Materials Science Forum
ISSN: 1662-9752, Vol. 1192, pp 81-87
doi:10.4028/p-LlTen7
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Submitted: 2025-09-15
Revised: 2025-12-22
Accepted: 2026-02-26
Online: 2026-05-20

NiSi Alloy/4H-SiC Reaction and Silicide Formation under Excimer Laser Annealing for Ohmic Contact

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

Abstract. Laser annealing is considered an enabling process for a new generation of SiC power devices, since it allows the formation of ohmic contacts on very thin wafers, significantly reducing their total ON resistance. Ni silicide and Ti silicide ohmic contacts have been widely investigated and reported in literature, exploring in detail the role of laser features, metal thickness and thinning process. Nevertheless, adding a small amount of Si to the contact layer could represent an opportunity to increase process options. In this work, a NiSi alloy has been used as a contact metal to study the role of the addition of Si to Ni in the reaction process under UV laser irradiation. Morphological and structural properties of the reacted layers have been investigated by means of Transmission Electron Microscopy (TEM) and X-Ray Diffraction (XRD) analyses. The electrical characterization of reacted contacts has been performed by measuring their Sheet Resistance (R_s) by Four Point Probe (FPP) method and, at device level, by measuring the forward voltage drop (V_f) of Schottky Barrier Diodes (SBDs) fabricated on 150 mm-diameter 4H-SiC wafers. Furthermore, a comparison has been made between Ni and NiSi alloy under the same irradiation conditions. It has been found that adding Si to Ni in the contact metal layer moves the silicide reaction forward, driving the strong relationship observed between structural, morphological and electrical properties of the reacted contacts.

Introduction

Silicon carbide has attracted increasing attention in recent years for power electronics and detectors applications, thanks to its excellent physical properties, which allow for obtaining higher breakdown voltage, higher switching frequency, lower resistance, higher heat dissipation, and smaller devices [1-6]. Laser annealing process has been widely adopted in silicon carbide device fabrication, for dopant activation [7, 8] and ohmic contact formation [9, 10]. In particular, among the alternative processes to Rapid Thermal Annealing (RTA) for silicide formation [11-13], laser annealing, thanks to its limited heat diffusion, is the most suitable one for the formation of ohmic contact on thin wafers, therefore allowing to significantly reduce the total ON resistance of SiC power devices [14]. Ohmic contacts on SiC based on Ti silicide [15, 16] and Ni silicide [17-28] have been already deeply investigated, and the reaction process has been also studied in detail from a theoretical point of view [29-31]. Nevertheless, the behavior of a NiSi alloy as a contact material under laser irradiation has not completely described and understood so far. In this work, the role played by the addition of a small amount of Si to Ni of the contact layer, in the ohmic contact formation by means of excimer UV laser annealing, has been investigated. A comparison between Ni and NiSi alloy under the same irradiation conditions is reported.

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Experimental Setup

Schottky Barrier Diode (SBD) devices have been fabricated on 150 mm-diameter 4H-SiC wafers, thinned at 180 µm. A 100 nm NiSi alloy layer has been deposited by sputtering in Ar ambient, at a base pressure of 1 x 10^{-3} mbar, on the ground face of the wafers. Wafers have then been irradiated on the backside by using an excimer UV laser, with pulse duration of 160 ns and wavelength of 308 nm. Structural properties of the reacted layers have been characterized by means of X-Ray Diffraction (XRD) analyses, using a Bruker AXS D8 DISCOVER diffractometer, working with a Cu-Kα source and a thin film attachment. Morphology of reacted layers has been investigated by means of Transmission Electron Microscopy (TEM) analyses, using a JEOL-JEM microscope working at 200 keV. The electrical characterization of reacted contacts has been performed by measuring their Sheet Resistance (R_s) by Four Point Probe (FPP) method and, at device level, by measuring the forward voltage drop (V_f) at nominal current of Schottky Barrier Diodes (SBDs), by using a semiconductor device parameter analyzer (Agilent B1500A) and a high-power curve tracer (Sony Tektronix 371A).

Results and Discussion

It has been reported [17] that the typical R_s curve, as a function of laser fluence, shows an increase of R_s values for low laser fluences, due to the initial intermixing between metal layer and Si, and then a rapid drop of R_s to a final plateau, above a threshold fluence. In particular, the value of threshold fluence depends on contact material and its thickness, number of laser pulses, and SiC roughness.

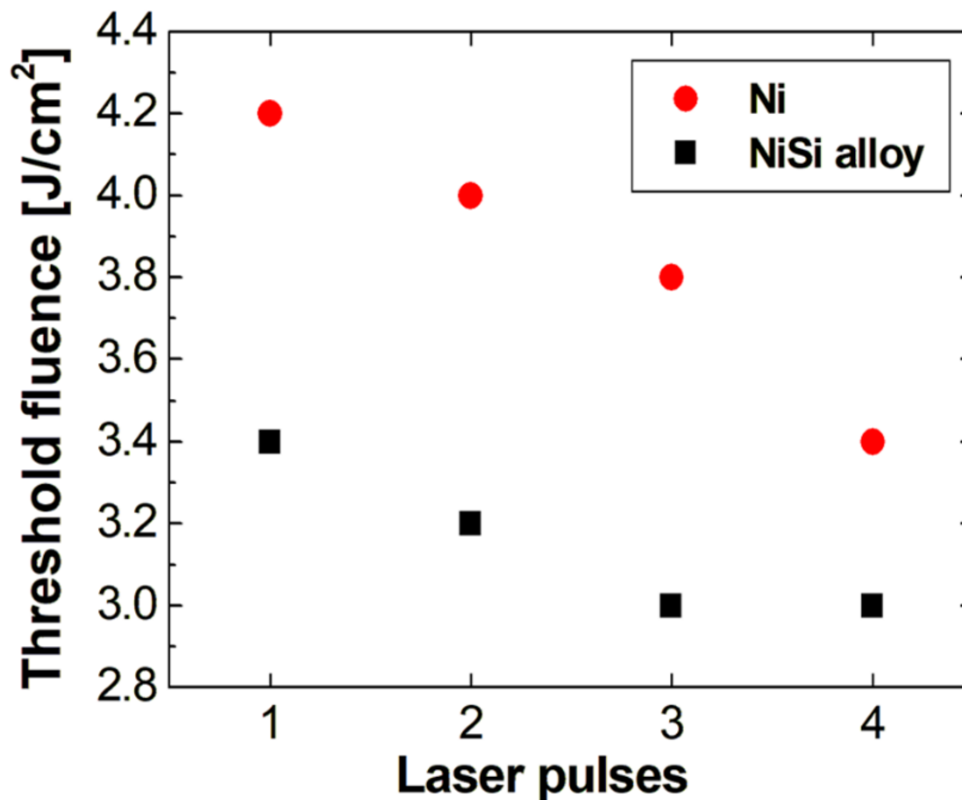

Fig. 1. Comparison between threshold fluence for the R_s drop of Ni and NiSi alloy, as a function of number of laser pulses. Fixed the laser conditions, the threshold fluence of NiSi alloy is lower than that of Ni.

As shown in Fig. 1, the threshold fluence at which the R_s drop is observed decreases with the increasing number of laser pulses, both for Ni and NiSi alloy, but the threshold fluence of NiSi alloy is lower than that of Ni, at the same number of laser pulses. This could mean that, fixed the laser annealing conditions, the addition of Si to Ni moves the reaction forward.

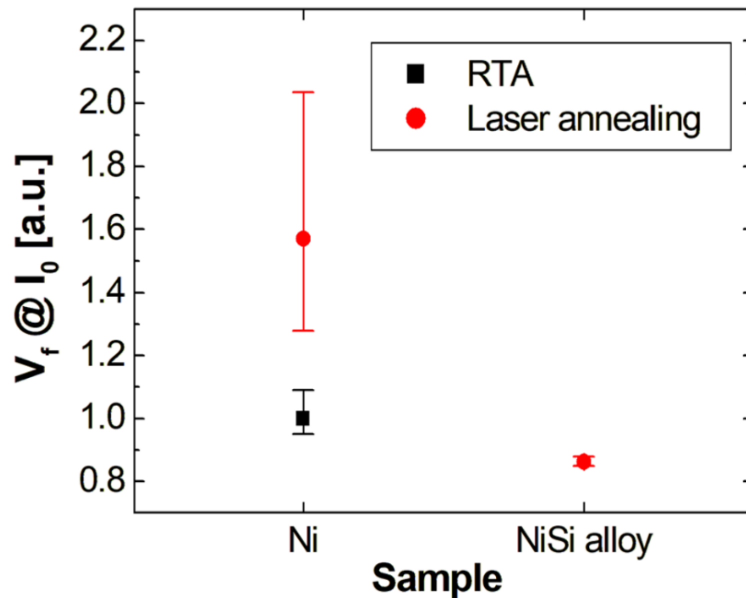

Fig. 2. Forward voltage drop (V_f) at nominal current (I_0) of Schottky Barrier diodes annealed at 3.8 J/cm^2 with two pulses. As a reference, the V_f of diodes treated with RTA is reported.

This hypothesis is confirmed by the measurement of V_f of SB diodes. As reported in Fig. 2, in fact, NiSi sample annealed at 3.8 J/cm^2 with two pulses shows a V_f significantly lower than the Ni sample annealed at the same conditions, and even lower than that of a Ni sample treated by Rapid Thermal Annealing (RTA), reported as a reference.

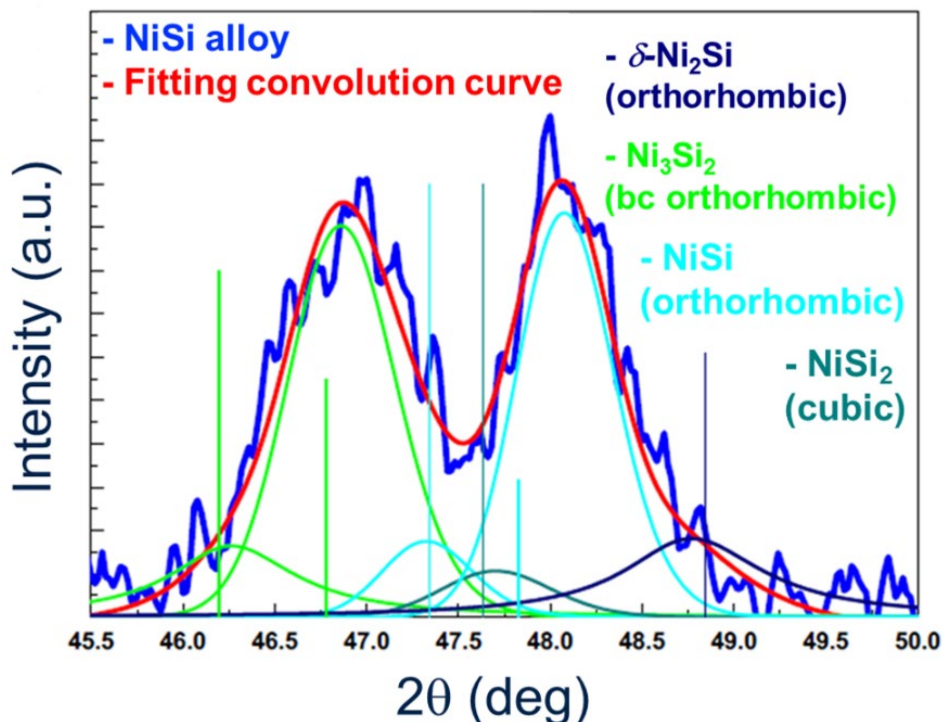

Fig. 3. XRD pattern, acquired in grazing incidence configuration, of NiSi alloy sample after laser annealing at 3.8 J/cm^2, two pulses, and corresponding deconvoluted component peaks.

Structural properties of Ni and NiSi alloy samples, annealed at 3.8 J/cm^2 with two pulses, have been characterized by XRD, performed in grazing incidence configuration. Fig. 3 shows the XRD pattern of the annealed NiSi sample and the deconvoluted contributions of the main peaks. The extracted quantitative fractions reveal the predominant presence of Ni_3Si_2 and NiSi phases, with lower contribution of Ni_2Si and $NiSi_2$.

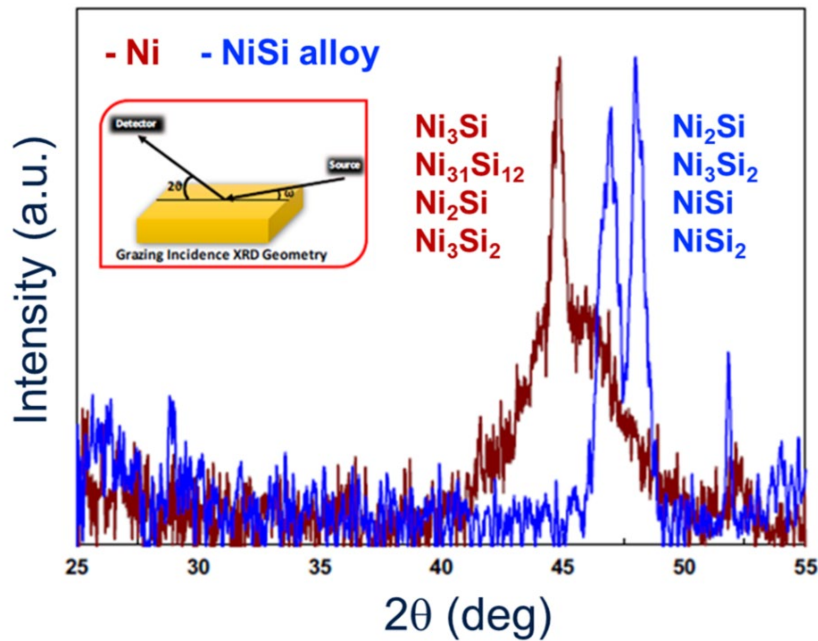

Fig. 4. Comparison between XRD patterns, acquired in grazing incidence configuration, of Ni and NiSi alloy samples annealed at 3.8 J/cm2, two pulses.

The same approach has been adopted to characterize the annealed Ni sample, revealing the presence of Ni_3Si, $Ni_{31}Si_{12}$, Ni_2Si and Ni_3Si_2 phases. The comparison between NiSi alloy and Ni annealed samples, reported in Fig. 4, shows the presence of Si-rich phases in NiSi alloy sample, confirming that adding Si to Ni moves the reaction ahead, fixed the laser annealing process parameters. In fact, the Ni-Si reaction starts at the interface between Ni and SiC and moves from Ni-rich phases towards Si-rich ones. As the silicide reaction moves forward, the electrical behaviour of ohmic contact improves, as shown by Sheet Resistance and Forward Voltage measurements reported in Fig. 1 and Fig. 2.

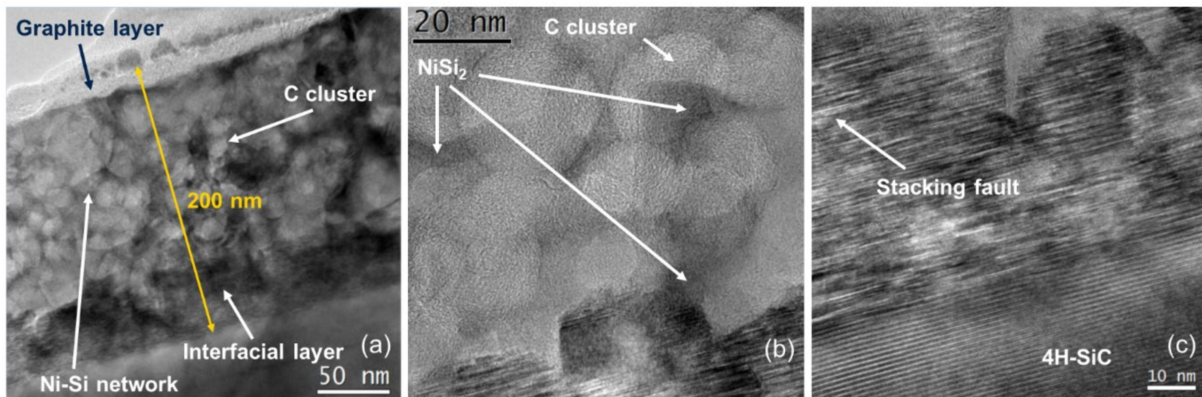

Fig. 5. Cross sectional TEM analysis of NiSi alloy sample annealed at 3.8 J/cm^2, two pulses. The reacted material shows an interfacial layer, a Ni-Si network region, and a graphite layer on top (a). HR-TEM micrographs show the presence of $NiSi_2$ regions and C-clusters in the Ni-Si network area (b), and the presence of stacking faults in the interfacial layer with 4H-SiC (c).

The morphology of NiSi alloy sample annealed at 3.8 J/cm^2 with two pulses has been investigated by cross-sectional TEM analyses (Fig. 5). As visible in Fig. 5a, the reacted material shows an interfacial layer, a Ni-Si network region, and a graphite layer on top. $NiSi_2$ regions and C-clusters are included in the Ni-Si network area, as shown by cross-sectional High-Resolution TEM micrograph reported in Fig. 5b. The presence of stacking faults in the interfacial layer with 4H-SiC has been revealed by HR-TEM (Fig. 5c).

Summary

The silicide reaction between a NiSi alloy and 4H-SiC under excimer UV laser annealing has been investigated, with the aim of finding an alternative to Ni and Ti for the ohmic contact formation on thin SiC wafers, enlarging the range of process options. It has been found that, fixed the laser annealing conditions, the addition of Si to Ni in the contact metal layer moves the silicide reaction forward. Moreover, a strong relationship has been observed between the electrical behavior of the annealed contacts and the structural and morphological properties of the reacted layers. Exploring the role of Si content in the NiSi alloy, by changing the composition of starting material, could shed additional light on the reaction process. NiSi alloy could represent a valuable opportunity for the formation of ohmic contacts on SiC by laser annealing.

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