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Effects of annealing on the structural and optical properties of sputtered SiC/Ag/SiC multilayer

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***Abstract*— In this work, the experimental analysis of the impact of annealing on the structural and optical performances of SiC/Ag/SiC thin-film multilayer structure deposited by RF sputtering technique has been performed. A comprehensive investigation of the developed heterostructure by analyzing the optical and structural characteristics was carried out using appropriate experimental facilities such as X-Ray Diffraction (XRD) and UV-Vis spectra measurements, in order to assess the optical and structural performances including the effects of annealing process. It was demonstrated that the annealing treatment paves a path toward developing high-performance visible-blind UV sensors, where the annealed structure exhibited a superior light-rejection ratio in comparison with that of the unannealed counterpart. Moreover, XRD structural measurements revealed the absence of peaks corresponding to the SiC bottom and top layers, confirming the amorphous state of the sputtered unannealed and annealed multilayer structures. Therefore, this work may help clarify the roles of annealing process in improving the properties of SiC/Ag/SiC multilayer structure to develop high-performance thin-films for CMOS-based optoelectronics and photovoltaic applications.**

Keywords*— *a-SiC; RF sputtering; multilayer; annealing; temperature

I. INTRODUCTION

The demands for microelectronic devices that have high break-down voltage and reliable against high-temperature variations has rapidly increased in the space of power electronics and optoelectronic applications. Recently, silicon carbide (SiC) was analyzed as a potential and active material for elaborating power devices, buffer layer for solar cells, memory devices, and phototransistors [1-5]. Its characteristics such as wide energy band gap, high thermal conductivity and high break-down voltage make it suitable material and potential candidate for developing reliable and high-performance optoelectronic and photovoltaic applications [4-8]. In this regard, SiC-based devices have got lot of attention for their ability for developing reliable high-temperature systems by keeping the compatibility with existing CMOS processing technologies. Nevertheless, several limitations associated with the weak responsivity and the low derived current of thin-film SiC-based devices are considered as the most important shortfalls, which can affect the microelectronic device reliability and optical performances [4]. In this context, several thin-film wide bandgap materials such as ZnO, ITO, NiO and Ga_2O_3 were deposited on crystalline (c)-SiC or hydrogenated amorphous (a:H)-SiC to elaborate CMOS-compatible microelectronic devices [9,10]. Nevertheless, for hydrogenated a-SiC, the hydrogen can affect the film characteristics, where new voids can be generated in the material which causes electrical and optical limitations [10]. Furthermore, for the c-SiC, the growth of this material is generally carried out using high-temperature conditions (higher than 1200 °C) [11], which is an important limitation in term of elaboration process cost. Moreover, this temperature value can create high defect carrier concentrations [11]. Consequently, new structures, design approaches, and low cost elaboration processes should be developed in order to enhance the optoelectronic and reliability performances of the device.

Recently, multilayered structures with intermediate metallic thin-films have been emerged as prospective structure for several applications including transparent conductive oxide, photovoltaic absorption and optical sensors [12-14]. In spite of the rapid progress of the SiC-based thin-film microelectronic devices, the growing demands and prospects from microelectronic industry requirements are in fact going beyond the actual stage of maturity of the SiC-based thin-film photodetectors. Consequently, more emergent flexible and solar blind UV sensors should be developed for environment monitoring and optical telecommunications. In this context, in the present work, we experimentally investigate the impact of annealing on the structural and optical properties of SiC/Ag/SiC thin-film multilayer structure deposited using RF magnetron sputtering technique at room temperature, in order to improve the electrical conduction and visible light blindness for UV-sensing and photovoltaic applications. To do so, the optical and structural properties of the sputtered structures were studied using UV-Vis and XRD measurements, respectively. It was demonstrated that the annealed structure at 600°C exhibits an amorphous morphology and effective visible-blind properties. The obtained results can provide new insights for the development of high-performance and flexible SiC-based thin-film devices for radiation sensing and photovoltaic applications.

II. Experimental Details

The investigated SiC/Ag/SiC (25nm/5nm/25nm) thin-film multilayer structure relies on sandwiching a silver ultrathin layer between two bottom and top a-SiC layers. Fig.1 (a) shows a 2D cross sectional view of the studied structure. The thickness of the tri-layer structure is considered very thin (55 nm) in order to ensure the flexibility (in the case of flexible substrate) of the device as well as the low elaboration cost. Optical properties such as the absorbance behavior against annealing temperature is considered as an important parameter, permitting the accurate assessment of the analyzed structure for photovoltaic and photodetection applications. In this context, we should extract this parameter to evaluate the optical performance of the multilayer structure. For that reason, the introduction of an intermediate silver layer can create several optical effects such as interference and plasmonic effects [15]

Before the deposition procedure of different thin-layers, the glass substrates have been cleaned up ultrasonically using acetone, water and ethanol and then dried by nitrogen jet process. After that, the SiC and Ag thin-layers have been sequentially deposited on the substrates via RF magnetron sputtering technique (MOORFIELD MiniLab 060) to develop SiC/Ag/SiC tri-layered thin-film structure. The use of this latter experimental facility allowed us the preparation of defect free structures, which are due to its low contamination and controllable deposition properties. The SiC films were grown in O_2 atmosphere (66% oxygen partial pressure) and Ar using SiC targets at room temperature conditions. In addition, the distance between the SiC target and glass substrate was 60mm, and the power of RF source was fixed at 140 W. Moreover, the deposition rate was 0.2 nm/s for the SiC thin-films and 0.7 nm/s for Ag ultrathin metallic layer. The ellipsometry technique was used to confirm the thickness of different sputtered layers. In order to study the effects of temperature annealing on the structure properties, the elaborated tri-layered samples have been subsequently annealed using a tube furnace. The annealing process was performed under a temperature value of 600°C during 30min, and thereafter cooled for 15min in ambient temperature conditions. The structural properties of the prepared samples with and without annealing process have been investigated using X-ray diffraction (XRD) technique via the diffractometer, ARL Equinox 3000. The optical parameter measurements were carried out in the wavelength range of [250-1000nm] by using the UV-Vis spectrophotometer (F10-RT-UV).

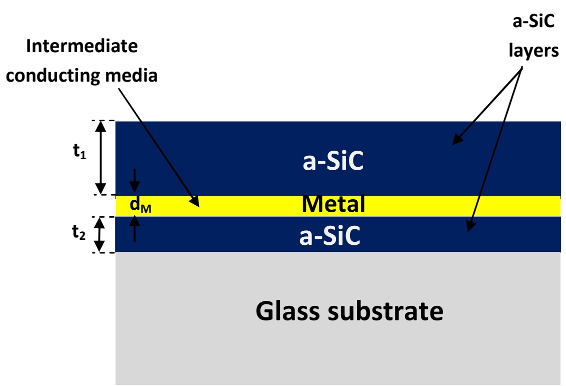


Fig.1. Cross-sectional view of the analyzed SiC/Ag/SiC multilayer structure.

III. Results and Discussions

The structural properties of the elaborated structures are investigated using XRD measurement technique. The obtained structural characteristics are shown on Fig.2. As it is demonstrated in this figure, the measurements are plotted in of the 2θ range 20° to 80° for both cases: with and without annealing effects. It is clear observed from this figure the absence of diffraction peaks associating to the SiC bottom and top thin-films, which can confirm the amorphous structural morphology of the deposited thin-layers. These results can be explained by the fact that the sputtered SiC thicknesses are not thicker enough to attain the crystallization phase. Moreover, the ultra-thin layer nature of the deposited silver metallic middle layer (5 nm) led to the absence of the Ag diffraction peak. On the other hand, the annealed structure shows also an amorphous state morphology. This is mainly due to the ultrathin thickness values of the sputtered layers, which are not thicker enough to achieve the crystallization phase under appropriate annealing process.

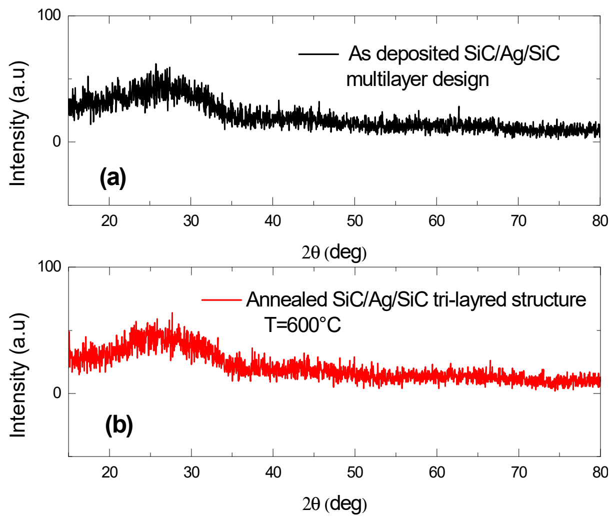
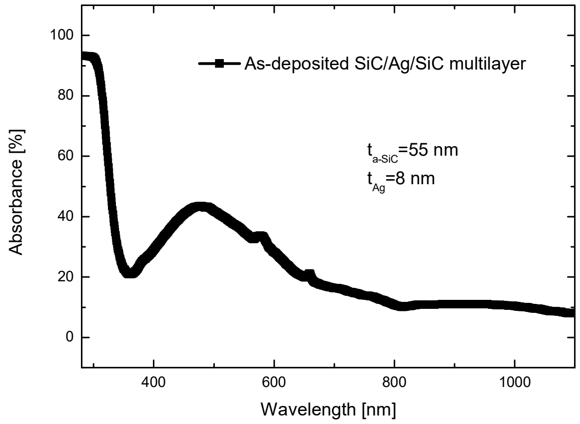


Fig. 2. X-ray diffraction patterns of the (a) sputtered SiC/Ag/SiC multilayer structure as deposited and (b) with annealing effects at 600°C.



(a)

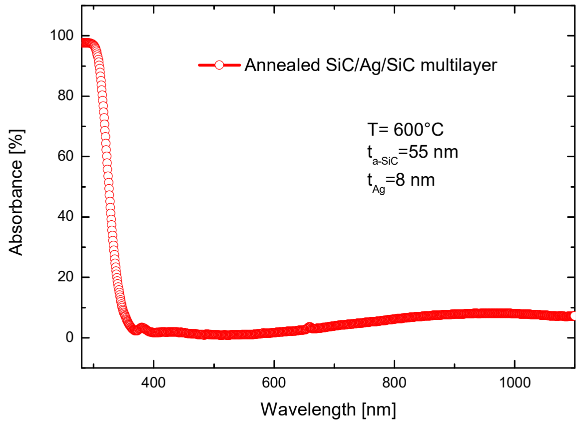


Fig. 3. Variation of the absorbance as a function of the wavelength f both prepared tri-layered structure (a) as-deposited structure. (b) annealed structure at 600°C .

In order to study the effects of temperature annealing and the inserted silver middle layer on the optical behavior of developed structures, Fig.3 shows the absorbance spectra associated with the prepared samples with and without temperature annealing process. From this figure, we can notice that proposed tri-layered structure including the ultrathin intermediate silver layer provides a broadband light absorbance behavior. This encouraging result can open a new path for developing multispectral SiC-based photodetectors and absorber materials for photovoltaic applications. This result can be attributed to the enhanced light scattering mechanisms, where the insertion of silver thin-film can modulate the optical scattering through improving the light trapping ability via complex behavior associated to the interaction light-metal/semiconductor interface and plasmonic effects, where the introduced silver middle layer shows a plasmon resonance in the visible region (Fig.3). Moreover, Fig.3 shows the impact of the annealing process on the absorbance behavior, as it is shown, the annealing process plays an important role in modulating the absorbance performance of the developed structure, where the diffusion mechanism of the silver caused by the heating treatment under annealing into the SiC films induces significant variations in the absorbance behavior. In this perspective, it can be shown from this figure that the annealed sample at 600°C provides an increased UV light absorbance and decreased absorbance values in the visible light region, which leads to improving the visible blindness properties for UV-photodetector applications. In other words, the partial diffusion mechanism of the silver in the top and bottom SiC layers can create random ultrathin Ag nanostructures instead of uniform Ag layer for the unannealed structure. This diffusion mechanism of the silver can lead to modulate the optical and electrical behavior of the structure. For that reason, the insertion of intermediate ultrathin silver layer with temperature annealing process can open new paths for developing high-performance SiC-based photodetectors with reduced rejection ratio and high derived currents level on the channel conductivity behavior. This infers the complex optoelectronic behavior of the investigated PT device based on GeSn capping layer on IGZO TFT platform.

IV. CONCLUSION

This paper investigated the effects of impact of temperature annealing on the structural and optical characteristics of sputtered thin-film SiC/Ag/SiC multilayer structure to identify appropriate design for developing photodetectors and photovoltaic devices. the performances of the elaborated samples have been analyzed in terms of structural morphology and absorption behavior with and without annealing process. It has been portrayed that the insertion of an intermediate silver ultrathin layer can increase the absorbance in the visible-light range via the plasmonic effects created at Ag/SiC interfaces as compared to conventional thin-film SiC material. It was revealed that after annealing process at 600°C, the morphological structural measurements exhibits an amorphous, indicating the diffusion of the Ag into the SiC top and bottom layers. Moreover, the obtained results demonstrated the capability of the annealed structure for jointly getting perfect absorption behavior in the UV range and decreased absorbance in the visible range, which leads to improving the solar blindness properties. Finally, the proposed study can open new paths in developing high-performance and reliable UV-photodetectors and photovoltaic devices.

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