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Optimisation of Ti Ohmic Contacts Formed by Laser Annealing on 4H-SiC

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Abstract. This work is focused on the fabrication of Titanium-based ohmic contacts by Laser Thermal Annealing (LTA) on n-type silicon carbide (4H-SiC). Their morphologies and electrical properties were studied by using two sets of parameters impacting the laser pulse overlap. With both sets, the ohmic contact transition was reached. The high overlap conditions produced a massive degradation of the contact morphology by leaving uncovered SiC. An optimisation of the annealing parameters was successfully performed by reducing the overlap. With the low overlap configuration, a specific contact resistance of 1.2×10^{-4} Ω.cm^2 was measured for a fluence of 4.25 J.cm^{-2} with a satisfying contact surface morphology.

Introduction

Silicon carbide (SiC) is well known as being an excellent material for working at high frequency, high temperature or at high power due to its wide bandgap and high electrical field [1]. After years of investigations, the quality of 4H-SiC became high enough to commercialize devices able to work in such expected applications.

In order to improve the energy efficiency of devices elaborated on larger and, hence, thicker SiC substrates, impacting their electrical performances due to the substrate resistance, the use of a thinned substrate is necessary. This involves achieving the ohmic contact at the end of the process as manipulating a thin wafer remains challenging. Nevertheless, the ohmic contact formation on wide band gap semiconductors is still a topic that can be improved to reduce its resistivity, which plays on the on-state resistance of devices [2, 3]. Commonly on SiC, a high temperature annealing is required to fabricate ohmic contacts on the substrate's backside. Then, a contact annealing that does not affect the wafer frontside is then mandatory. The laser irradiation is certainly one of the best alternative to succeed in this task [4, 5]. By employing optimized laser parameters, simulations of laser thermal annealing (LTA) demonstrated that the irradiated contact surface was heated up to 2000°C while keeping the opposite face at low temperature ($T < 600$°C) [6].

Recently, several investigations were focused on ohmic contact formation by LTA. As it gives the best ohmic contact by Rapid Thermal Annealing (RTA), Nickel (Ni) is the most widely investigated to form ohmic contact by LTA. Nevertheless, the morphology seems to be strongly inhomogeneous by creating a segregation of the Ni phases leaving uncovered SiC, as demonstrated by Rascunà *et al.* [7]. We experimented to anneal Ni contacts but, in our case, the morphology was also strongly inhomogeneous (not shown here). Titanium (Ti) is also a candidate to form ohmic contact as it can form phases with both Si and C, that could improve the contact morphology compared to Nickel. A Specific Contact Resistance (SCR) of 4.0×10^{-4} Ω.cm^2, determined by Transfer Length Method (TLM), has been already demonstrated using Ti [8].

In this study, the electrical and morphological characterisations will be performed on Ti-based ohmic contact on n-type 4H-SiC, formed by LTA. Based on our experience, a lot of annealing parameter combinations are capable to reach the ohmicity. Nevertheless, here we investigated the contact behaviour as a function of the laser fluence with two sets of pulse overlap by adapting the laser scanning speed and the distance between irradiated lines.

Experimental

Onto the Si-face of a production-grade 4H-SiC wafer from TankeBlue, a vertical isolation was achieved by the epitaxial growth of a 5 µm thick non-intentionally doped layer. Then a highly nitrogen-doped (1.9×10^{18} cm^{-3}) SiC layer was grown on the top of the isolation. The wafer was cut into 22×22 mm² samples. Firstly, a RCA cleaning was performed. Between each bath, samples were dipped into diluted fluoridric acid (HF) 1% and rinsed with deionized water. A 100 nm thick Ti layer was deposited onto 4H-SiC by DC magnetron sputtering and then it was irradiated thanks to a microPRO OFC tool from 3D-Micromac equipped with a frequency-tripled YAG pulsed laser (355 nm). The beam produced has a near 40×40 µm² square footprint with a top-hat energy density profile. The irradiations were performed at 30 kHz with a scanning speed of 185 or 800 $mm.s^{-1}$ under N_2 atmosphere. To evaluate the electrical performance of the contacts, circular TLM structures were fabricated as presented on Fig. 1. To do so, the TLM structures were fabricated by the etching of the spacings thanks to Ion Beam Etching (IBE) and, as a refill layer, 300 nm Aluminium (Al) were deposited onto the TLM patterns by a lift-off process.

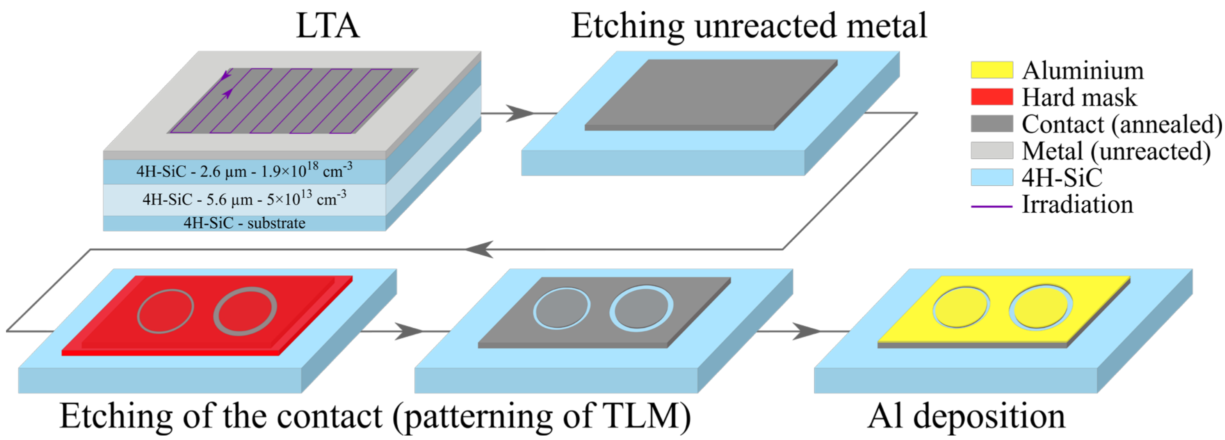

Fig. 1: Schematic representation of the fabrication process used to define the TLM structures.

Results and Discussion

Contacts annealed at 185 $mm.s^{-1}$ (high overlap)

Prior to the electrical characterisations, an investigation of the contact morphologies was performed by Scanning Electron Microscope (SEM). The aim is to select conditions compatible with industrial throughput that generate homogeneous contact with regular morphology to limit the failure due to the contact. After the irradiation, samples were dipped into HF to remove the unreacted Ti, without etching the titanium silicides and carbides, which allows to highlight the reaction between Ti and SiC. First, on Fig. 2, a set of annealing was performed at 185 $mm.s^{-1}$ with a distance between the irradiation lines of 13 µm. We observed a satisfying surface morphology only for the lowest annealing at 3.0 $J.cm^{-2}$. With the fluence increasing, a segregation between the contact and SiC appears, creating holes into the contact. An Energy Dispersive Spectroscopy (EDS) analysis of the holes (not shown here) did not reveal the presence of titanium. It is assumed that the titanium turned into liquid phase under the irradiation and was rejected from the centre of the irradiation and crystalised quickly around it. From 4.0 $J.cm^{-2}$, the morphology is critically impacted by the high pulse overlap, the titanium forms thick lines following the laser scanning.

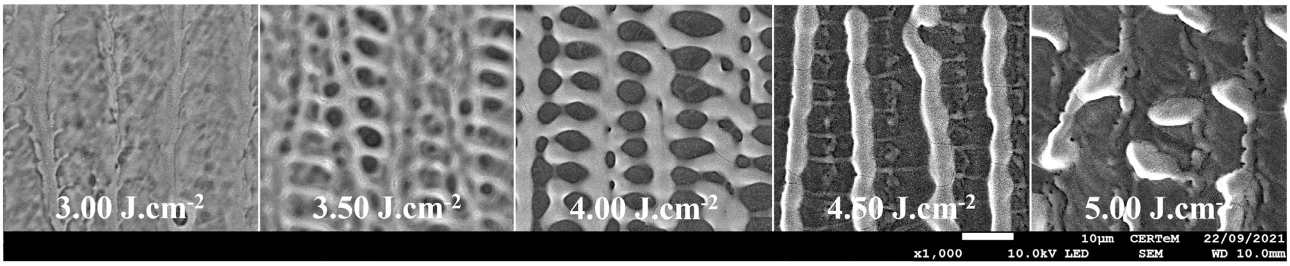

Fig. 2: SEM images of Ti annealed between 3.0 and 5.0 J.cm^{-2} at 185 mm.s^{-1}.

Electrical measurements were performed on test structures to find conditions that lead to ohmicity. Only the I-V characteristics of contacts annealed at 3.0 and 3.5 J.cm^{-2} are presented on Fig. 3, because the etching of contacts produced at higher energy densities was not satisfying for the electrical measurements. In the case of the contact annealed at 3.5 J.cm^{-2}, the I-V curve is linear, that indicates the successful ohmic contact formation. Nevertheless, based on SEM observations, an optimisation of the annealing parameters must be done to improve the contact morphology by reducing the overlaps.

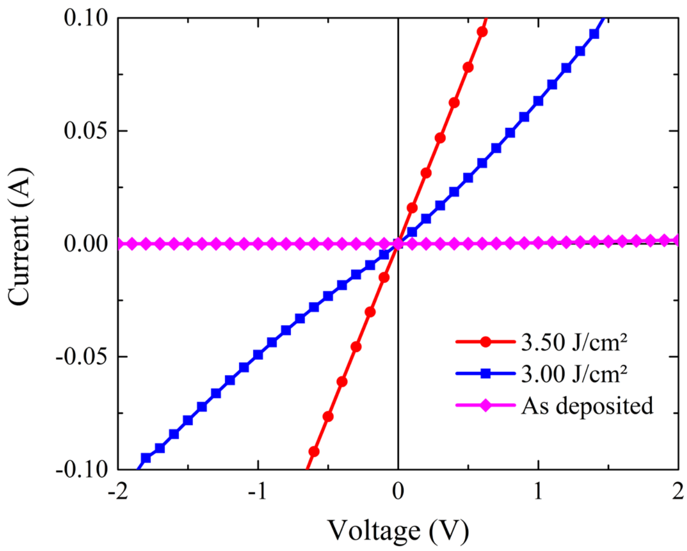

Fig. 3: I-V characteristics for a tests structures made of Ti/4H-SiC contact annealed at 185 mm.s^{-1}.

Contacts annealed at 800 mm.s^{-1} (low overlap)

A second annealing setup was performed by increasing the scanning speed to 800 mm.s^{-1} and the distance between lines to 20 µm. The SEM observations are presented on the Fig. 4 after the HF treatment to reveal Ti-Si-C phases. The contact annealed at 3.0 J.cm^{-2} shows large uncovered SiC between irradiation lines that indicates a lack of energy to form silicides and/or carbide due an inadequate distance between lines. At 3.5 J.cm^{-2}, the contact morphology appears highly smooth and then degrades with the increasing of the fluence, mostly on the overlapping areas. AFM measurements on 30×30 µm² (not shown here) determined a roughness R_q between 30-40 nm for the 4.5 J.cm^{-2}, annealing that is comparable with a classical RTA treatment. At 5.0 J.cm^{-2}, thick Ti-Si-C phases are formed on the overlapping area and a lot of dark spots, corresponding to a lack of Ti, with an average size of 450 nm are observed.

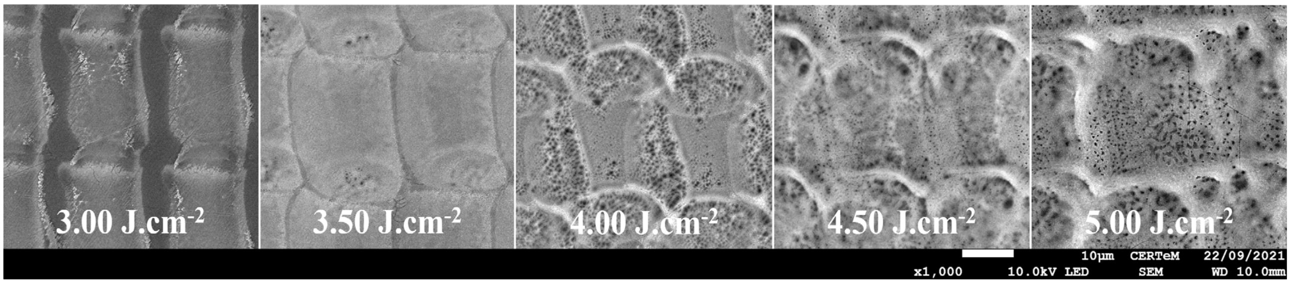

Fig. 4: SEM images of Ti annealed between 3.0 and 5.0 J.cm^{-2} at 800 mm.s^{-1}.

The I-V characteristics for the spacing equals to 30 µm of contacts annealed from 3.0 to 5.5 J.cm^{-2} are presented on Fig. 5(a). The current evolves with the increasing of the fluence, which reveals a modification of the contact composition. From 4.0 J.cm^{-2}, the I-V characteristics are linear, indicating the ohmicity is reached. The Fig. 5(b) presents the evolution of the SCR with the fluence. The optimal SCR of (1.2 ± 0.3) × 10^{-4} Ω.cm^2 was obtained at 4.25 J.cm^{-2}, which represents an improvement compared to the literature [8]. From 5.0 J.cm^{-2}, the contact electrical performances degrade which can be explained by a degradation of the morphology. For such high energy densities, with our setup, no optimisations led to satisfying morphology even with overlap close to 0, dark spots are always presents. Probably that a thickness modification could help to improve the contact homogeneity.

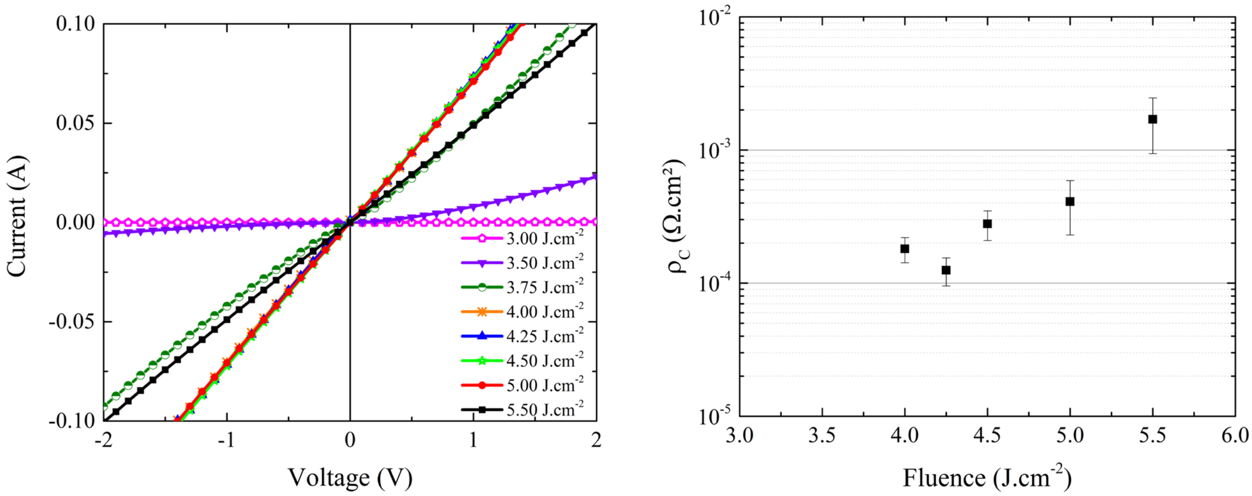

Fig. 5: (a) I-V characteristics between adjacent TLM pads for a Ti/4H-SiC contact annealed at several fluences. (b) Evolution of the SCR as a function of the annealing fluence for Ti/4H-SiC contacts.

Summary

Laser irradiations on Ti(100 nm) contact have been investigated on n-type 4H-SiC substrate. The overlap conditions play an important role on the contact morphology. With a high overlap, ohmic contact were produced but the morphology quality was poor. A consequent decrease of the overlap allowed to massively improve the contact surface while keeping the ohmic properties. A specific contact resistance of 1.2×10^{-4} Ω.cm² was reached at 4.25 J.cm^{-2}. This value is 3 times lower than the literature on laser annealing of Ti contact but, the fluence almost is twice higher. The origin of this improvement could be linked with a structural contact modification which will be investigated in the future.

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