Properties of Inclined Silicon Carbide Thin Films Deposited By Vacuum Thermal Evaporation

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Abstract

In this work, thermal evaporation system was employed to deposit thin films of SiC on glass substrates in order to determine the parameters of them. Measurements included transmission, absorption, Seebak effect, resistivity and conductivity, absorption coefficient, type of energy band-gap, extinction coefficient as functions of photon energy and the effect of increasing film thickness on transmittance. Results explained that SiC thin film is an n-type semiconductor of indirect energy and-gap of ~3eV,cut-off wavelength of 448 nm, absorption coefficient of $3.4395x10^4 cm^{-1}$ and extinction coefficient of 0.154. The experimental measured values are in good agreement with the typical values of SiC thin films prepared by other advanced deposition techniques.

Keyward: Silicon Carbide, Vacuum Thermal evaporation , thin film semiconductors

خواص أغشية كاربيد السليكون الرقيقة المرسبة بشكل مائل باستخدام التبخير الحراري في الفراغ

الخلاصة

في هذا البحث ، استخدمت منظومة التبخير الحراري لترسيب أغشية رقيقة من كاربيد السليكون على قواعد زجاجية من اجل تحديد معاملات هذه الأغشية . تضمنت القياسات التي تم أجراؤها قياس طيف النفاذية والامتصاص وتأثير سيباك والمقاومية والتوصيلة ومعامل الامتصاص ونوع فجوة الطاقة ومعامل التخميد كدالة لطاقة الفوتون الساقط وكذلك تأثير زيادة سمك الغشاء على نفاذية العينات . أظهرت النتائج التي تم الحصول عليها أن أغشية كاربيد السليكون الرقيقة هي مادة من النوع المانح ذات فجوة طاقة غير مباشرة مقداره (3eV) وكانت قيم الطول الموجي القاطع (448 nm) ومعامل الامتصاص $(3.439x10^4 cm^{-1})$ ومعامل التخميد (0.154) . تبدو القيم المستحصلة عمليا متفقة بشكل جيد مع القيم النموذجية لأغشية كاربيد السليكون الرقيقة المحضرة باستخدام تقنيات متقدمة للترسيب .

I. Introduction

One very interested semiconductor material is silicon carbide. Silicon carbide is a promising material, in comparison with Si, for high-power, high-frequency and high-temperature electronics [1-2]. This material is characterized by a wide band gap, high thermal and chemical stability and the property to crystallize in different structural modifications. The material has extremely high thermal conductivity, can withstand high electric fields before breakdown and also high current densities. The wide band gap results in a low leakage current even at high temperatures and the gap of SiC depends on the present poly-type. SiC thin polycrystalline or epitaxial films on Si have also attracted considerable interest for solar cells or high power heterojunction devices, respectively. Moreover, Si is an advantageous substrate material for SiC films in comparison to SiC because of the considerable lower costs, larger wafers and the established technology. However, there is a large lattice misfit of about 20%. Therefore, mechanical stress and island growth occur causing many defects within the film [3].

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Among the different poly-types of SiC the cubic 3C one because its crystal structure is of interest for piezoresistive applications such as pressure sensors [4]. SiC affords a plethora of potential applications based on SiC electronic and optical properties [5].

All the properties mentioned above make SiC promising as a power device material. The electro-technical industry, with applications at high voltages could thus in the future advantageously replace Si power transistors, thyristors and SiC MOSFETs and also VJFETs unipolar device [6,14]. Recent progress in crystal growth of silicon carbide (SiC) has led to the availability of commercial wafers and epitaxial structures. However, it is widely appreciated that the optimal performance of microwave devices is related to the quality of ohmic contacts. Low contact resistance and high temperature stability are required [7].

In recent years, silicon carbides (SiC, Si_2C and SiC_2) have received rapidly growing attention due to their wide range applications in research and industry. Among these carbides, SiC is used intensively in electronic and optoelectronic devices, such as solar cells, detectors, modulators and semiconductor lasers, especially under Pure α-SiC is an intrinsic semiconductor with an energy band gap sufficiently large (1.90±0.1eV) to make it a very poor electrical conductor (~10-13 $\Omega^{-1}.cm^{-1}$). However, the presence of controlled amount of impurities makes it a valuable extrinsic semiconductor (0.01-3 $\Omega^{-1}.cm^{-1}$) with a positive temperature coefficient. This, combined with its mechanical and chemical stability, accounts for its extensive use in electrical heating elements. In recent years, pure α-SiC has received much attention as a hightemperature semiconductor with applications in transistors, diode rectifiers, electro-luminescent diodes, etc [8].

SiC high purity crystal growth and SiC epitaxy has allowed the realization of charge particle [9], neutron [10], and x-ray [11] detectors and dosimeters [12].

II. Experimental Details

In this experiment, 5gm of β-SiC powder was sieved by a 100μm sieve. The collected amount was about 2gm and used to deposit a thin film of SiC on a glass slide. The purity of SiC used is about 99.99%. The powder was placed in a graphite pot in front of a glass substrate mounted on an xy-stage to produce thin films at inclined position. The evaporation chamber was evacuated to 10^{-6}torr using the diffusion pump. In order to ensure the evaporation homogeneity, the heating temperature was gradually scaled by 50ºC step until the SiC began to vaporize. After 15 minutes, the system was turned off and a 50nm-thickness SiC film was deposited on the glass substrate. Then, this procedure was repeated to deposit inclined films by inclination of the substrate by angle of 5º. Samples were kept in an evacuated vessel before they were tested. Measurements included transmission and absorption spectrum, type of conductivity (σ) and resistivity (ρ) as functions of temperature, absorption coefficient (α) as function of photon energy (hv) in order to determine the value and nature of the energy band gap (E_g) of the formed SiC structure, measurement of extinction coefficient (k_{ex}) at cut-off wavelength, and measurement the transmittance at different points at the inclined surface.

III. Results And Discussions

Fig. 1. explains the transmission spectrum of the SiC thin film in the range (300-900) nm wavelengths. Three distinguished regions are observed from this figure. In the first one (UV range), transmittance increases rapidly from

53.1% to about 80% within the range (300-400) nm, i.e., SiC thin film absorbs the UV wavelength well and the maximum absorption is included. Within the visible range (400-700 nm), the increasing of transmittance is slow from 80% to 92.5% and the cut-off wavelength is included in this range. Hence, the absorption is mainly determined by the thickness of SiC film according to Beer-Lambert law. Beyond 700 nm, absorption is at the minimum and SiC film is approximately transparent to the infrared (IR) wavelengths and this encourages using such films as optical windows.

Fig. 2. shows the results of Seebak measurements, which confirm that the SiC film is n-type semiconductor since the slope of this figure is negative. Seebak voltage develops continuously with increasing temperature until a certain value at which this voltage remain constant due to the stability of electrical properties related to the density of carriers and the dimensions of sample.

Fig. 3. explains variation of resistance and conductivity of SiC thin film with temperature. Both properties are constant over 70ºC that such thin films are characterized by steady properties at elevated temperatures.

Fig. 4. represents the relation of absorption coefficient (α) with photon wavelength (λ). The absorption coefficient drops rapidly within the range (300-600) nm assigning the minimum at about 448nm which represents the cut-off wavelength (λ_{cutoff}) measured experimentally. Hence, the value of energy band-gap (E_g) of SiC is about 3eV.

In order to introduce the nature of energy band-gap and dominant absorption processes, α^2 was graphed versus photon energy (hν). Consequently, the SiC prepared in this work has an indirect band-gap and the allowed fundamental absorption processes are the dominant. Accordingly, the extinction coefficient (k_{ex}) is represented in Fig. 6. as a function of photon energy. The typical value of kex at minimum absorption (448 nm) is 0.154. Due to the inclination of the thin film deposition, the transmittance is supposed to change with the film thickness on the inclined surface. Since we did not measure the film thickness at each point on the inclined surface, we measured the transmittance as function of incident wavelength then determine the relative transmittance at four different point on the inclined surface.

Fig. 7. shows the decrease in transmittance as the thickness is increasing on the inclined surface. We can roughly determine the thickness at each point at certain wavelength as follows:

$I_1=I_0 \exp(-\alpha d_1)$ at thickness d_1 (1a)

$I_1=I_0 \exp(-\alpha d_P)$ at thickness $d_p=ud_1$ (1b)

where u is the multiple of thickness at different point (p) than the center (d_1=50nm). Then

$u=Ln(T_p)/Ln(T)$ ……… (2)

where T_p is the transmittance at point (p), T is the transmittance at the minimum thickness (50 nm). Hence, as transmittance decrease to about 4% at the last point (point4), then we predict that the thickness at this point is 5 times thicker than that at the center (i.e., 0.2μm).

IV. Conclusions

In conclusions, inclined SiC thin films were deposited on a 5˚-inclined glass substrate using vacuum thermal evaporation system. From results obtained, the deposited SiC films are high-transparent at visible and IR wavelength, the electrical conductivity is of n-type and being constant at temperatures over 70˚C, the experimental measured values included cut-off wavelength of 448nm, the energy band-gap is indirect and of about 3eV, the absorption coefficient of about

3.4395x104cm^{-1} and extinction coefficient of 0.154. The transmittance of such structure could be controlled by the thickness along the inclined surface, which is in turn a function of the substrate inclination angle. Such films are extremely used in high-temperatures, high-power and high-frequency applications, so, this attempt may encourage to construct devices such as TFT's, detectors, solar cells and optoelectronics.

V. References

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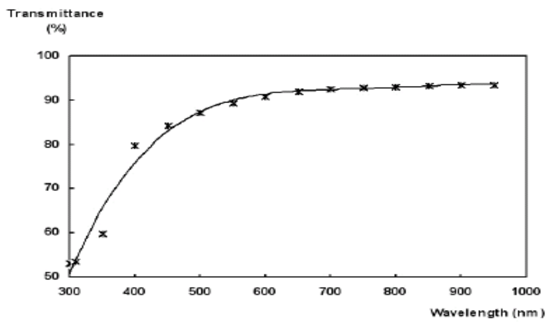
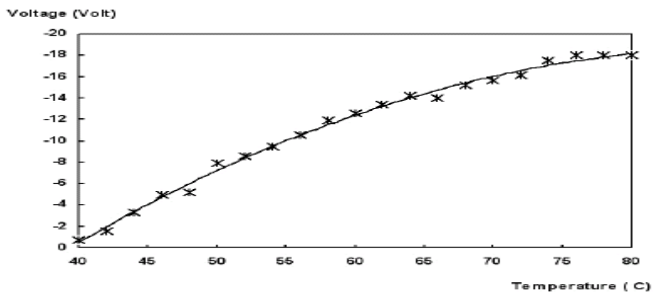


Fig. 1. Variation of SiC thin-film transmittance with incident wavelength



-+Fig. 2. Variation of Seebak voltage with temperature

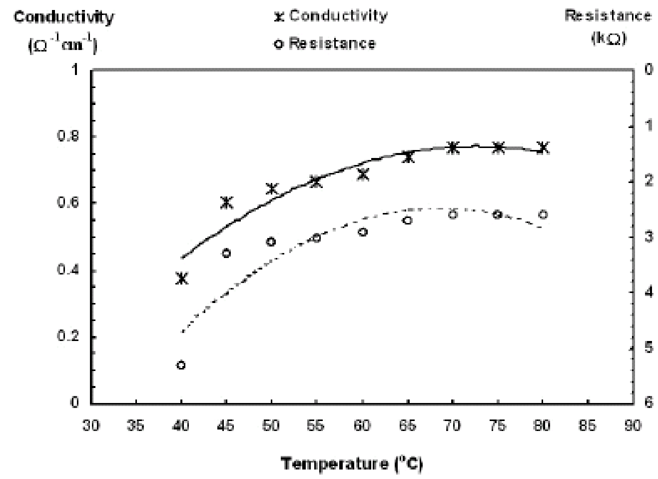


Fig. 3. Variation of SiC film resistance and conductivity with temperature

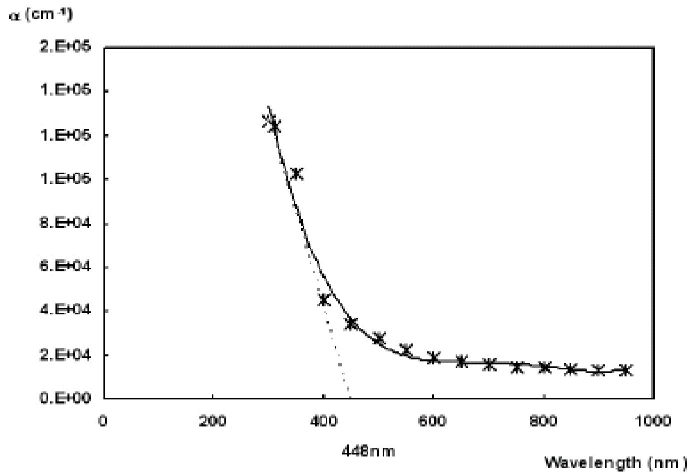


Fig. 4. Variation of absorption coefficient with incident photon wavelength of SiC thin film. The cut-off wavelength is 448nm

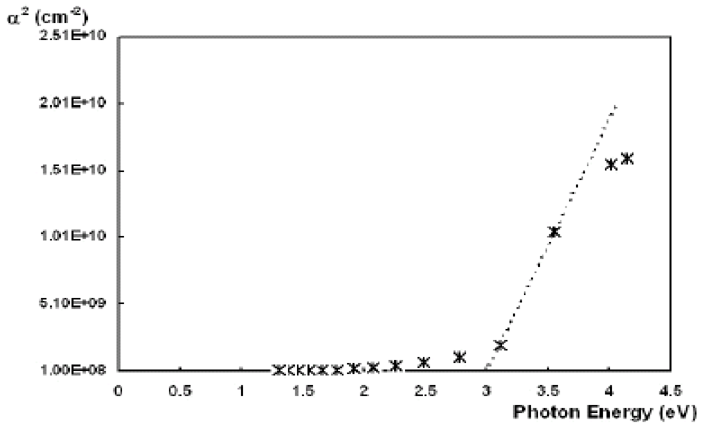


Fig. 5. Variation of α2 with incident photon energy of the SiC thin film. The energy gap is about 3eV

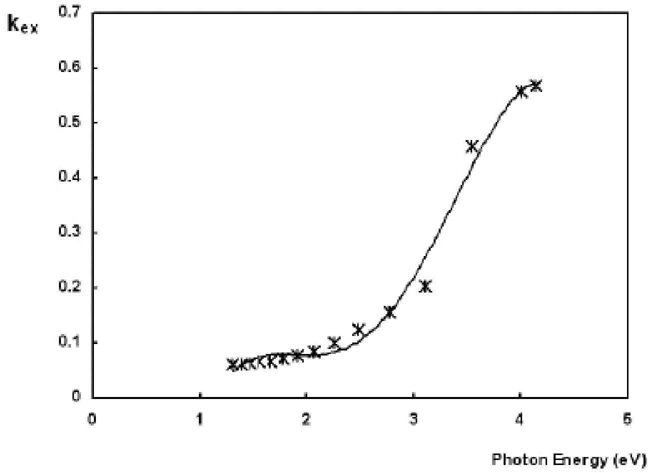


Fig. 6. Variation of extinction coefficient (kex) with the incident photon energy

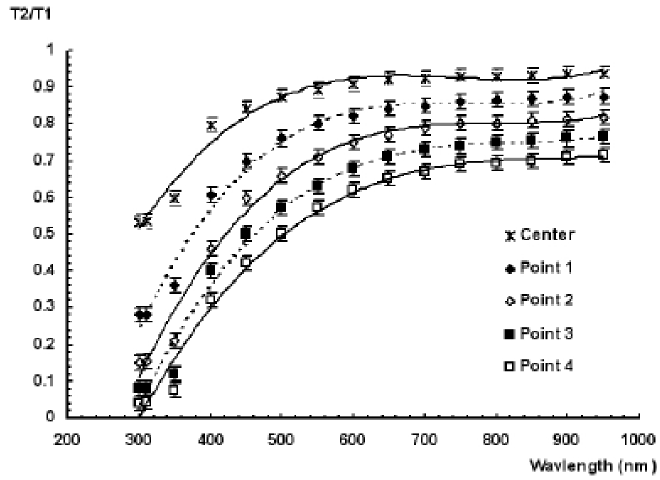


Fig. 7. Variation of transmittance at different points on the inclined deposited thin films