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Efficiency of Photoconductivity in Amorphous Silicon-Carbide Films

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The photoconductivity spectrum of amorphous silicon-carbide (a-SiC) films has been obtained. The films were fabricated by using the plasma-enhanced chemical-vapor deposition method with methylthreechlorosilane (CH_3SiCl_3) molecules. The efficiency of the photocurrent yield was calculated from the spectrum. The technique and the measurement procedure are described.

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I. INTRODUCTION

Amorphous silicon carbide (a-SiC) is a very promising material for optoelectronic devices. For example, this material was used for electroluminescence displays by Kruagam *et al.* [1] and for solar cells by Gao *et al.* [2]. The photoelectrical properties of a-SiC films are the basis for making light-emitting and photo-voltaic systems. Therefore, the efficiency of the photocurrent yield is a very important characteristic of a-SiC films because it indicates the possibility of using a-SiC can be used for optoelectronic devices.

The steady-state electron photoconductivity is given by

$$\sigma_{ph} = en\mu = eG\eta\mu\tau, \qquad (1)$$

where n is the photocarrier density, η the quantum efficiency, μ and τ the electron mobility and lifetime, respectively, G the volume generation rate of carriers,

$$G = F(1-R)[1-\exp(-\alpha d)]/d, \qquad (2)$$

F the incident photon flux, α the absorption coefficient. R the reflectivity, and d the sample thickness. The parameters of the photoconductivity depend on each other and it is very difficult to measure them separately. Thus, values such as the product $\eta\mu\tau$ are often given in the literature. Many authors obtained this value for a-SiC films as 10^{-9} - 10^{-10} (cm^2 V^{-1}) [3]. However, it is not convenient to characterize photoelectrical properties of films by using this value. In this article, we introduce and define experimentally for a-SiC films the parameter N_{eff} - the number of effective photoconductivity electrons.

II. EXPERIMENT

The a-SiC films were prepared by using the plasma-enhanced chemical-vapor deposition method with the technological parameters described Ref. 4, 5. The Si and C ions by decomposing methylthreechlorosilane (MTCS) molecules in a high-frequency (40 MHz) electric field with a power density of 0.5 W/cm^2 were produced. The films were deposited on the oxidized surface of a Si substrate at 250 °C, and the gas pressure was 1 Torr. Hydrogen carried out the role of the gas carrier, which supplied

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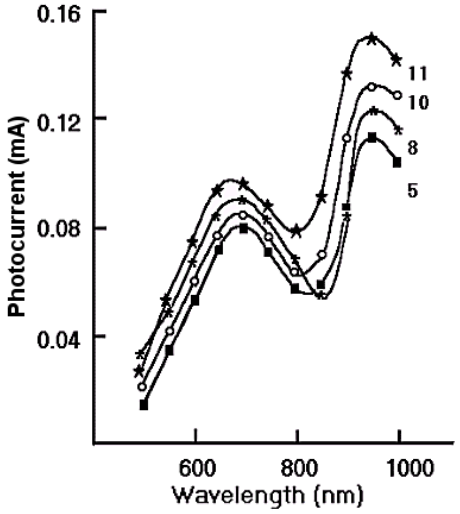

Fig. 1. Spectral dependence of the photocurrent for some a-SiC samples (5, 8, 10, 11 - the sample number from 4 different sets).

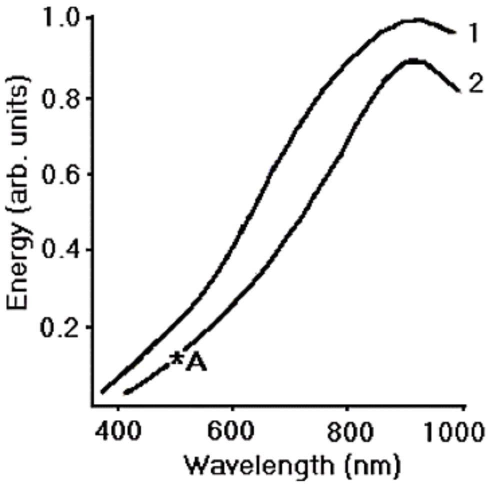

Fig. 2. Energy distribution in non-dimensioned units: 1 is the emission of tungsten glower at 2850 °C (simulation), and 2 is the escape light stream of a monochromator (experiment).

MTCS molecules in the field of the HF discharge. The growth rate of the films was maintained 8-9 Å/s. The thicknesses of fabricated films had about 1 micron and resistances of ~10^6 Ohm-cm. The optical gap was measured by using the Tauc optical method [6] and consisted of ~2.3 eV. The films had n-type conductivity.

The measurements of the photoconductivity were performed on a setup which used a SDL-1 monochromator (LOMO, USSR). An SI-6-100 spectrometer lamp (100 W) at the temperature of 2850 °C of the tungsten glower was used as the light source. The radiation was focused on the a-SiC sample through monochromator by using a cylindrical lens between two In-Ga contacts. The light spot on a sample had a rectangular size of 2 × 7 mm^2. The spectral width of slit was about 16 Å. The distance between the contacts was 2 mm. Contacts were shadowed to prevent their influencing the photocurrent.

III. RESULTS

The spectral dependence of the photocurrent (difference between the light and the dark current) for some samples of a-SiC film was obtained (Fig. 1). The samples were taken from 4 different film sets obtained under the same conditions. These data cannot be used in practice because the light stream from the lamp and the monochromator transmittance are not constant over the full spectral range. That is the reason the curves in Fig. 1 were recalculated, and the recalculated data were used to estimate the effective number of electrons (N_{eff}) taking part in the conductivity per 100 incident light photons.

To estimate N_{eff}, one must know the E(λ) function which expresses the energy at a wavelength λ incident on the sample. We obtained the function E(λ) from experimental measurements. For this purpose, the spectral emission of an SI-6-100 lamp was recorded using an FEU-130 phototube, which had a sensitivity in the 400- to 1000-nm region. The maximum in this spectrum was assumed to be unity, and all spectral curves were recalculated in non-dimensional units. The curve of the spectral responsivity of the FEU-130 phototube is known, so we could draw it in normalized, non-dimensional form. Curve 2 in Fig. 2 is the result of these two curves and represents the energy distribution E(λ) of the monochromator output in relative units. The Planck curve of the lamp emission energy (SI-6-100) at the glower temperature of 2850 °C was accounted for by using the data in Ref. 7 and is shown in Fig. 2. Curve 2 gives the true spectral distribution of the energy in the output of optical devices in relative units. However, for the calculation of N_{eff}, it is necessary to know the absolute number of photons that fall on the sample. For this purpose, an argon-ion laser (λ = 4880 Å) was used. A cylindrical lens was used to focus the laser radiation on an area of 2 × 7 mm^2 between two electrodes, and the photocurrent was measured.

In Eq. (1), n is the number of photoelectrons taking part in the photocurrent. As a rule, for a small, applied electric field, the registered photocurrent is defined by number of electrons extracted from a distance of one diffusion length in an external electric circuit. The diffusion length of a-SiC is an unknown parameter. However, from continuity of an electrical current through a previous film, a distance equal to the diffusion length should pass the same number of photoelectrons. If we assume that the film is homogeneous, the light on a previous film distance should be the same as that on the next, so the photocurrent (n photoelectrons in an external circuit extracted from a diffusion length) was generated by

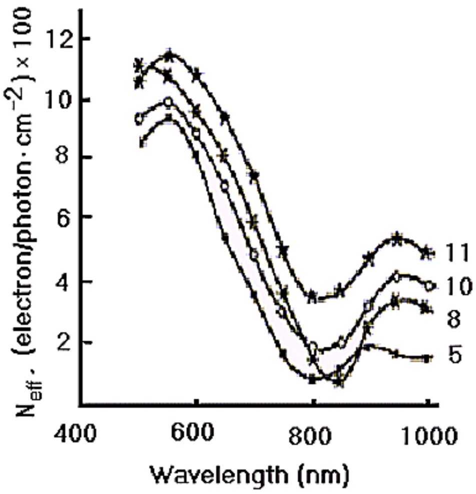

Fig. 3. Efficiency of the photoconductivity for some a-SiC samples (5, 8, 10, 11 - the sample number from 4 different sets).

a certain light stream. Hence, for a quantitative characterization of an incident light stream, it must be normalized to the density of photons on 1 cm^2; then, N$_{eff}$ is related to 100 photons of such a normalized light stream. In this case, Eq. (1) may be rewritten as

$$\sigma_{ph} = e\mu N_{eff} J/100, \tag{3}$$

where J is the light stream reduced to 1 cm^2. Samples N 5, N 8, N 10, N 11 had currents of 5.3, 6.4, 5.7, and 6.2 mA, respectively at a radiation power of 20 mW. These results led to calculated N$_{eff}$ ralues of 8.5, 11.4, 10.0, and 11.0, respectively.

These data were used to calculate the absolute number of photons at any wavelength that fall on the sample. Due to the fact that the photocurrent is measured in both cases for a lamp and for Ar-laser ($* = 4880$ A, power 20 mW), we defined the absolute value of energy at the wavelength 4880 A (Fig. 2 the point "A"). We assume that nonlinear processes do not take place for a 20-mW radiation. The curve 2 shows the spectral distribution of a relative light energy, which falls on the sample. Thus, knowing the absolute value of the energy in the point "A", we can define the energy at any point in this curve. The energy was recalculated into a number of photons; then, N$_{eff}$ was calculated for the full spectral range (Fig. 3).

The maximum of N$_{eff}$ occurs at $\lambda = 5400$ Å(2.3 eV), which coincides with the band gap. The small maximum at 950 nm ($\sim$1.2 eV) corresponds to electron states in the center of the forbidden zone, which, in the Davis-Mott model [8], are due to the network of defects, *i.e.*, the existence of broken bonds, vacancies, *etc.* The obtained results do not characterize the parameters η, μ, and tau, but they allow an estimate of the ability of the films to generate photoelectrons.

It should be noticed that the values N$_{eff}$ and R (or conductivity) are determined by the same film parameters as η, μ, and tau. These parameters characterize the film quality, so the values N$_{eff}$ and R (or conductivity) are useful for estimating the suitability of developing optoelectronic devices on the basis of a-SiC films. It is estimated that the error in the N$_{eff}$ measurement does not exceed 30 %. The small differences between the N$_{eff}$ values for samples randomly taken from four sample sets confirms the repeatability of the experiment and provides assurance the N$_{eff}$ values are real.

IV. CONCLUSIONS

In summary, N$_{eff}$ is a very suitable value for evaluating the photoconductivity properties of films because there are no large difficulties in its measurement. In fact, it plays the role of the quantum photocurrent yield because N$_{eff}$ points out how many electrons participating in the photoconductivity are generated in 1 sec by 100 photons of the full incident light focused stream on a film area of 1 cm^2. For the investigated a-SiC films, N$_{eff}$ was 10-12 electrons. These data are very important for estimating the suitability of developing optoelectronic devices on the basis of a-SiC films.

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