Structural and electrical characterization of Ni-based ohmic contacts on 4H-SiC formed by solid-state laser annealing

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Keywords: 4H-SiC, laser annealing, ohmic contact, silicide, power device, XRD.

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. In order to predict the thermal evolution of materials during annealing, laser process simulations have been performed. 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. 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 [2-3]. 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 [4]. Among the alternative processes to RTA already demonstrated for Si [5-8], laser annealing seems to be the most promising for ohmic contact formation on SiC [9]. 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 [10-12]. However, alternatives in term 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 behaviour of reacted layers. Schottky Barrier Diodes (SBDs) have been studied to evaluate the electrical behaviour 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 5.0 J/cm^2 and 6 J/cm^2. Overlap between two consecutive annealing streets 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-K αsource, and by TEM analysis, using a JEOL-JEM microscope working at 200 keV. Laser process simulations have been performed by LIAB computation tool. 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) for ohmic contact formation.

Results and discussion

XRD analyses have been performed in symmetric and gracing incidence configurations, to get information on structural properties of reacted layers. Fig. 1a shows XRD patterns collected in symmetric configuration on three different samples annealed at 5.5 J/cm^2 of fluence, with streets overlap tailored to obtain single, double and triple scan. All the three samples show the presence of Ni_2Si phase and the absence of un-reacted Ni signal. 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 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.

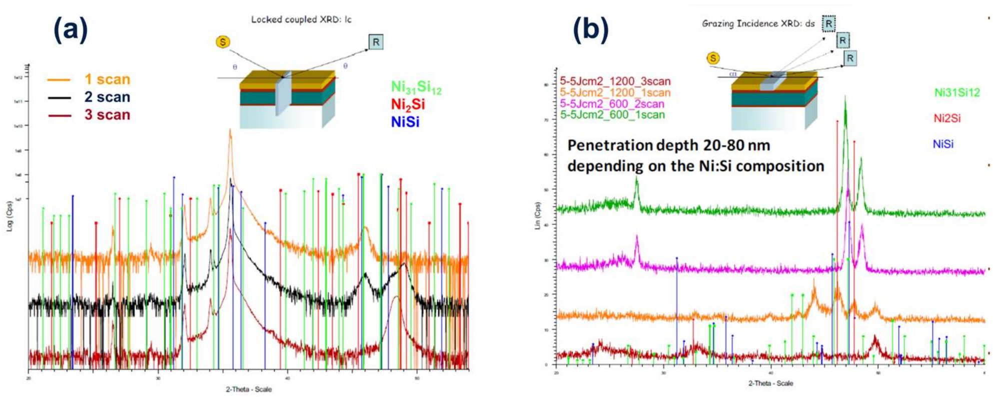

Fig. 1. (a) XRD patterns in symmetric configuration of the Ni samples annealed at 5.5 J/cm^2 of fluence for single, double and triple scan process. With increasing of scan number, a shift towards Si rich phases is observed. (b) XRD patterns in grazing incidence configuration of the Ni samples annealed 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 fluence in the range between 5 and 6 J/cm^2, compared with standard RTA pattern. Ni_2Si peaks are observed for all three laser annealed samples. For lowest 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, probably due to film stress.

Cross sectional Transmission Electron micrographs of the Ni sample annealed with double scan approach at 6 J/cm^2 of fluence, reported in Fig. 3, show the absence of un-reacted Ni, a continuous layer of C-clusters close to the interface between SiC substrate and reacted layer (a) and the absence of C-clusters outside of this region (b). It is worth to be noticed that such concentration of C-clusters could be detrimental for mechanical robustness of power devices.

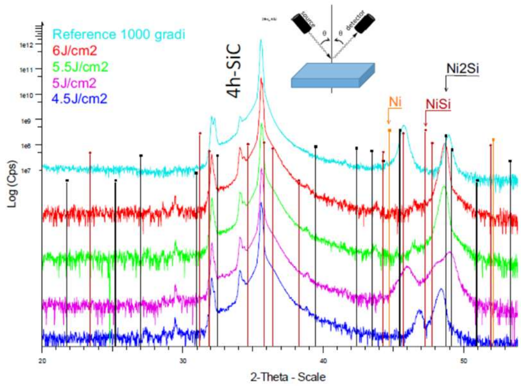

Fig. 2. XRD patterns in symmetric configuration of Ni samples annealed at different fluence with double scan process, compared with standard RTA pattern. Ni_2Si peaks are observed for all three laser annealed samples.

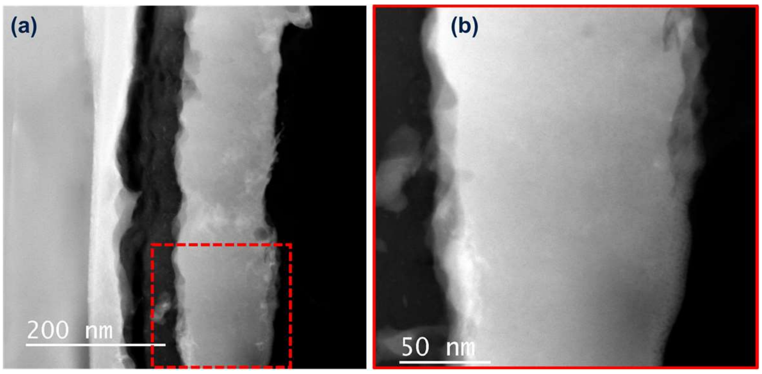

Fig. 3. Cross sectional TEM images of the Ni sample annealed with double scan at 6 J/cm^2, showing a continuous layer of C-clusters close to the interface between SiC substrate and reacted layer (a) and the absence of C-clusters outside of this region (b).

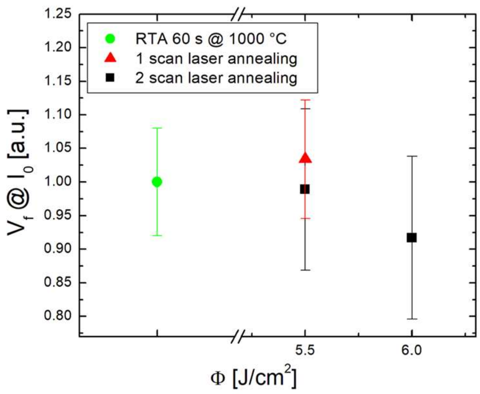

Fig. 4. Forward voltage (V_f) of diode at nominal current as a function of fluence and scan number of laser annealing process, compared with standard RTA results. Increasing of fluence and multiple scan play a crucial role in V_f reduction.

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/cm2 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.

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 revealed. Based on these results, solid-state laser annealing could represent a valuable solution for ohmic contact formation on thin 4H-SiC wafers.

Acknowledgments

The authors thank the project MADEin4 (Metrology Advances for Digitized Electronic Components and Systems Industry 4.0) that has received funding from the ECSEL-JU under grant agreement No 826589.

References

[1] F. Roccaforte, P. Fiorenza, G. Greco, R. Lo Nigro, F. Giannazzo, F. Iucolano, M. Saggio, Emerging trends in wide band gap semiconductors (SiC and GaN) technology for power devices, Microelectron. Eng. 187 (2018) 66-77.

[2] A. Sciuto, M. Mazzillo, P. Badalà, M. Scuderi, B. Carbone, S. Coffa, Thin Metal Film Ni_2Si/4H-SiC Vertical Schottky Photodiodes, IEEE Photonics Technology Letters, 26 (2014) 1782-1785.

[3] M. Mazzillo, A. Sciuto, G. Mannino, L. Renna, N. Costa, P. Badalà, Towards a high performing UV-A sensor based on Silicon Carbide and hydrogenated Silicon Nitride absorbing layers, Journal of Instrumentation, 11 (2016) P10010.

[4] S. Rascunà, P. Badalà, C. Tringali, C. Bongiorno, E. Smecca, A. Alberti, S. Di Franco, F. Giannazzo, G. Greco, F. Roccaforte, M. Saggio, Morphological and electrical properties of Nickel based Ohmic contacts formed by laser annealing process on n-type 4H-SiC, Materials Science in Semiconductor Processing, 97 (2019) 62-66.

[5] A. Alberti, P. Badalà, G. Pellegrino, A. Santangelo, Structural and electrical characterization of silicided Ni/Au contacts formed at low temperature (< 300° C) on p-type [001] silicon, J. Appl. Phys., 110 (2011) 123510.

[6] P. Badalà, A. Santangelo, G. Pellegrino, A. Alberti, Silicided Au/Ni bilayer on p-type [001] silicon for low contact resistance metallization schemes, Microelectronic Engineering, 107 (2013) 196-199.

[7] P. Badalà, G. Faro, C. Marcellino, G. Pellegrino, A. Santangelo, A. Alberti, Structural characterization of in-situ silicided contacts textured on p-type [001] silicon, Phys. Status Solidi C, 11 (2014) 160-163.

[8] A. Alberti, P. Badalà, and A. Santangelo, U.S. Patent 9,728,412 (2017).

[9] Z. Zhou, W. He, Z. Zhang, J. Sun, A. Schöner, Z. Zheng, Characteristics of Ni-based ohmic contacts on n-type 4H-SiC using different annealing methods, Nanotechnol. Precis. Eng., 4 (2021) 013006.

[10] P. Badalà, S. Rascunà, B. Cafra, A. Bassi, E. Smecca, M. Zimbone, C. Bongiorno, C. Calabretta, F. La Via, F. Roccaforte, M. Saggio, G. Franco, A. Messina, A. La Magna, A. Alberti, Ni/4H-SiC interaction and silicide formation under excimer laser annealing for ohmic contact, Materialia, 9 (2020) 100528.

[11] S. Sanzaro, C. Bongiorno, P. Badalà, A. Bassi, G. Franco, P. Vasquez, A. Alberti, A. La Magna, Inter-diffusion, melting and reaction interplay in Ni/4H-SiC under excimer laser annealing, Applied Surface Science, 539 (2021) 148218.

[12] S. Sanzaro, C. Bongiorno, P. Badalà, A. Bassi, I. Deretzis, M. Enachescu, G. Franco, G. Fisicaro, P. Vasquez, A. Alberti, A. La Magna, Simulations of the ultra-fast kinetics in Ni-Si-C ternary systems under laser irradiation, Materials 14 (2021) 4769.