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Electrical and Structural Properties of Amorphous Silicon Carbide and Its Application for Photovoltaic Heterostructures

Amorphous silicon carbide/nitride (a – SiC(N)) films were prepared by PECVD technology in capacitive parallel plate plasma reactor. A gas mixture of SiH_4, CH_4 and NH_3 was directly introduced into the reaction chamber through a shower head. Properties of thus produced films were studied by electrical measurement. Forward (FW) and reverse (RW) current-voltage (IV) characteristics (Al – SiC(N)/Si–Al structures) are shown in this paper. Calculated and measured parameter as refractivity index, thickness, factor ideality, saturation current are included in this work. Identification of bonds at surface of amorphous layers by FTIR was presented.

Keywords: Silicone Carbide, IV characteristic, IR spectroscopy

I. INTRODUCTION

Amorphous silicone carbide can be classified as a tetrahedrally bonded binary alloy. Amorphous alloys of SiC are a relatively new subject of investigation. SiC(N) materials may allow the fabrication of higher band gap solar cells that can be used as tandem elements on top of a conventional Si cell [1]. Construction of crystalline thin film solar cells on low cost substrates with a – SiC as a diffusion barrier were also presented [2]. One can find other applications of SiC layers as a barrier layer in silicon hetero structures (within construction amorphous silicone solar cells), as anti-reflection coatings for module glasses and rear side passivation layers [3]. In non-electric applications amorphous SiC appears as a protective coating against corrosion, moisture, etching and abrasion or for bio-molecular and medical applications. All of these applications are based on unique properties of SiC, such as wide band gap, high electron mobility, high thermal conductivity, and high melting point.

The significance of this material follows from the fact that its electrical and structural properties depend on the deposition methods and preparation conditions. These conditions include the source gases, the r.f. power, the chamber pressure and the substrate temperature.

II. EXPERIMENTAL

Measured samples were prepared at the Institute of Electrical Engineering, SAS Bratislava. Keithley 5A Source Meter, Model 2440 was used to measure current-voltage characteristics at room temperature. SiC resp. SiC(N) layers were deposited according the flow rates of NH_3. For electrical characterization the Schottky barrier diodes (Fig.1) were formed on prepared SiC/Si structures.

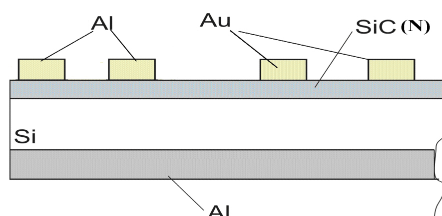

Fig.1. Cross-cut formed Schottky barrier diodes with Au and Al gates

Circular Au / Al dots with a diameter of 2 mm and a thickness of 17 nm were evaporated after the cleaning procedure of SiC surface.

A mixture of SiH_4, CH_4 and NH_3 was introduced into capacitively coupled plasma reactor through a shower head, which is also an upper electrode with 20 cm diameter. Both gases were flown vertically toward the substrate on bottom electrode. A p-type silicon wafer with resistivity 2-7 Ω.cm and (111) orientation was used as the substrate for the silicon carbide films. Ammonia flow rates varied from 0 sccm for P27 to 12 sccm for P32, respectively. Information about prepared samples and measured and presented parameters are in Table 1.

Tab.1. Measured thickness, flow rates of NH_3 gas and refractivity index of prepared structures

Sample	Measure thickness [nm]	Flow rates NH_3 [sccm]	Refractivity index [-]
P27	136.9	0	2.6
P30	128.2	1	2.55
P31	129.5	2	2.26
P26	124.3	4	2.19
P33	125.3	8	2.04
P32	135.8	12	1.93

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 nitrogen ambient. The thicknesses and refractivity index of prepared amorphous SiC (SiCN) layers were determined by spectroscopic ellipsometry.

III. ELECTRICAL AND STRUCTURAL CHARACTERIZATION

Characterization of the PECVD prepared a–SiC/Si system would not be complete without a detailed evaluation of its electrical properties. Forward I-V characteristics of the Al/a-SiC/Si/Al are shown in Figure 2a. As shown, in general, for a fixed FW bias the current magnitude increases as flow rate of NH_3 increases.

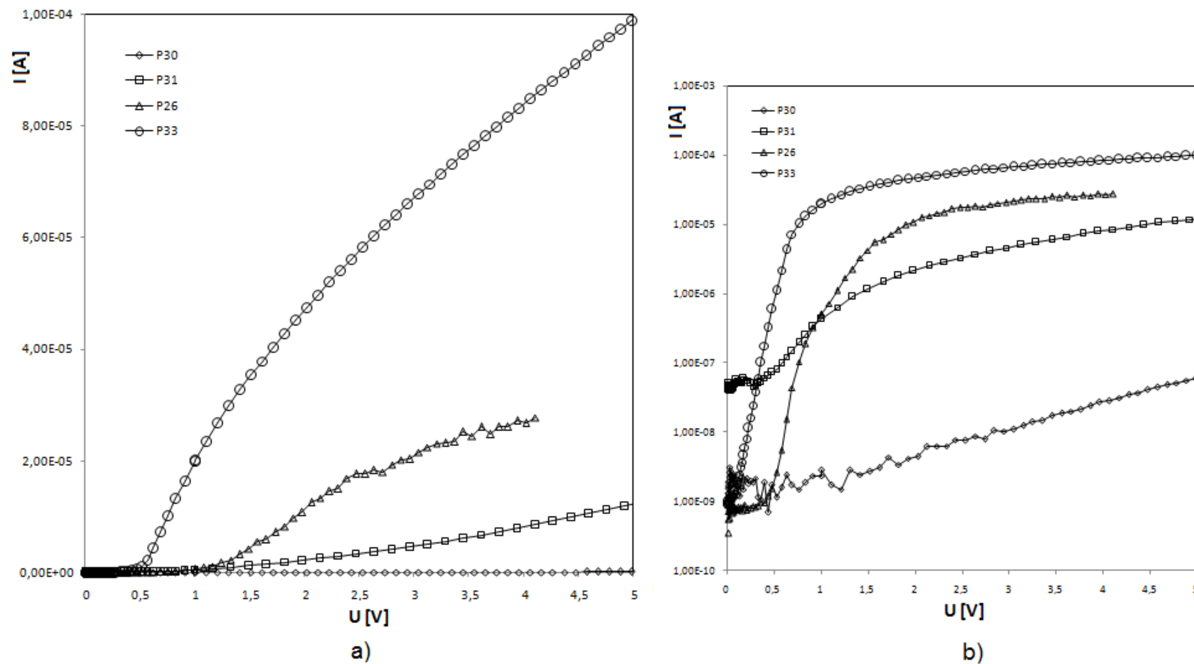

Fig.2. Current versus voltage characteristic of PECVD prepared films

Much more information can be gathered from the current – voltage characteristic. A plot of log I against U for nitrogenizated samples is shown in Fig.2b. The obtained curve can be classified into two areas, the low and high electric fields region. Influence on the conductivity of the samples by increasing the flow of the ammonia is particularly evident in the high field region (above 1V).

One can see different transport mechanisms in the low field region. There is an evident difference between highly (P33, P26) and lowly (P31, P30) doped samples. Influence on the conductivity of the samples by increasing the flow of the ammonia is also particularly evident in the high field region of reverse IV characteristic (Fig.3) above 3V.

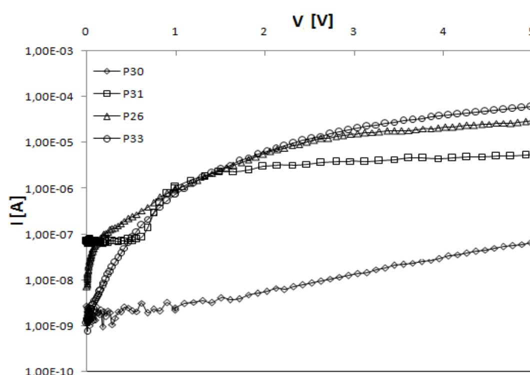

Fig.3. Semi log current versus voltage RV characteristic of PECVD prepared films

It should be noted, that some samples have similar behavior as the classic capacitor structure and vice versa diode character of prepared samples (P26, P32, P33) is observable. The saturation current could be obtained by extrapolating the linear region of forward-biased characteristic. In the low voltage region, the current obeys the function exp (qV/nkT). The ideality factor n was obtained by plotting lnI = f(V) and measuring the gradient. Calculated diode parameters as diode ideality factor and saturation current are presented in Tab.2.

Tab.2. Calculated diode parameters

Sample	I_s	Ideality fact. n
P26	1.47467E-11	3.801144614
P33	4.24546E-10	2.590070427
P32	2.8248E-11	3.643658397

A very powerful method of quantification and identification of bonds in amorphous layers is the Fourier infrared spectroscopy (FTIR). The FTIR spectra were recorded with a Bruker Vector 22 spectrometer (resolution 1cm^{-1}). Figure 4 shows a characteristic spectrum of a SiC layers deposited at 250 ºC in our plasma reactor. A list of possible absorption frequencies in SiC layers can be found in [4]. As one can see in Fig. 4, the dominant absorption band can be found between 740 and 970 cm^{-1}. The form and shape of the peaks indicates different overlapping signals. In the region from 2000 to 2140 cm^{-1} Si-H related absorption bands can be recognized for all presented samples, but the most obvious for the sample P31. Existence of CH_n bonds at wave number around 1450 cm^{-1} is clearly and best visible for P31 against. Existence of Si-O bonds at wave number around 1108 cm^{-1} is clearly and observable for all presented samples [5]. Fuzziness spectrum between 1350 and 3500 cm^{-1} preventing better recognition of the peaks is due to the moisture. CH_3-Si and some oxygen related vibration modes are observable in the region of 960 cm^{-1}. The presence of the Si-H_2 stretching mode would usually require the existence of the Si-H_2 bending mode at around 885 cm^{-1}. It is well known that the oxygen incorporation in silicon nitride causes a shift in the absorption band due to Si–N bond stretching near 880 cm^{-1}. We can observe two main Si - C stretching modes, corresponding to wave numbers 609 cm^{-1}, 746 cm^{-1} which are reported by other authors for the SiC films [5, 6]. However we can learn from the data that there are still CH_4 and SiH_4 related molecules in the network of the layer as deposited which probably could not be broken in the plasma process.

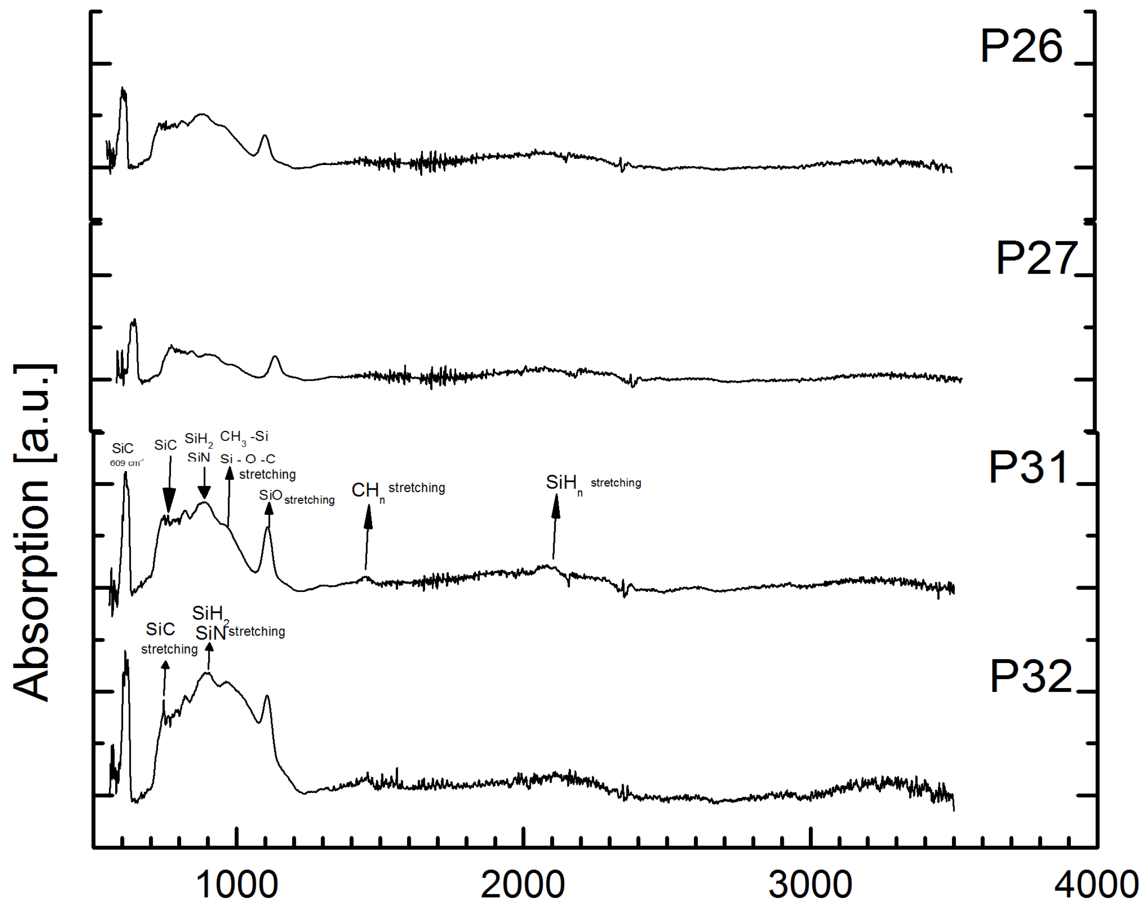

Fig.4. FTIR spectra of prepared samples

IV. CONCLUSION

This work shows, that the electrical properties of films (electric conductivity) prepared by PECVD method could be influenced by varying of nitrogen content in film. Films prepared with high content of nitrogen have better electrical properties and are more suitable to be used as material in Si heterojunctions devices. On the other hand, films without or with small content of nitrogen in film becomes less conductive and tends towards becoming an insulator. From measured FTIR spectra is evident, that there are still CH_4 and SiH_4 related molecules in the network of the layer.

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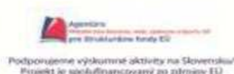

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