HYDROGENATED AMORPHOUS N-DOPED SILICON CARBIDE FILMS DEPOSITED BY PECVD: STRUCTURAL AND ELECTRICAL PROPERTIES

J. Huran¹, I. Hotovy², A.P. Kobzev³, N.I. Balalykin³,

¹Institute of Electrical Engineering, Slovak Academy of Sciences, Dúbravská cesta 9, 842 39 Bratislava, Slovakia
²Microelectronics Department, Slovak University of Technology, Ilkovicova 3, 81219 Bratislava, Slovakia
³Joint Institute for Nuclear Research, 141980 Dubna, Moscow Region, Russia

Abstract

We present properties of nitrogen-doped amorphous silicon carbide films that were grown by a plasma enhanced chemical vapour deposition (PECVD) technique and annealed by pulsed electron beam. Samples with different amounts of N were achieved by a small addition of ammonia NH₃ into the gas mixture of silane SiH₄ and methane CH₄. A simulation of the RBS spectra was used to calculate the concentration of carbon, silicon and nitrogen. The ERD analyses show that the amount of incorporated H for all samples are approximately 20 at.%.

There is no essential difference between the IR spectra of the samples. The AFM micrographs of the SiC films reveal that the film surface is rather smooth and compact. It was found that with increased silicon concentration and following activation of nitrogen the resistivity of the amorphous SiC films was reduced.

1. Introduction

Silicon carbide (SiC) has received increased attention as a material for future high-temperature devices, high-voltage power-conditioning electronics, high-power microwave devices, etc., because of its advantage of high breakdown field, high saturated carrier velocity, and excellent thermal conductivity [1]. Hydrogenated amorphous silicon carbide (a-SiC:H), together with other group IV alloys such as a-SiGe:H, has received much attention recently due to its potential application in photovoltaic devices and thin film transistors [2]. These applications include the use of a-SiC:H films as window material for amorphous silicon solar cells [3], image pickup tubes and electrophotography receptors [4]. The electrical and optical properties of the alloy can be modified by varying the elemental composition, and different growth methods are currently being explored in order to control the alloy composition and structure. For materials such as a-SiC:H, there has been considerable effort made to obtain a homogeneous distribution of the alloy atoms [5]. The application of SiC in semiconductor device technology also requires controlled and selective doping. Standard technologies for silicon device production, such as ion implantation at room temperature and the subsequent thermal annealing of radiation damage at moderate temperatures cannot be adopted because the radiation damage in SiC is extremely stable. Very high temperatures are necessary for its annealing and to activate dopants. One way to overcome this problem is to perform high current pulse electron or ion beam irradiation instead of high temperature annealing.

In this contribution the attention is focused on the structural and electrical properties of a-Si₁₋ₓCₓ:H films prepared by the plasma enhanced chemical vapour deposition (PECVD) of silane SiH₄ and methane CH₄ as a function of the flow rate. Samples with different amounts of N were achieved by a small addition of ammonia NH₃ into the gas mixture of silane SiH₄ and methane CH₄.
The properties were investigated by RBS, ERD, IR and AFM measurement techniques. The current-voltage (I-V) characteristics of diodes made of doped and annealed SiC films grown on silicon substrates were studied.

2. Experimental

A n-type silicon wafer with resistivity 2-7 Ω cm and (111) orientation was used as the substrate for the a-SiC:H films. Prior to deposition, standard cleaning was used to remove impurities from the silicon surface, and the 5% hydrofluoric acid was used to remove the native oxide on the wafer surface. The wafer was then rinsed in deionized water and dried in a nitrogen ambient. PECVD silicon carbide films were deposited in a high frequency parallel-plate plasma reactor, in which the frequency, the RF power and the substrate temperature were maintained at 13.56 MHz, 0.06 W cm\(^{-2}\), and 350 °C respectively. The diameter of electrodes was 12 cm, and they were 6 cm apart. The RF power was fed to the upper electrode, while the lower electrode, which held the substrates, was grounded. A gas mixture of SiH\(_4\), CH\(_4\) and NH\(_3\) was directly introduced into the reaction chamber, and the flow rates of these gases were 10 sccm, 20-40 sccm and 2-5 sccm respectively. For annealing experiments we used electron beams with a kinetic energy 160 keV a pulse duration 300 ns, and a beam current approximately 150 A/cm\(^2\). The hydrogen concentration was determined by the ERD method. For this purpose the He\(^+\) ion beam from a Van de Graaff accelerator at JINR Dubna was applied. The energy 2.4 MeV was chosen. The target was tilted at an angle of 15° with respect to the beam direction and the recoiled protons were measured in forward at an angle of 30°. For electrical characterization of the SiC films vertical diode structures were formed on the prepared SiC/Si samples. Circular Au dots with a diameter of 0.5 mm and a thickness of 50 nm were evaporated after the cleaning procedure of SiC surface. Al served as large area back contact to Si substrate. The I-V characteristics of devices prepared from different SiC films were measured and evaluated.

3. Results

The thickness and refractive index of the SiC films were measured by a Gaertner Ellipsometer. For technological conditions, that represented by samples H11 and H12 with the flow SiH\(_4\): 10 sccm, the CH\(_4\): 40 sccm and the NH\(_3\): 5 and 2 sccm, respectively, the deposition rate was 5 nm per minute and refractive index was 1.9. For samples H13 and H14, SiH\(_4\) flow 10 sccm, CH\(_4\) flow 25 sccm and NH\(_3\) flow 2 and 5 sccm, respectively, the deposition rate was 4 nm min\(^{-1}\) and the refractive index was 2. Our results show that the deposition rate increases if the flow of CH\(_4\) is increased, however the value of refractive index is decreases. Figure 1 shows RBS spectra of four samples H11, H12, H13 and H14 with different deposition conditions of the deposited amorphous silicon carbide films. The channel numbers at which the steps occur correspond to those of carbon and silicon. After modelling, we can show from calculated results the presence of small amounts of oxygen but the concentrations of hydrogen in the SiC films are approximately 20 at. %. In the case of samples H11 and H12 the concentration of silicon, carbon and nitrogen are 25, 40 and 10-12 at. % respectively. The concentration of Si and C in samples H13 and H14 are 30, 35 and 10-12 at. % respectively. There was no evidence of the substrate
Fig. 1: RBS spectra of SiC films deposited onto a silicon substrate for 2 MeV alfa particles detected at scattering angle of 170°. The spectra are for samples H11 (thickness of film 120 nm), H12 (90 nm), H13 (110 nm) and H14 (80 nm).

Fig. 2: The ERD spectra of recoiled hydrogen obtained with 2.4 MeV ⁴He⁺. The concentration of hydrogen for samples H11, H12, H13 and H14 are 22, 20, 19 and 18 at %, respectively.

Hydrogen was detected by means of elastic recoil detection. The ERD analyses (Figure 2.) show that the amount of incorporated H for samples H11, H12, H13 and H14 were 22 at %, 20 at % 19 at % and 18 at % respectively. The concentration of H increases with increasing CH₄ flow. The AFM micrographs (Figure 3.) of the SiC films prepared by PECVD reveal that the film surface is rather smooth and compact. The mean roughness R and the root mean square RMS of the samples, as deduced from the AFM analysis, are similar.
Fig. 3: AFM micrograph showing the surface (450 x 450 nm²) of samples H11 and H13.

Figure 4 shows the infrared spectra of as deposited samples H11 and H13. There is no essential difference between the spectra of the two samples with different amount of carbon. The films contain features typical for hydrogenated amorphous silicon carbide: the main band at 780 cm⁻¹ is related with the Si-C stretching modes, the C-H stretching band at around 2900 cm⁻¹ and the band around 2100 cm⁻¹ are assigned to Si-H stretching vibrations. From I-V characteristics of Schottky diodes prepared on SiC surface of sample H11 and H13 we observed dispersion in characteristics that is due to the inhomogeneity of SiC film parameters. The thickness of SiC film was 200 nm. The forward I-V characteristics follow the empirical equation I= I₀ [exp(qU/kT)-1]. The thermonic emission theory over the barrier gives the saturation current I₀=SA**T² exp(-Φ₀/kT), where S is the diode area, T is temperature and Φ** is the modified Richardson constant (the values of Φ**=72 A cm⁻² K⁻² is considered for SiC). From linear region of ln I versus U plots the values of the Au/SiC barrier height Φ₀ = 0.96- 1.2 V and the ideality factor n= 1.15- 1.3 were determined. At higher voltages, the current is limited by the series resistance due to ohmic contact and the bulk resistance of SiC layer. The current transport dominating in the low voltage region (at forward currents of 10⁻¹⁰ -10⁻⁸ A) has n~2. The large value of n is likely caused by recombination currents via deep levels near the mid-gap. Furthermore, at low voltages, the leak current passing through the surface and interface defects may also not be negligible in this type of sample.
4. Conclusion

We have investigated the structural and electrical properties of amorphous silicon carbide films prepared by plasma enhanced chemical vapour deposition. The experimental results obtained from this work can be summarised as follows. The RBS results showed that the concentrations of Si, C and N in the films are practically the same. The concentration of hydrogen was determined by the ERD method and the value is approximately 20 at. %. The films contain a small amount of oxygen. IR results showed the presence of Si-C, Si-H, C-H and Si-O bonds. The electrical
conductivity was evaluated by means of I-V measurements of diodes prepared from nitrogen-doped SiC films and the influence of different silicon and carbon concentration was investigated. It was found that with increased silicon concentration and following activation of nitrogen the resistivity of the amorphous SiC films was reduced.

Acknowledgements

The work was supported by the Slovak Grant Agency for Science through grants No. 1/7614/20.

References