsilon(\omega) = (n + ik)^2$. To account for doping effects, the Drude model is employed and the dielectric function of both intrinsic and doped silicon is expressed as follows [6]:

$$\varepsilon(\omega) = \varepsilon_{bl} - \frac{N_e e^2 / \varepsilon_0 m_e^*}{\omega^2 + i\omega/\tau_e} - \frac{N_h e^2 / \varepsilon_0 m_h^*}{\omega^2 + i\omega/\tau_h} \quad (4)$$

The scattering time, τ_e or τ_h, depends on the collisions of electrons or holes with the lattice (phonons) and the ionized dopant sites (impurities or defects); hence, it generally depends on temperature and dopant concentration. The total scattering time (for the case of τ_e), which consists of the above two mechanisms, can be expressed as [7]:

$$\frac{1}{\tau_e} = \frac{1}{\tau_{e-l}} + \frac{1}{\tau_{e-d}} \quad (5)$$

Where τ_{e-l} and τ_{e-d} denote the electron-lattice and electron-defect scattering time, respectively. Similarly, τ_e can be related to τ_{h-l} and τ_{h-d}. In addition, the scattering time τ is also related to the mobility μ by

$$\tau = m^* \mu / e \quad (6)$$

Details of the Drude model are described [4, 8].

RESULTS

Consider the case in which the silicon wafer is coated with a silicon dioxide layer on both sides. The thickness of silicon wafer is 500 μm and the temperature of silicon wafer with thin-film coatings is 25°C and the electromagnetic waves are at normal incidence. The considered wavelength range is 0.7 $\mu m < \lambda < 2$ μm. Doped silicon is used and the incoherent formulation is applied. The thickness of SiO_2 is 400 nm. The Drude model for

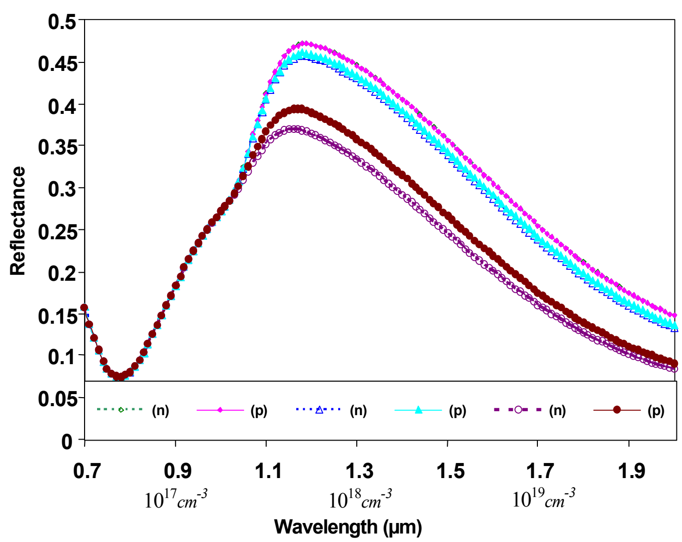

Fig. 2: Spectral Reflectance of silicon wafer coated by silicon dioxide film on both sides with doped silicon, at room Temperatures and normal incidence

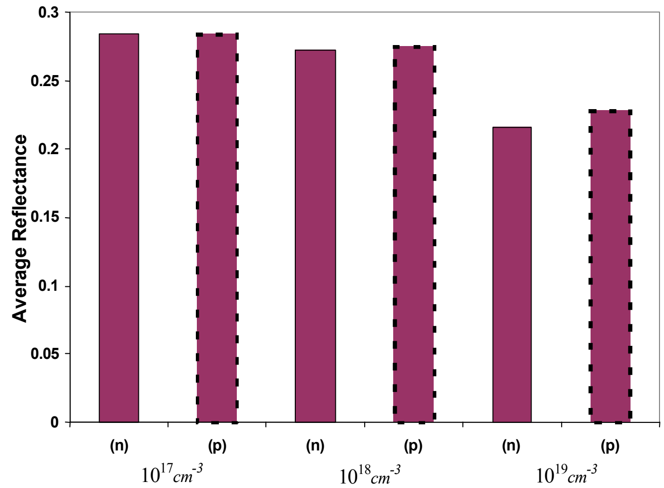

Fig. 3: Average Reflectance of silicon wafer coated by silicon dioxide film on both sides with doped silicon, at room Temperatures and normal incidence

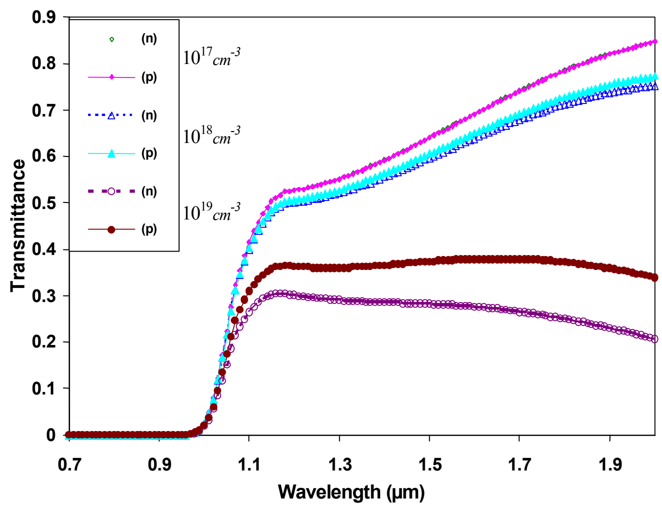

Fig. 4: Spectral Transmittance of silicon wafer coated by silicon dioxide film on both sides with doped silicon, at room Temperatures and normal incidence

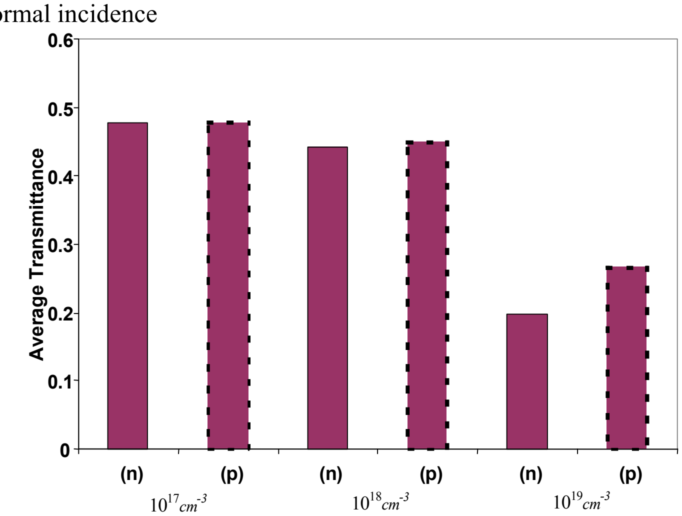

Fig. 5: Average Transmittance of silicon wafer coated by silicon dioxide film on both sides with doped silicon, at room Temperatures and normal incidence

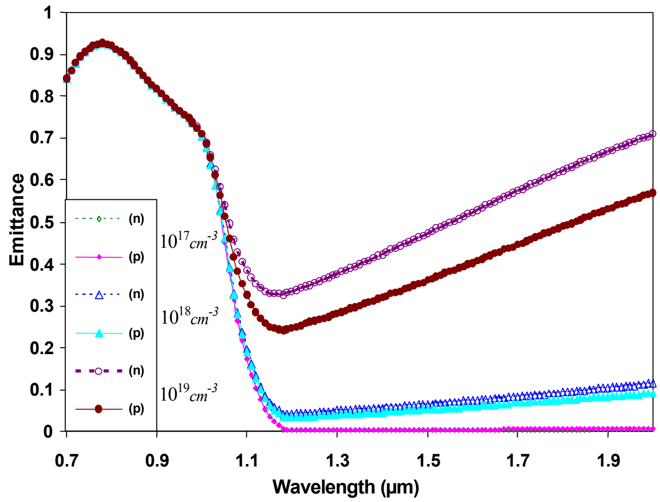

Fig. 6: Spectral Emittance of silicon wafer coated by silicon dioxide film on both sides with doped silicon, at room Temperatures and normal incidence

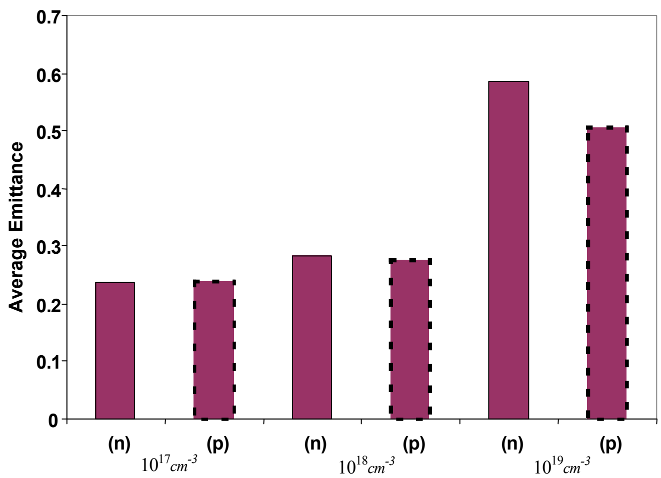

Fig. 7: Average Emittance of silicon wafer coated by silicon dioxide film on both sides with doped silicon, at room Temperatures and normal incidence

the optical constants of doped silicon is employed. Phosphorus acts as donor (n-type) and born acts as acceptor (p-type) for doped silicon. Impurity concentration differ form 10^{17} cm^{-3} to 10^{19} cm^{-3}. Some results of this study are shown below in Figures 2 to 7.

CONCLUSIONS

Results showed that the average reflectance for a dopant concentration of 10^{17} cm^{-3} is 0.2842 for donors and 0.2840 for acceptors. The average reflectance for a dopant concentration of 10^{19} cm^{-3} is 0.2159 for donors and 0.2286 for acceptors. Average reflectance changed from 0.2842 to 0.2159 for donor concentrations of 10^{17} cm^{-3} and 10^{19} cm^{-3}, respectively. It may be concluded that average reflectance decreases with increasing concentration. It was also observed that the average emittance for a dopant concentration of 10^{17} cm^{-3} is 0.2375 for donors and 0.2381 for acceptors. This is while the average emittance values for a dopant concentration of 10^{19} cm^{-3} are 0.5865 and 0.5057 for donors and acceptors, respectively.

A donor concentration of 10^{19} cm^{-3} yields an average emittance around 2.47 times greater than that yielded by a concentration of 10^{17} cm^{-3}. An acceptor concentration of 10^{19} cm^{-3} yields an average emittance about 2.12 times greater than that by a concentration of 10^{17} cm^{-3}. For infrared wavelengths, less reflectance occurs in greater concentrations and the emittance increases as the concentration increases. Results showed that donors and acceptors act similar for spectral radiative properties in infrared wavelengths.

At room temperature for concentration less than 10^{19} cm^{-3}, concentration has not important influence on radiative properties. At room temperature, the scattering process is dominated by lattice scattering for lightly doped silicon and the impurity scattering becomes important for heavily doped silicon when the dopant concentration exceeds 10^{18} cm^{-3} .

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