Improvement in reverse bias leakage current of Ni/4H-nSiC Schottky barrier diodes via MeV selective ion irradiation

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Abstract. Present work deals with enhancement in reverse bias leakage current of Ni/4H-nSiC schottky barrier diode (SBD) via irradiating with 200 MeV 107 Ag14+ ions at a fluence of 1013 ions/cm2 in selective way. Compared to pristine SBD, the reverse bias I-V characteristics of selectively irradiated SBD show significant improvement in leakage current. Role of quodons have been discussed to rationalize the performance of irradiated SBD.

1. Introduction

The comfort, transportation and healthcare of modern society depend upon power devices. Therefore, significant interest has been generated in advancement of power generation, distribution and management technologies. The key ideas in development of power devices are their low switching loss, low conduction loss and high temperature tolerance [1]. Outstanding properties of SiC i.e. wide band gap, high thermal conductivity, low intrinsic carrier concentration, high breakdown electric field, high chemical inertness, etc., makes it promising material for fabrication of power devices. Miniaturization of power devices is requirement for advancement in their technology. But, proper design for reduction in electric field at the edges of miniaturized devices is a challenge yet [2]. For power devices, many edge termination techniques like field plate (FP), floating metal rings (FMR), junction termination extension (JTE), ion implantation, etc. have been reported in literature [1, 3]. Moreover, aforementioned techniques increase the size of device and hence their cost [2].

Moreover, literature reveals that swift heavy ion (SHI) irradiation can potentially modify the surface and bulk structures of the material, in a controlled way at nanoscale range [4]. Recently, it has been suggested that electronic energy loss by SHIs in crystalline medium transported as energy packets, namely, quodons [5, 6]. These quodons were found effective in interaction with lattice defects and move them to the boundary of masked (cold region) and irradiated region (hot region), so called “transition region”. As a result, the atomic structure will be modified at the “transition region”. This novel approach has been implemented for realization of good quality Si based p-n junction [2]. So, the purpose of this experiment is to demonstrate the implications of MeV selective ion irradiation in wide bandgap material i.e. SiC. To the best of our knowledge, this is the only report that integrates SHI irradiation with wide bandgap materials and based microelectronics. It is anticipated that this work could become a recipe for development of next generation solid state devices.
2. Experimental Details

N-type 4H-SiC wafer of <0001> orientation and 2 inch in diameter with n-type Si face of 25 µm epitaxy with doping of $5 \times 10^{14}$ cm$^{-3}$ was procured from CREE Res. Inc. USA. These wafers were cleaned as per standard chemical procedure i.e. degreasing, Radio Corporation of America (RCA), piranha followed by a short dip in dilute (2%) hydrofluoric acid. Thereafter, the wafer was baked for 4–6 hours in the oven for moisture baking [7]. Chemically cleaned molybdenum metal mask was used to (1) pattern the circular shaped SBDs of diameter 1.6 mm and (2) selectively irradiating the SBDs. This shadow mask was then fixed on the cleaned Si- face of the cleaned SiC wafer using a suitable adhesive. Nickel as schottky metal (200 nm) was deposited on the masked Si-face of the wafer using e-beam evaporation technique. Afterwards, Ohmic contact was formed on the C-face of the wafer using bilayer metallization of Ti/Au (50/150 nm). The selective ion irradiation was then performed using 200 MeV of $^{107}$Ag$^{14+}$ ions with fluence of $1 \times 10^{13}$ ions/cm$^2$. A schematic diagram for experimental plan is given in figure 1.

![Schematics representation of (a) 2D atomic arrangement of chemically cleaned SiC (green balls) wafer procured from CREE Res. Inc. USA and deposited Ni as Schottky metal (red balls). Black balls represent the wafer in-built defects in material. (b) The shadow mask was kept placed in some portions for selective way (SW) irradiation. Yellow wave represent the generated quodons which interact with defects and let them move towards edges of the SBD.](image)

The current-voltage characteristics of these devices, before and after ion irradiation were acquired using Keithley 4200 semiconductor characterization system (SCS).

3. Results and Discussion:

The reverse characteristics of both pristine and selectively irradiated SBDs were acquired by sweeping the DC bias from 0 to -200 V and shown in figure 2.

![Reverse bias leakage current density in pristine and selectively irradiated SBDs.](image)
It can be seen from figure 2 that selectively SHI irradiation improved the reverse bias characteristics. In case of pristine SBD, the reverse bias leakage current density is estimated to $1.77 \times 10^{-9}$ A/cm$^2$. On the other hand, in case of selectively irradiated SBD, leakage current density is calculated to be $3.12 \times 10^{-10}$ A/cm$^2$ which is an order of magnitude lower than pristine SBD. These findings are in contrast to reported literature, where it has generalized that SHI irradiation at higher fluence produce generation centres in material which causes more leakage current in SBDs [8-11]. Moreover, if initially the leakage current is very high in SiC based SBDs then, sometimes deactivation of dopants by SHI irradiation, may cause its reduction [10]. Further reports reveal that if initially the leakage current is very low then after few MeV (i.e. < 10 MeV) ion irradiations on SiC SBDs, it will be increased. Moreover, in ion implantation induced edge termination technique, improvement in the leakage current, at -200 V was marginal [1]. In contrast to these reported results, present work shows that with selective SHI irradiation, leakage was reduced by an order of magnitude, which was already very low in pristine case. This suggest that, more studies are required to understand the fundamental physics behind SHI irradiation induced modifications in structural and electrical properties of SiC based SBDs.

The underlying phenomena in the selective area SHI irradiated SiC SBD is perceived by generation and interaction of quodons with interface defects and cause their accumulation at the boundary of masked and irradiated site i.e. at the “transition region”. It has been well established that the impulsive force of SHI irradiation introduces nonlinearity in the crystalline medium. This causes transport of stored vibrational energy from the irradiation site towards transition region. Due to localization of vibrational energy at the transition region, the lattice structure gets reordered locally by changing bandgap and surface roughness [5, 6]. Based on these reported hypotheses, it is proposed in this work that SHI induced reordering of atomic structure at the boundary of the SBD (or edges of the fabricated SBD) minimize electric field there and hence causes improvement in their leakage current.

4. Conclusion

In summary, a novel approach for the realization of high quality SiC based SBD has been proposed and demonstrated. The 4H-nSiC based SBDs were fabricated and irradiated in selective way with $^{107}$Ag$^{14+}$ of energy 200 MeV at a fluence of $1 \times 10^{13}$ ions cm$^{-2}$. Reverse bias performance of these diodes revealed that, as compared to the pristine, the selective way ion irradiated diode shows improvement in leakage current by an order of magnitude. These experimental findings reveal that due to localization of vibrational energy at the transition region, the lattice structure gets reordered there. This results in minimizing the local electric field and hence improves the leakage current.

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References

[1] B. J. Baliga, SiC Power Devices, (World Scientific Publishing Co. Pte. Ltd. Singapore, 2005).
[2] Vibhhor Kumar, A.S. Maan and J. Akhtar, 2013 Journal of Physics : Conference Series 423 012057.
[3] L. J. Brillson, 1982 Surface Science Reports 2 123.
[4] O. Ochedowski, O. Osmani, M. Schade, B. K. Bussmann, B. Ban-d’Etat, H. Lebius & M. Schleberger, 2014 Nature communications 5 3913.
[5] P. Sen, J. Akhtar, and F. M. Russell, 2000 Europhys. Lett., 51 401.
[6] P. Sen, and J. Akhtar, 2000 Pure Appl. Chem., 74, 1631.
[7] V. Kumar, Shuvam Pawar, A. S. Maan, and J. Akhtar, 2015 Journal of Vacuum Science & Technology B, 33, 052207.
[8] V. Raineri, F. Roccaforte, S. Libertino, A. Ruggiero, V. Massimino, L. Calcagno, 2006 *Materials Science Forum*, 527, 1167.

[9] F. Roccaforte, S. Libertino, V. Raineri, A. Ruggiero, V. Massimino, and L. Calcagno 2006 *Journal of Applied Physics*, 99 013515.

[10] C. Kamezawa, H. Sindoua, T. Hirao, H. Ohyama, S. Kuboyama, 2006 *Physica B*, 376, 362.

[11] G. Izzo, G. Litrico, L. Calcagno, G. Foti, F. L. Via, 2008 *Journal of Applied Physics*, 104, 093711.