LASER ION SOURCE FOR SEMICONDUCTOR APPLICATIONS

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INTRODUCTION AND SETUP LAYOUT

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 ($\leq$5 ns) requires high fluences and irradiation time. Proton irradiation at high fluences leads to doping by small donors and some instability of the achieved electrical parameters. Therefore, for these purposes, He^+ ion irradiation is often used, which produces displacements more efficiently, 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 con-centrations ($1 \cdot 10^{16}$–$1 \cdot 10^{17}$ cm^{-3}) is present in single-crystal silicon, i.e., additional contamination with foreign impurities is minimal.

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

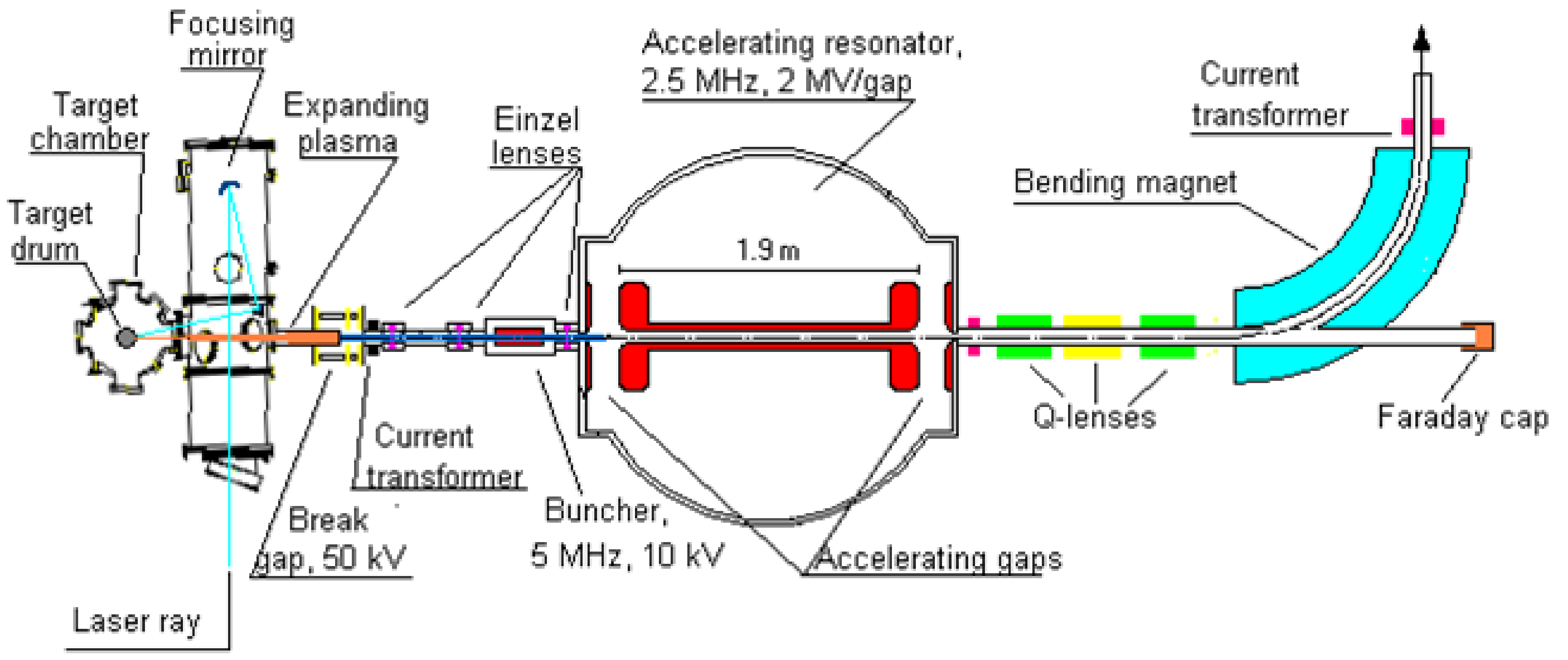

Fig. 1:

Figure 1. Setup layout

LASER-PLASMA ION SOURCE

The laser-plasma ion source is based on the pulsed CO_2 laser which is 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 ($f = 1600$ mm) 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 as shown in Fig. 2. Carbon ion 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. 3. Extracted beam is accelerated by the I-3 ion injector, which is a single drift tube linac designed to accelerate ions in a wide range of charge to mass ratio.

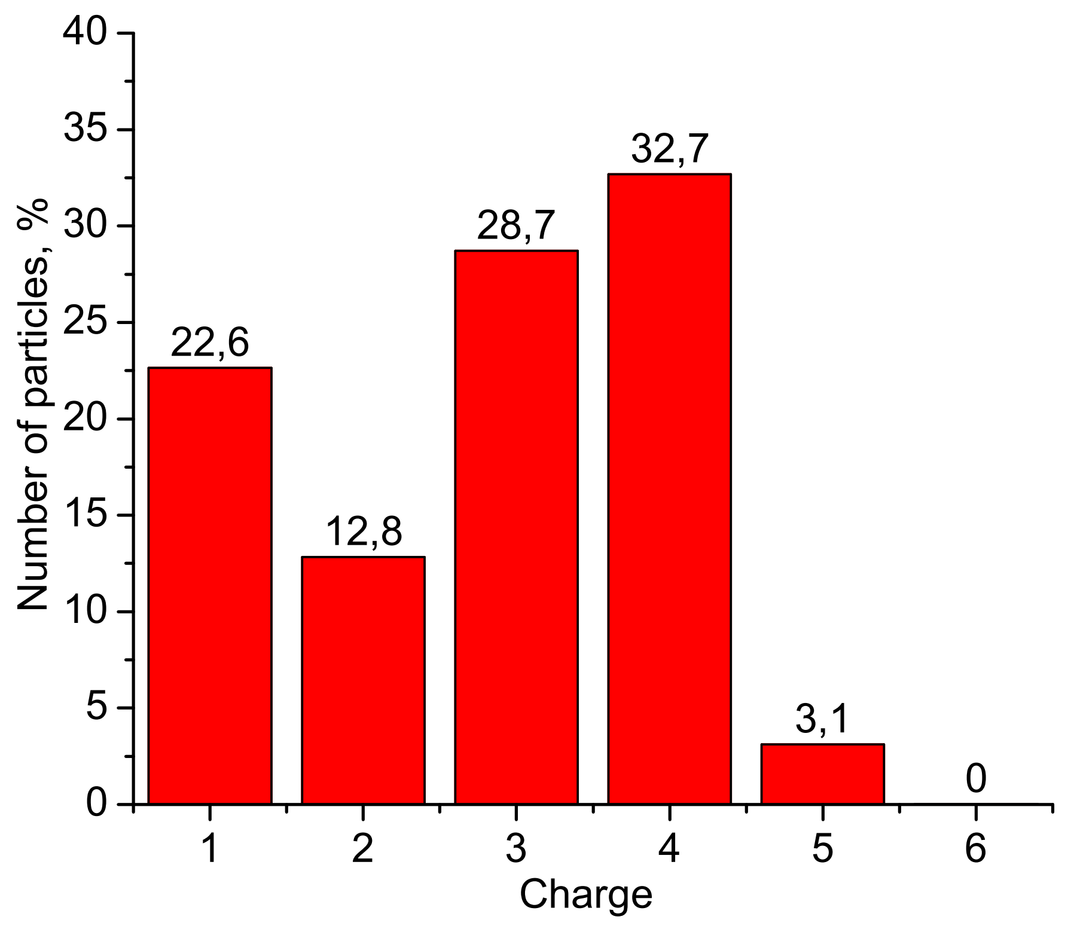

Fig. 2: Charge state distribution

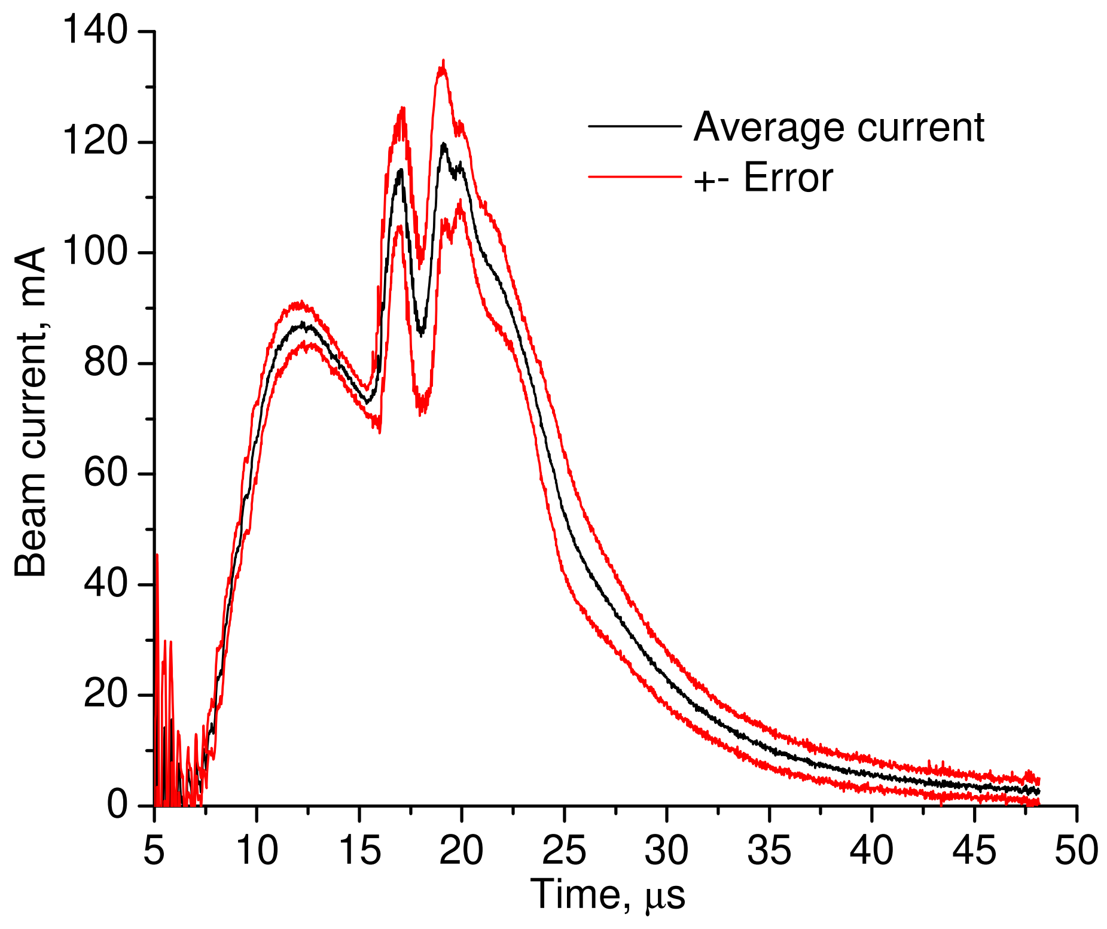

Fig. 3: Laser plasma ion source output current (contains all generated charge states)

IRRADIATION CONDITIONS AND RESULTS

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 was not worse than 18%. 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 $1 - 4 \cdot 10^{12}$ 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].

Three parameters were taken in consideration: t_{rr} – reverse recovery time, I_R – reverse (leakage) current, U_F – forward voltage drop at forward current of 10 mA. The combination of these three parameters is considered to be the best when the lowest t_{rr} is reached with minimum I_R increase. Decrease in U_F due to growth of recombination component of forward current is also a positive effect. Such a decrease is typical for epitaxial diode structures with thick base width and low reverse voltage (less than 100 V), to which the investigated diode structure belongs.

In our case the best combination of parameters is achieved at an energy of 8.7 MeV and a fluence of $2 \cdot 10^{12}$ cm^{-2}. This combination provides necessary frequency and pulse characteristics of the diode for operation in certain pulsed circuits.

Irradiation by C^{3+}	t_{rr}, ns	I_R, nA	U_F, V (at $I_F = 10$ mA)
Initial	> 100	< 3	0.81 ± 0.01
8.4 MeV, F = $1 \cdot 10^{12}$ cm^{-2}	18 ± 2	< 100	0.80 ± 0.01
8.4 MeV, F = $4 \cdot 10^{12}$ cm^{-2}	5.5 ± 0.5	900 ± 100	0.76 ± 0.01
8.7 MeV, F = $2 \cdot 10^{12}$ cm^{-2}	2.2 ± 0.2	< 10	0.78 ± 0.01

Table 1: Parameters of diode structures (70 V at 0.25 A)

The setup is supposed to be used to determine optimal conditions for irradiation of semiconductor devices. The data obtained is required to design industrial accelerators for semiconductor production.

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