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Structural and Electrical Characterization of Ni-Based Ohmic Contacts on 4H-SiC Formed by Solid-State Laser Annealing

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Abstract. Laser annealing process for ohmic contact formation on 4H-SiC has attracted increasing attention in the last years, because it enables the fabrication of SiC power devices on very thin substrates. We have investigated the formation of Nickel-based ohmic contact on 4H-SiC by using a Yb:YAG laser in scanning mode, with a wavelength of 515 nm and a pulse duration of 1200 ns. A 100 nm thick Ni layer has been deposited on SiC and irradiated at different process conditions. The reaction process has been studied, as a function of fluence and scan number of laser annealing, by means of X-Ray Diffraction (XRD) and Transmission Electron Microscopy (TEM) analyses. The electrical properties of the annealed layers have been evaluated on Schottky Barrier Diodes (SBDs) devices, confirming the ohmic behavior of the reacted contact and showing improved performances respect to RTA approach. The compatibility of thermal budget of the process in the front side has been verified by means of process simulation. A strong relationship between structural properties of reacted layers and electrical behavior of SBDs devices has been revealed. Solid-state laser annealing process, with wavelength in green light region, can indeed represent a suitable solution for ohmic contact formation of 4H-SiC power devices, fabricated on thin substrates.

Introduction

Silicon Carbide has attracted increasing attention in the last years as suitable material for power devices [1] and sensors [2]. For power electronics, wafer thinning is assuming a crucial role in ON-Resistance (R_{ON}) reduction, but it is demanding at the same time for a new manufacturing approach able to skip the Rapid Thermal Annealing (RTA) process [3]. Among the alternative processes to RTA already demonstrated for Si [4-7], laser annealing seems to be the most promising for ohmic contact formation on SiC [8]. In particular, the use of UV excimer laser annealing for Nickel-based ohmic contact formation on SiC has been widely studied and reported in literature [9-11]. However, alternatives in terms of pulse duration and wavelength could offer additional process option and a wider process window. The formation of Ni-based ohmic contact on 4H-SiC has been investigated by using a Yb:YAG laser in scanning mode. Morphological and structural properties of reacted layers have been studied by means of XRD and TEM analyses. Laser process simulations have been performed to predict the temperature field at the wafer scale. Schottky Barrier Diodes (SBDs) have been studied to evaluate the electrical behavior of the annealed layer.

Experimental Setup

SBD devices have been fabricated on 4H-SiC substrates, mechanically grinded at 110 µm of thickness. A 100 nm thick Ni layer has been deposited on grinded SiC surface by DC sputtering in Ar ambient at a base pressure of 1 x 10^{-3} mbar. Ni layer has been annealed by Yb:YAG laser in scanning mode, with wavelength of 515 nm, pulse duration of 1200 ns, scan speed of 30 mm/s and frequency of 10 kHz, with fluence in the range between 5 J/cm^2 and 6 J/cm^2. The laser beam had a top hat profile on the long dimension (3 mm) and a gaussian profile on the short dimension (30 µm). Overlap between two consecutive annealing lines on the long dimension has been tailored to obtain single, double or triple scan. Morphological and structural properties of reacted layers have been studied by XRD analysis, using a Bruker AXS D8 DISCOVER diffractometer working with a Cu-Kα source, and by TEM analysis, using a JEOL-JEM microscope working at 200 keV. SBD devices have been evaluated by using a semiconductor device parameter analyzer (Agilent B1500A) and a high-power curve tracer (Sony Tektronix 371A). As a reference for electrical evaluation, SB diodes have been fabricated on 150 µm thinned substrate, by using standard RTA process (T = 1000 °C, t = 60 s, N_2 ambient) for Ni silicide-based ohmic contact formation.

Results and Discussion

XRD analyses have been performed in symmetric and grazing incidence configurations to get information on structural properties of the reacted layers. Fig. 1a shows XRD patterns collected in symmetric configuration on three different samples annealed at 5.5 J/cm^2 of fluence, changing the scanning condition to obtain single, double or triple irradiation on the same area. All the three samples show the presence of a Ni_2Si phase and the absence of un-reacted Ni. For triple scan annealing, a shift of the peak at $2\theta \approx 48.6°$ to the left with respect to the Ni_2Si peak is observed, due to the co-existence of Ni_2Si and NiSi phases, stating for a shift of the reaction towards Si-rich phases with the increasing of scan number. Fig. 1b shows XRD patterns collected in grazing incidence configuration, with an incidence angle of 0.4°, on Ni samples annealed at 5.5 J/cm^2 of fluence, with single and triple scan. In this configuration, the penetration depth is limited to a range of 20-80 nm, depending on layer composition. Ni_2Si peaks are observed for single scan annealed samples, while $Ni_{31}Si_{12}$ peaks are observed for both samples as residuals of reaction, stating for a compositional gradient along reacted layer depth profile.

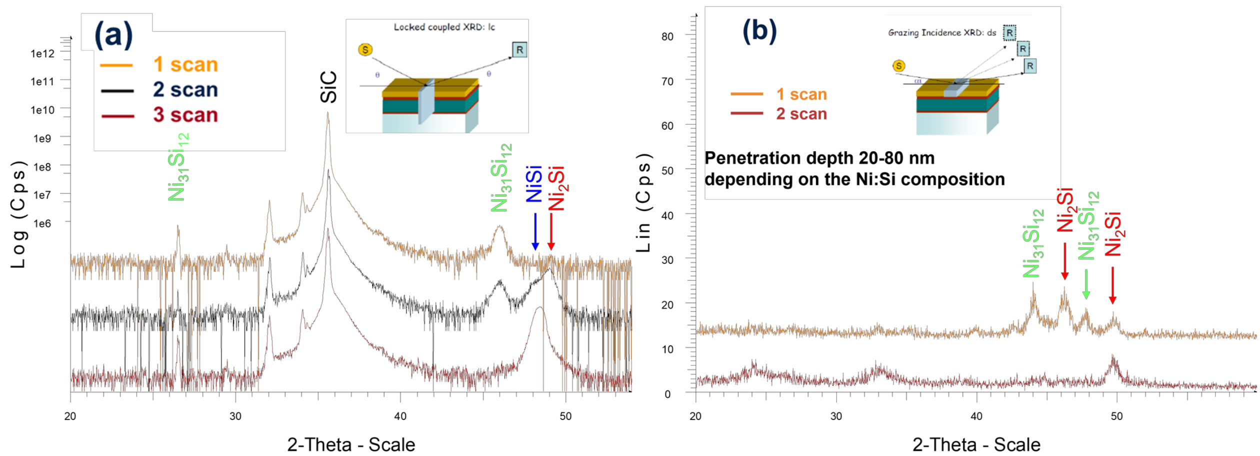

Fig. 1. (a) XRD patterns in symmetric configuration of the Ni samples annealed at 5.5 J/cm^2 of fluence for single, double and triple scan process. With increasing of scan number, a shift towards Si rich phases is observed. (b) XRD patterns in grazing incidence configuration of the Ni samples annealed at 5.5 J/cm^2 of fluence for single and triple scan process. $Ni_{31}Si_{12}$ peaks are observed in both samples.

Fig. 2 shows XRD patterns collected in symmetric configurations on samples annealed with double scan at different fluences in the range between 5 and 6 J/cm^2, compared with a standard pattern from RTA-treated samples. Ni_2Si peaks are observed for all three laser annealed samples. For lower fluence (5 and 5.5 J/cm^2), the peak at $2\theta \approx 48.6°$ is slightly shifted with respect to the Ni_2Si peak, likely due to film stress.

Cross sectional Scanning Transmission Electron micrographs of the Ni sample annealed with double scan approach at 6 J/cm^2 of fluence, reported in Fig. 3, show a continuous 150 nm thick Ni silicide, without any embedded carbon clusters. All the carbon atoms were segregated in a continuous layer placed close to the interface with the SiC substrate. Any residual un-reacted Ni was observed at the surface. It is worth to be noticed that such concentration of segregated carbon could be detrimental for mechanical robustness of power devices because their shear strength is reduced.

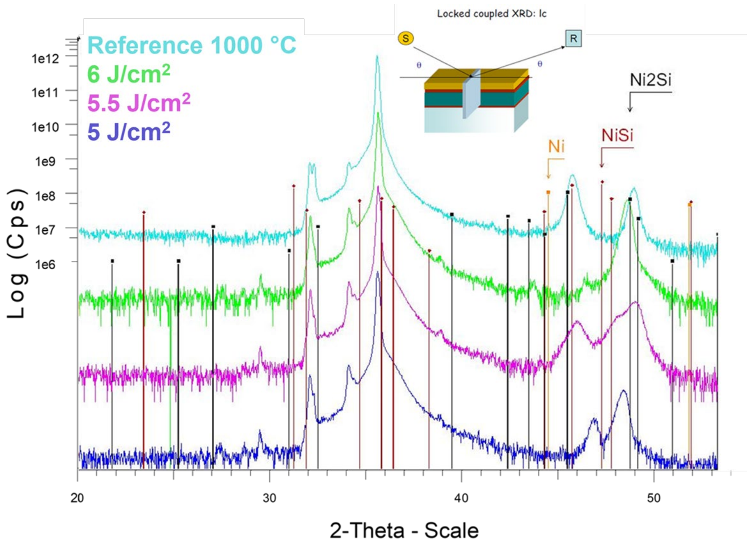

Fig. 2. XRD patterns in symmetric configuration of Ni samples annealed at different fluences with double scan process, compared with standard RTA pattern. Ni_2Si peaks are observed for all three laser annealed samples.

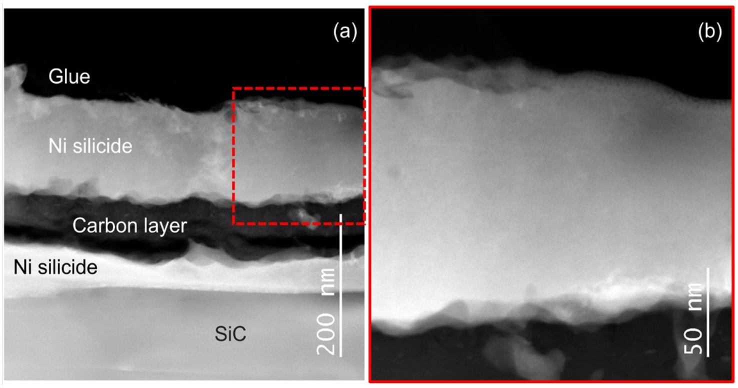

Fig. 3. Cross sectional High Angle Annular Dark Field (HAADF) STEM images of the Ni sample annealed with double scan at 6 J/cm^2, showing a continuous carbon layer close to the interface between SiC substrate and reacted layer (a) and the absence of segregated carbon outside of this region (b).

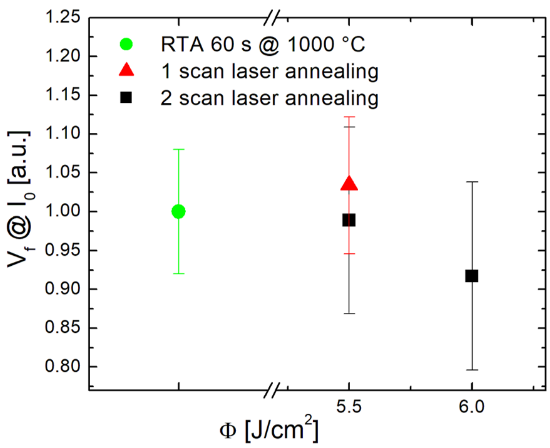

Fig. 4. Forward voltage (V_f) of diode at nominal current as a function of fluence and scan number of laser annealing process, compared with standard RTA results. Increasing of fluence and multiple scan play a crucial role in V_f reduction.

The electrical properties of the reacted layers have been evaluated on power devices. The forward voltage (V_f) of Schottky Barrier diodes at nominal current is reported in Fig. 4 as a function of fluence and scan number of laser annealing process. As a reference, the V_f of a SB diode annealed with standard RTA approach (T = 1000 °C) is shown. Single scan annealing at 5.5 J/cm^2 of fluence results in higher V_f than RTA reference (~ +3.5%), while double scan process at the same fluence gives V_f values comparable with RTA. If we consider the difference of substrate thickness, i.e. 110 µm for laser annealing and 150 µm for RTA, we can conclude that in both cases the quality of ohmic contact formed by laser is worse than the reference, as expected by considering structural properties shown in Fig. 1. SB diodes annealed with double scan approach at 6 J/cm^2 of fluence show V_f values lower with respect to the reference diodes annealed by RTA (~ -8%). This improvement is in line with thickness difference between the two approaches. Process simulation [9] demonstrates that the thermal budget in the device region (front) for the laser process is below the one induced by the conventional RTA process for all the cases here considered.

Summary

Ni-based ohmic contact formation on 4H/SiC by Yb:YAG laser annealing has been investigated. A strong relationship between structural properties of reacted layers and electrical behavior of SBDs devices has been discussed, showing that they can be properly tuned through the calibration of scan number and fluence of laser annealing process. Based on these results, solid-state laser annealing could represent a valuable solution for ohmic contact formation on thin 4H-SiC wafers.

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