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Electrical and Structural Properties of Ohmic Contacts of SiC Diodes Fabricated on Thin Wafers

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Abstract. New generations of SiC power devices require to be fabricated on very thin substrates, in order to significantly reduce the series resistance of the device. The role of thinning process on the formation of backside ohmic contact has been investigated in this work. Three different mechanical grinding processes have been adopted, resulting in different amounts of defectivity and surface roughness values. An excimer UV laser has been used to form a Ni-silicide based ohmic contact on the backside of the wafers. The reacted layer has been studied by means of Atomic Force Microscopy (AFM), Transmission Electron Microscopy (TEM) and X-Ray Diffraction (XRD) analyses, as a function of grinding process parameters and laser annealing conditions. The ohmic contact has been evaluated by measuring the Sheet Resistance (R_s) of silicided layers and the V_f at nominal current of Schottky Barrier Diode (SBD) devices, fabricated on 150 mm-diameter 4H-SiC wafers. A strong relationship has been found between the crystal damage, induced by thinning process, and the structural, morphological and electrical properties of silicided ohmic contact, formed by UV laser annealing, revealing that the silicide reaction is moved forward, at fixed annealing conditions, by the increasing of crystal defectivity and surface roughness of SiC.

Introduction

Among the wide bandgap semiconductor materials, silicon carbide is the most mature and the most widely used for power electronics [1-2] and sensors applications [3-4]. In the last years, in order to lower the series resistance of power devices, the reduction of wafer thickness has become progressively more demanding, requiring the introduction of a new integration scheme for the backside ohmic contact formation [5-6]. The replacement of Rapid Thermal Annealing (RTA) [7-11] with laser annealing process has been proposed and reported, both from experimental [12-21] and theoretical [22-24] point of view, for the formation of silicide-based ohmic contact. Even if the silicide reaction process has been widely described as a function of deposited material and laser annealing features, the role of wafer thinning process has not been yet deeply investigated so far. In this context, the impact of crystal damage, induced by mechanical grinding process, on the formation of ohmic contact has been studied and is reported in this work, with particular focus on the influence of sub-surface damage and surface roughness on the silicide formation by laser annealing.

Experimental Setup

Schottky Barrier Diode (SBD) devices have been fabricated on 150 mm-diameter 4H-SiC wafers, grinded on the backside down to a thickness of 180 µm. A 100 nm Ni layer has been deposited by sputtering in Ar ambient, at a base pressure of 1 x 10^{-3} mbar, on the back side of the wafers. The Ni layer has been irradiated by using an excimer UV laser, with wavelength of 308 nm and pulse duration of 160 ns. Three different mechanical thinning processes, classified as *rough* grinding, *fine* grinding and *ultra-fine* grinding, have been adopted in this work, studying their impact on the reaction between Ni and 4H-SiC under laser irradiation. Sub-surface damage and substrate roughness have been evaluated by Atomic Force Microscopy (AFM) and Transmission Electron Microscopy (TEM) analyses, using respectively a Digital Instrument D3100, equipped with a Nanoscope V controller, and a JEOL-JEM microscope working at 200 keV. Morphological and Structural properties of Ni silicide contacts have been investigated by X-Ray Diffraction (XRD) analysis, using a Bruker AXS D8 DISCOVER diffractometer, working with a Cu-Kα source and a thin film attachment, and by AFM and TEM analyses, as a function of thinning process and UV excimer laser annealing conditions. A preliminary evaluation of the electrical properties of reacted layers has been done by sheet resistance measurements, performed by Four Point Probe (FPP) method. Moreover, to evaluate the electrical behaviour of the annealed samples on power devices, the V_f at nominal current of SBD devices has been measured, by using a semiconductor device parameter analyzer (Agilent B1500A) and a high-power curve tracer (Sony Tektronix 371A).

Results and Discussion

Surface roughness of thinned wafers has been measured by AFM analysis. As shown Fig. 1, the ultra-fine grinding process leaves a very smooth surface (Fig. 1a), while the fine-grinding process induces well visible marks and damage on the surface (Fig. 1b). These marks become more and more visible when the rough grinding process is adopted (Fig. 1c).

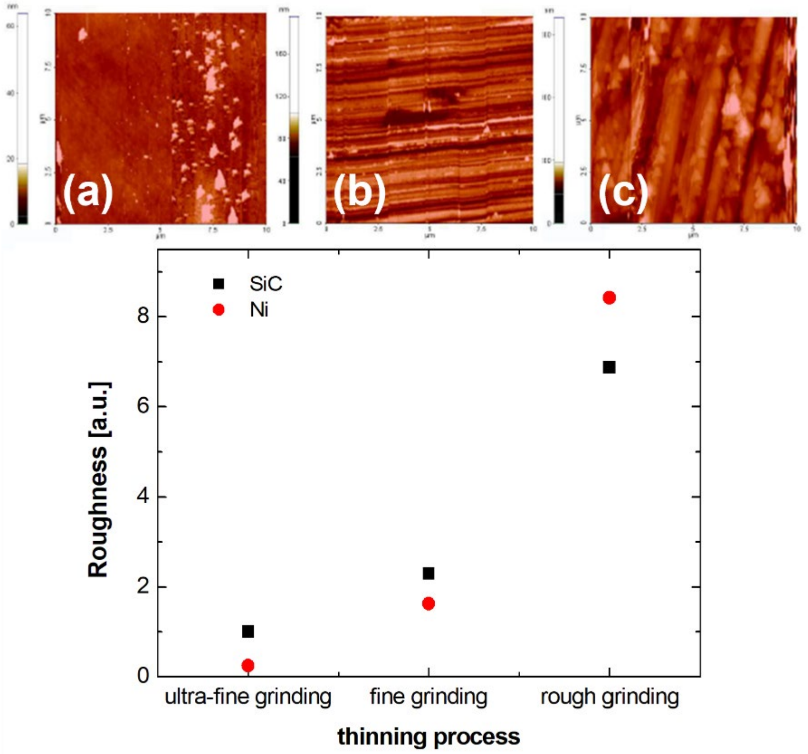

Fig. 1. AFM analysis of samples thinned by ultra-fine (a), fine (b) and rough (c) grinding process. Surface damage and marks induced by thinning process become more and more visible while moving from ultra-fine to rough grinding process. The normalized surface roughness, measured by AFM, shows a similar trend after grinding and after Ni deposition (d).

The normalized surface roughness of SiC wafers, measured after thinning and after Ni deposition, is reported in Fig. 1d, showing a similar trend in both cases, as a function of thinning process. The difference between the roughness values for the different thinning processes is even more evident after the deposition of the nickel layer. In fact, while deposition seems able to make smoother the surface of ultra-fine and fine grinded samples, on the contrary it seems to make coarser the surface of rough grinded one.

As already reported [6], the typical Sheet Resistance (R_s) curve, as a function of laser energy density, shows an increasing of R_s values for lower laser energy density, due to the initial intermixing between Ni and Si, and then a rapid drop of R_s to a final plateau. A similar behavior has been observed for all the three examined thinning processes, with a shift towards lower laser energy density with the increasing of roughness and surface damage. This trend can be explained by the increased number of defects and the reduced reflectivity of more damaged samples. As a case study, we focused our investigation on a fixed laser annealing process, performed at 3.4 J/cm^2 with three pulses, that gives different R_s values for the different substrates, as reported in Fig. 2.

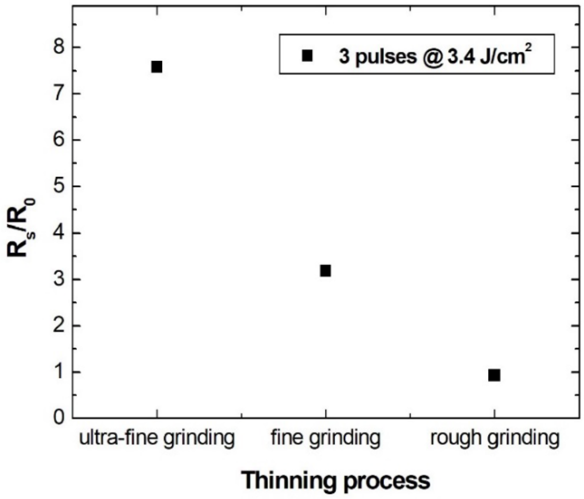

Fig. 2. R_s values, normalized to the sheet resistance of as deposited Ni, of samples annealed at 3.4 J/cm^2 with three pulses, as a function of thinning process. At fixed annealing conditions, a lowering of R_s is observed with the increasing roughness and surface damage.

The surface morphology of the laser annealed contacts has been investigated by AFM analysis (Fig. 3), showing significant differences among the three samples. In fact, while the surface of ultra-fine grinded sample still appears quite smooth (Fig 3a), de-wetting starts to be visible on fine grinded one (Fig. 3b). Moreover, a highly irregular surface is observed on rough grinded sample (Fig. 3c).

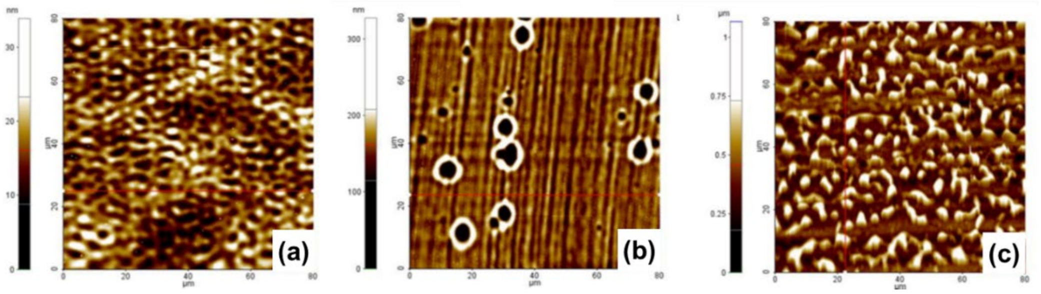

Fig. 3. AFM analysis of samples annealed at 3.4 J/cm^2 with a three pulses laser process reveals significant differences of surface morphology, as a function of thinning process. The surface of ultra-fine grinded sample (a) still appears quite smooth after laser annealing, while de-wetting starts to be visible on fine grinded one (b). A highly irregular surface is observed on rough grinded sample (c).

Cross sectional TEM analyses (Fig. 4) have been performed to evaluate the reaction interface, the morphology of silicide layer and the residual amount of defectivity. The silicide layer shows very flat interfaces and uniformly distributed C clusters for the ultra-fine grinded sample (Fig. 4a). On fine grinded sample, C clusters are distributed in two well defined lines and crystal damage is almost completely recovered (Fig. 4b). On the other hand, the rough grinded sample shows a highly non uniform thickness of silicide layer, with some exposed SiC area. Moreover, deep crystal damage is still visible below the interface between Ni silicide and silicon carbide (Fig. 3c). By looking more in detail, it is possible to observe that reaction interface moves down in correspondence of defects (Fig. 4d). This could be explained by the increased amount of silicon available for the reaction.

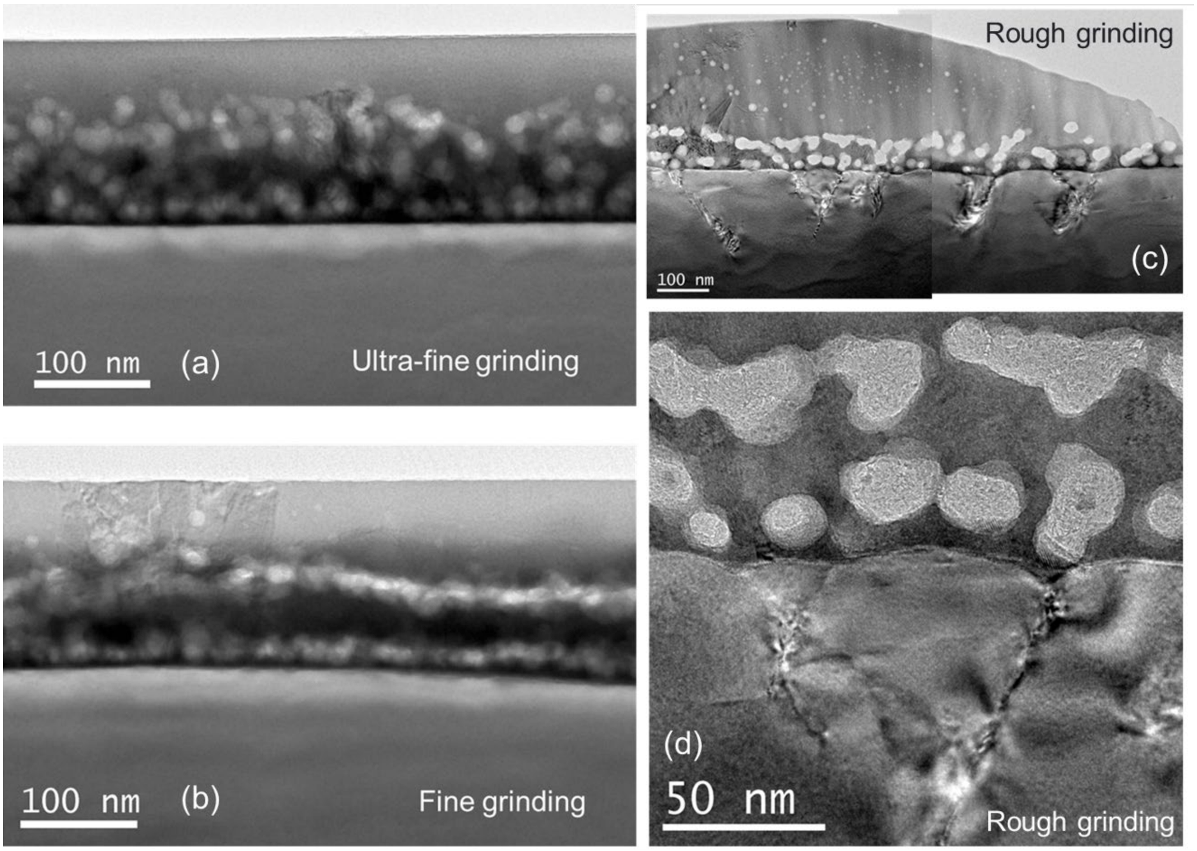

Fig. 4. Cross sectional TEM analysis of samples annealed at 3.4 J/cm^2 with a three pulses laser process. Silicide layer shows very flat interfaces and uniformly distributed C clusters for ultra-fine grinded sample (a). On fine grinded sample (b), C clusters are distributed in two well defined lines and crystal damage is almost completely recovered. The rough grinded sample (c) shows a highly non uniform thickness of silicide layer. The reaction interface moves down in correspondence of defects, still well visible below the Ni silicide layer (d).

The structural properties of silicide layers of the three samples have been evaluated by X-Ray Diffraction analysis (Fig. 5), revealing that $Ni_{31}Si_{12}$ is the predominant phase for ultra-fine grinded and fine grinded samples, with some presence of Ni_3Si phase in the first case. Co-existence of several phases has been observed on rough grinded sample, with predominance of Ni_2Si. These findings state a shifting of the reaction, at fixed annealing conditions, from Ni richer phases towards lower Ni/Si ratio phases, with the increasing of crystal defectivity.

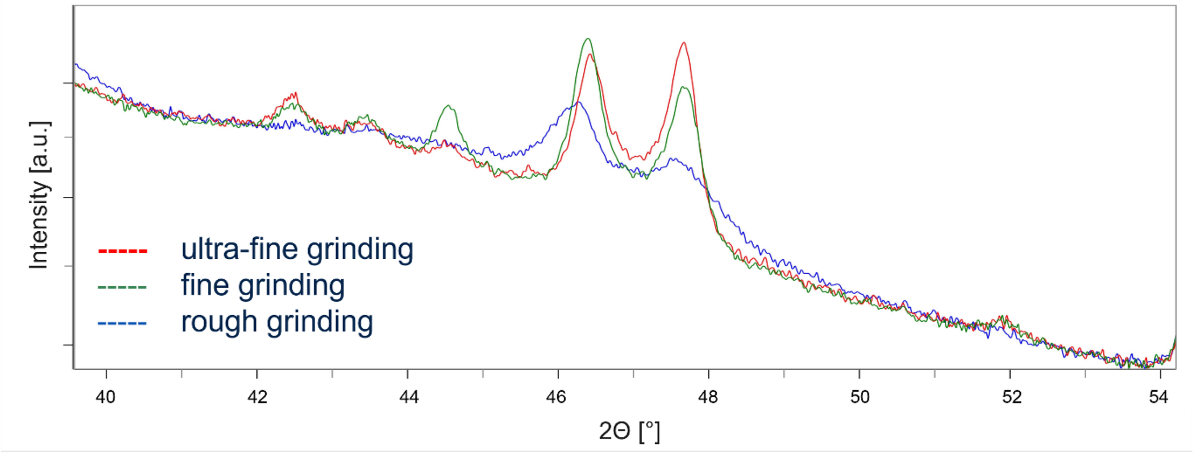

Fig. 5. XRD analysis of annealed samples shows that $Ni_{31}Si_{12}$ is the predominant phase for ultra-fine grinded and fine grinded samples, with some presence of Ni_3Si in the first case. Co-existence of several phases is observed on rough grinded sample, with predominance of Ni_2Si.

The forward voltage drop V_f at nominal current I_0 of Schottky Barrier diodes has been measured, to evaluate the electrical properties of the reacted layers, as shown in Figure 6. A comparison between the three different thinning processes has been performed, on samples annealed at 3.4 J/cm^2 with three pulses. As a reference, the V_f of diodes annealed by conventional Rapid Thermal Process (60 s @ 1000 °C in N_2) is reported.

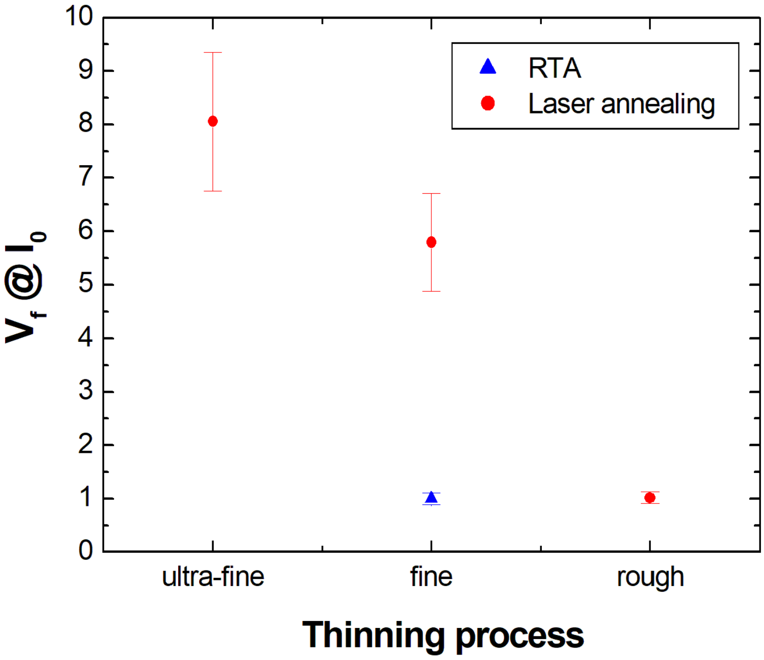

Fig. 6. V_f at nominal current I_0 of Schottky Barrier diodes, annealed at 3.4 J/cm^2 with 3 pulses. As a reference, the Vf of diodes treated with Rapid Thermal Annealing is reported. At fixed laser process conditions, the V_f decreases with the increasing of surface damage.

Figure 6 shows that V_f decreases when the amount of defectivity induced by thinning process in the sub-surface region increases. Moreover, the V_f measured on rough grinded diodes is comparable with the reference diodes annealed by RTA.

Summary

Ni silicide ohmic contacts formation by UV laser annealing has been investigated. The reaction process has been studied as a function of thinning process and laser annealing conditions. A strong relationship between roughness and crystal damage, induced by mechanical thinning, and structural, morphological and electrical properties of the reacted layers has been revealed. Silicide reaction process at fixed annealing conditions is moved forward by the increasing of sub-surface damage and surface roughness of SiC.

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