ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-TUPAB057

CARBON BEAM AT I-3 INJECTOR FOR SEMICONDUCTOR IMPLANTATION

A. A. Losev†, Yu. A. Satov, N. N. Alekseev, A. V. Shumshurov, A. D. Milyachenko, P. N. Alekseev, T. V. Kulevoy, Institute for Theoretical and Experimental Physics named by A. I. Alikhanov of National Research Centre "Kurchatov Institute", Moscow, Russia
P. B. Lagov[1], National University of Science and Technology "MISiS", Moscow, Russia
Yu. S. Pavlov, A. N. Frumkin Institute of Physical Chemistry and Electrochemistry, Moscow Russia
M. E. Letovaltseva, Russian Technological University MIREA, Moscow, Russia
[1]also at A. N. Frumkin Institute of Physical Chemistry and Electrochemistry, Moscow, Russia

Abstract

Carbon implantation can be effectively used for axial minority charge carriers' lifetime control in various silicon bulk and epitaxial planar structures. When carbon is implanted, more stable recombination centres are formed and silicon is not doped with additional impurities, as for example, when irradiated with protons or helium ions. Economically, such a process competes with alternative methods, and is more efficient for obtaining small lifetimes (several nanoseconds). I-3 ion injector with laser-plasma ion source at Institute for theoretical and experimental physics (ITEP) is used as ion implanter in semiconductors. The ion source uses pulsed CO_2 laser setup with radiation-flux density of 10^{11} W/cm^2 at target surface. The ion source produces beams of various ions from solid targets. The generated ion beam is accelerated in the two gap RF resonator at voltage of up to 2 MV per gap. Resulting beam energy is up to 4 MV per charge. Parameters of carbon ion beam generated and used for semiconductor samples irradiation during experiments for axial minority charge carriers lifetime control in various silicon bulk and epitaxial planar structures are presented.

INTRODUCTION

Many silicon devices, including power MOSFET, IGBT, FRD etc. require applying technologies to control the lifetime of minor charge carriers [1, 2]. As a result, one utilizes Au- or Pt-thermodiffusion, radiation, and combined methods. In practice the most widely utilized method is treatment by accelerated electrons, protons or He^+ ions. The accelerated (usually 4-8 MeV) electrons provide uniform formation of defects in the volume of semiconductor wafers arranged one after the other (~ 10 pcs). However, achieving small switching times (≤ 5 ns) requires high fluences and irradiation time. Proton irradiation at high fluences leads to doping by shallow donors and some instability of the achieved electrical parameters. Therefore, for these purposes, He^+ ion irradiation is often used, which more efficiently produces displacements, and the behavior of device structures after irradiation and subsequent annealing is more stable.

Due to the fact that carbon ions also have a relatively large range at relatively low (no more than 20 MeV) accelerating voltages, the possibility to obtain low switch time for reference diode by carbon implantation was investigated. In addition, carbon in sufficiently high concentrations (10^{16}-10^{17} cm^{-3}) is present in single-crystal silicon, i.e., additional contamination with foreign impurities is minimal.

SETUP LAYOUT

The setup consists of a laser plasma ion source, a buncher, an accelerating RF resonator, a bending magnet and ion beam transfer system as shown in Fig. 1.

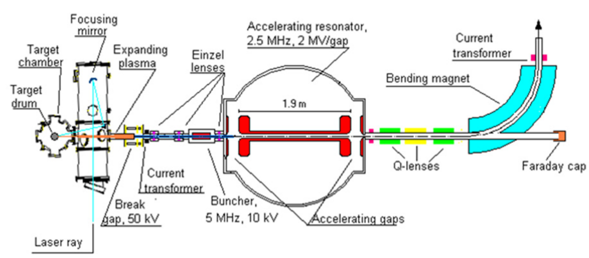

Figure 1: I-3 injection complex layout.

Ion Source

The laser-plasma ion source is based on the pulsed CO_2 laser described in [3]. It provides laser beam with high quality of temporal and spatial characteristics: pulse energy – 6 J, peak power – 60–70 MW, FWHM duration – 30 ns, repetition rate – 0.1 Hz, beam spatial profile is close to Gaussian. Its radiation is transfered by flat copper mirrors to the vacuum chamber and focused by combination of spherical and flat mirror. Carbon target surface is irradiated by laser pulses at a radiation flux density of 10^{11} W/cm^2. Generated plasma contains a set of charge states of carbon ions, of which C^{3+} and C^{4+} are most represented in terms of the number of particles. Carbon beam is extracted from expanding plasma by high-voltage gap with grids, placed 1.68 m away from target surface. Total beam current from the source is measured by current transformer installed behind extraction gap and is shown in Fig. 2.

† Anton.Losev@itep.ru

ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-TUPAB057

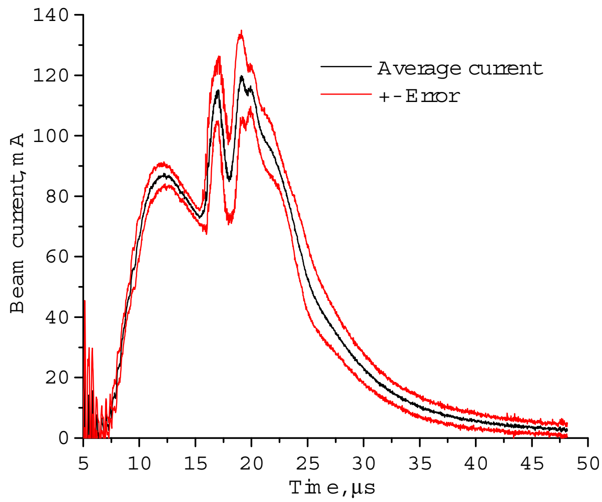

Figure 2: Laser plasma ion source output current, which contains all generated charge states.

I-3 Ion Injector

The I-3 ion injector is a single drift tube linac designed to accelerate ions in a wide range of charge to mass ratio. It can slightly vary accelerated beam energy. Its parameters are presented in Table 1.

Table 1: I-3 Linac Parameters

Parameter	**Value**
Frequency	2.504 MHz
Number of accelerating gaps	2
Voltage per gap	up to 2 MV
Length of drift tube	1920 mm
Aperture	70-90 mm
Range of Z/A ratio	0.2-0.5
Input energy	50 kV per charge
Transverse acceptance	2000 π·mm·mrad

A 90° bending magnet is used to select charge state of ions in accelerated beam therefore this setup allows to change beam energy in wider range to meet irradiation requirements.

IRRADIATION CONDITIONS

Fluence was calculated by integration of ion beam current signal (shown in Fig. 3) measured as voltage drop caused by 50 Ohm load connected to the target holder. This calculation was carried out for each ion current pulse. Irradiated area of the sample was determined using target holder photos and four marker holes as shown in Fig. 4. Marker holes made it possible to take into account distortion of scintillator image caused by target chamber configuration. Irradiation uniformity was calculated as standard deviation of ion beam luminosity in irradiated area of the sample using scintillator images as shown in Fig. 5.

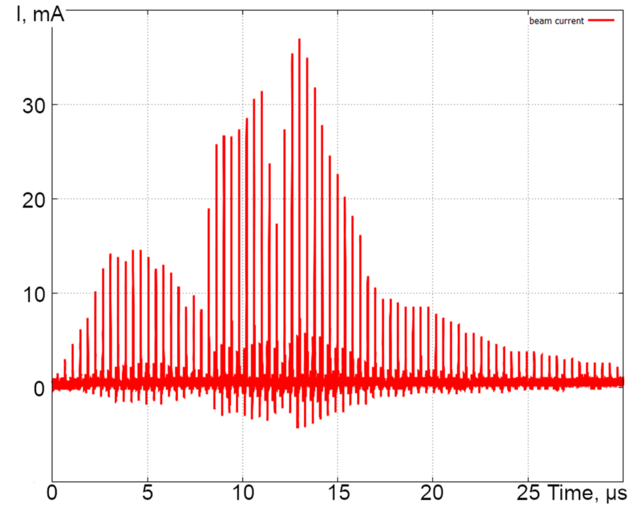

Figure 3: Ion beam current signal for fluence calculation.

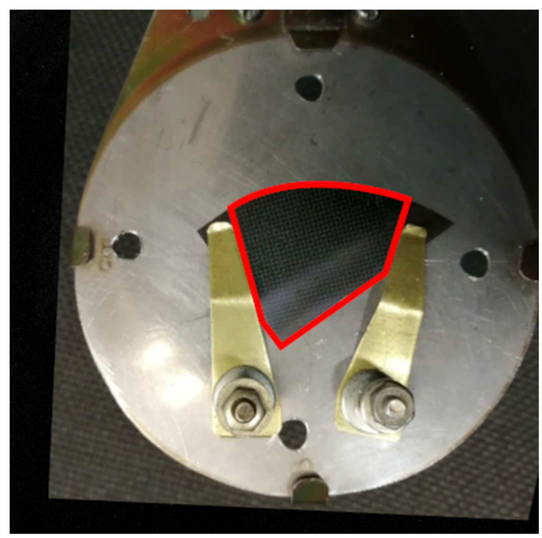

Figure 4: Wafer sample in a holder.

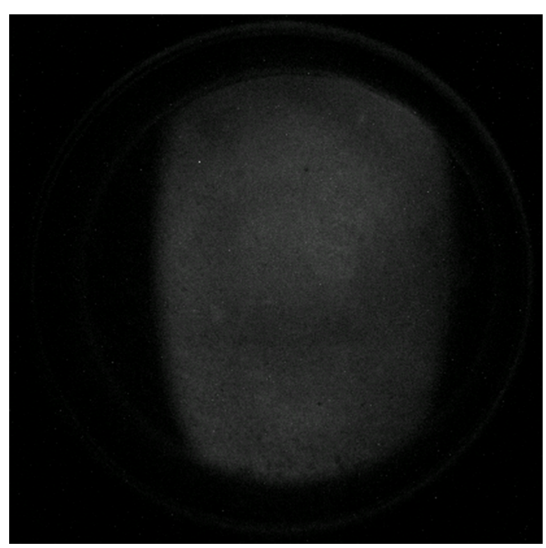

Figure 5: Accelerated carbon beam profile image.

ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-TUPAB057

C^{3+} ion was chosen for sample irradiation, accelerating voltage was set to 2.9±0.3 MV resulting in 8.7±0.9 MeV beam energy. Irradiation uniformity of the sample area (Fig. 4, red polygon) was not worse than 18%.

RESULTS

Experimental reference diode structures were obtained by forming a 3 µm junction in 10 µm epitaxial n-type layers, followed by vacuum deposition of the 1 µm anode Al-contact. The optimal carbon implantation energy range of 8.4-8.7 MeV and fluences $1\text{-}4\cdot10^{12}$ cm^{-2} was selected using the SRIM [4] software package and real experience of previous radiation experiments with different particles and device structures [1, 2, 5].

Analysis of the diode parameters after irradiation showed that the best "reverse recovery time-leakage currents" ratio is achieved at an energy of 8.7 MeV and a fluence of $2\cdot10^{12}$ cm^{-2}.

In addition, it was found that carbon-irradiated diodes have better direct voltage drop characteristics compared to electron-irradiated diodes at close switching times and leakage currents.

REFERENCES

[1] P.B. Lagov *et al.* "Proton-irradiation technology for high-frequency high-current silicon welding diode manufacturing", *J. Phys.: Conf. Ser.,* vol. 830, p. 012152, May 2017. doi:10.1088/1742-6596/830/1/012152

[2] Y.S. Pavlov *et al.* "Accelerator-based electron beam technologies for modification of bipolar semiconductor devices", *J. Phys.: Conf. Ser.,* vol. 747, p. 012085, Sept. 2016. doi:10.1088/1742-6596/747/1/012085

[3] Yu.A. Satov *et al.* "Characteristics of a pulse-periodic CO_2 laser for applications in the field of laser-produced plasma", *Instrum. Exp. Tech.,* vol. 59, pp. 412-419, May 2016. doi:10.1134/S0020441216020251

[4] SRIM software package, http://www.srim.org

[5] In-Hwan Lee *et al.* "Deep Electron and Hole Traps in Electron-Irradiated Green GaN/InGaN Light Emitting Diodes", *ECS J. Solid State Sci. Technol.,* vol. 6, no. 10, p. Q127, 2017. doi:10.1149/2.0131710jss