IMALION - CREATION AND LOW ENERGY TRANSPORTATION OF A MILLIAMPERE METAL ION BEAM*

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Abstract

IMALION - which stands for IMplantation of ALuminum IONs - is a facility designed for high-current metal ion beam implantation and surface modification such as in semiconductor, medical or optical industry. IMALION is a newly developed 30 kV metal ion wide area implantation platform, which is suitable for the irradiation of a target width of 200 mm to produce homogeneous implantation profiles over the entire surface. Electrostatic and magnetic beamline elements such as a deflector as well as analyzing and parallelization magnets were designed for precision guiding of a milliampere metal ion beam. The implanter is fed by a novel ECR metal ion source, which is equipped with an integrated cylindrical sputter magnetron as metal vapor supply. Stable operation of the sputter magnetron under ECR magnetic mirror conditions was proven by optical emission spectroscopy and Langmuir probe measurements.

INTRODUCTION

The aim of the IMALION project is to develop a new high current metal ion source together with a wide area metal ion implantation platform suitable for substrate widths of 200 mm and scalable to 2 m for large surface applications in semiconductor, optical and medical industry. Proof of principle experiments are conducted with Aluminum ions as they can show the significant advantage of the system in the field of photovoltaics. The new solar cell generation based on n-type silicon wafers utilizes p-type emitter layers usually generated by thermal diffusion of Boron from gaseous compounds. As an alternative, Al ion implantation out-performs the diffusion procedure as one can achieve a well defined doping level and profile together with better homogeneity and reproducibility as well as higher purity. Furthermore, the number of process steps is reduced because there is no need for edge isolation and parasitic glass layer removal [1–3]. As Boron is replaced by Aluminum the use of toxic B-containing starting materials can be avoided.

MAGNETRON ECR ION SOURCE

A new high-current metal ion source prototype was developed. It combines magnetron sputter technology with electron cyclotron resonance (ECR) ion source technology — a so-called **M**agnetron **ECR** **I**on **S**ource named “MECRIS” (Fig. 1). An integrated inverted cylindrical sputter magnetron is acting as a metal atom source with a ring shaped Al cathode with an inner diameter of 200 mm, a width of 50 mm, and a thickness of 10 mm. The cathode is part of the chamber wall of the cylindrical ion source volume with a radius of 100 mm and a length of 200 mm. The ECR plasma is sustained by injection of microwaves with a frequency of 2.45 GHz in TE_{10} mode through a rectangular waveguide and it is used to ionize the metal atoms by electron impact. In order to protect the quartz glass microwave transmitting window from Al vapor deposition it had to be placed behind a 90° elbow element of the waveguide. Mostly singly charged Al^+ metal ions and ions of the process gas (Ar^+, Kr^+ or Ne^+) are extracted through a one hole aperture with a variable diameter of 4 mm to 10 mm by a 3 electrode system of the accel-decel-type. The MECRIS is operated on a 30 kV platform so that Al^+ ions with a maximum kinetic energy of 30 keV can be implanted into the grounded target.

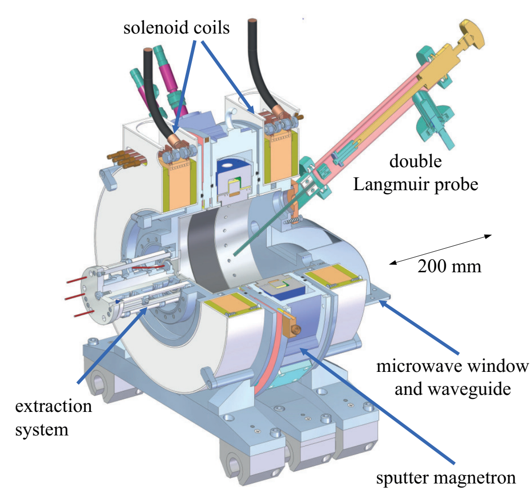

Figure 1: Sectional view of the ECR ion source with integrated cylindrical sputter magnetron.

The magnetic field used to confine the plasma inside the ion source is produced by a pair of solenoid coils and by the permanent magnets of the sputter magnetron. Depending on the coil current (max. 200 A each) an off-axis minimum-B-field-structure is obtained, which contains a closed magnetic flux density surface at 87.5 mT satisfying the ECR condition (Fig. 2). Spatially resolved double Langmuir probe and optical emission spectroscopy measurements show an increase in electron density by one order of magnitude from 1×10^{10} cm^{-3} to 1×10^{11} cm^{-3} when the magnetron

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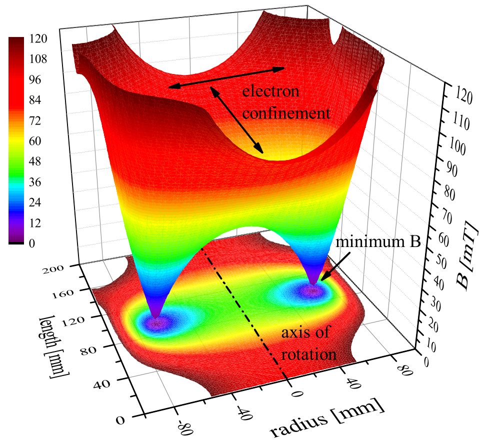

Figure 2: *COMSOL* - FEM - simulation of magnetic flux density of z - r cut plane of the MECRIS. Coil current combination 150 A / 135 A.

plasma is exposed to the minimum-B-field of the ECR ion source. A detailed study of electron temperature and density of the magnetron plasma as well as the magnetic field design of the MECRIS was published elsewhere [4]. Experimental investigation of the plasma parameters of the MECRIS plasma will be published separately.

IMALION IMPLANTER

The IMALION implantation platform is fed with an Al^+ ion beam from the MECRIS and uses a magnetic steerer to guide the beam into a double-focus analyzing dipole magnet, which separates the process gas ions from the Al^+ ions. After this, an electrostatic deflector is used to scan the Al^+ ion beam into a parallelization dipole magnet, which produces parallel Al^+ ion beams impacting on the substrate surface. In this way, the entire surface of a substrate with a width of 200 mm is implanted by scanning the beam in horizontal direction and by upward or downward movement of the substrate (Fig. 3). All beamline elements of the IMALION implanter were designed for precision guiding of a 30 mA Al^+ ion beam using the FEM simulation software *Field Precision* [5]. Because of the wide ion beam cross section the effect of coulomb repulsion of the Al^+ ions was neglected.

Analyzing Magnet

Filtering of the Al^+ ions from the process gas ions Ar^+, Kr^+ or Ne^+ and ions of the background gas is achieved by a 90° q/A analyzing dipole magnet with q being the charge state and A the atomic mass. For the simulation of the magnetic field and the ion trajectories a pole gap of 80 mm, a bending radius of 250 mm as well as a beam diameter of 15 mm was used. The magnet pole shoes were designed to approximate a Rogowski profile with two level stages at different angles [6]. Two dimensional focusing is achieved by tilting the front and rear faces of the pole shoes in relation

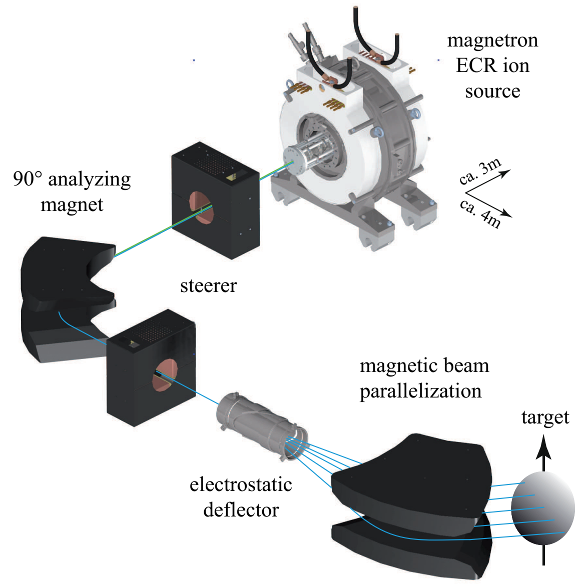

Figure 3: Design of the IMALION facility for Al^+ ion implantation into large area substrates via ion beam scan optics.

to the beam line axis by 33°. The analyzing magnet was optimized for a 30 mA and 30 keV Al^+ ion beam. It is able to resolve $^{27}Al^+$ from $^{28}N_2^+$, which was the most critical precondition in terms of q/A resolution.

Ion Beam Scan Optics

After the analyzing magnet the beam passes an electrostatic deflector. It consists of two electrodes with the shape of a half cylinder cut diagonally in relation to the beam direction. In this way, a compact system was designed that is able to deflect the beam by ± 10° using electrode potentials with a difference of maximum 8 kV. Additionally, the deflector works as an electrostatic lens when it is operated with a potential offset of a few kV above ground potential. Then the deflector focuses the scanned beam into the parallelization magnet (Fig. 4).

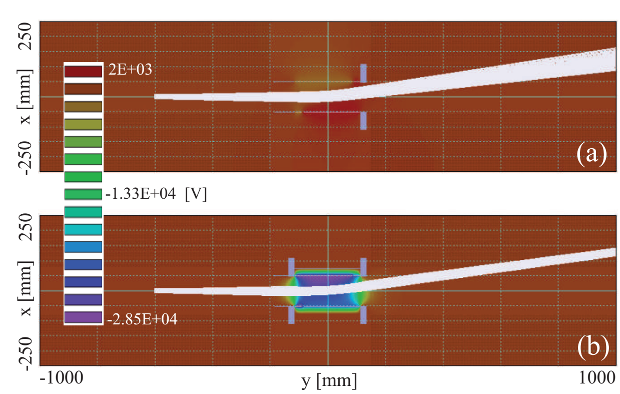

Figure 4: FEM simulation of electric potential as well as Al^+ ion beam displacement by the electrostatic deflector. (a) - lens potential 0 V, deflection potentials ± 2 kV. (b) - lens potential -25 kV, deflection potentials ± 3.5 kV.

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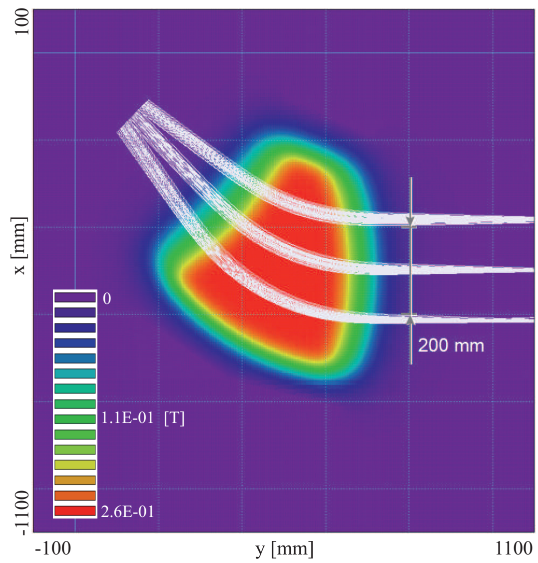

Figure 5: FEM simulation of magnetic flux density as well as Al^+ ion beam parallelization with the dipole magnet.

The parallelization magnet produces parallel Al^+ ion beams in horizontal direction over a width of 200 mm to irradiate a substrate perpendicular to its surface (Fig. 5). The magnet uses a beam bending angle of 45°. The beam meets the front face of the magnet perpendicularly under each deflection angle. At the exit, the pole shoe face is tilted in relation to the beam axis by an angle, which is equal to the respective deflection angle. Furthermore, a pole gap of 80 mm and a deflection radius of 500 mm were used for the simulations.

The combination of deflector and parallelization magnet as an ion beam scanning unit is suitable to provide a homogeneous Al^+ ion dose of 2.25×10^{16} cm^{-2} $\pm$ 0.1% at an Al^+ ion current of I = 30 mA with an average beam spot size of 41.0 mm $\pm$ 0.8 mm in vertical direction and 23 mm $\pm$ 4 mm in horizontal direction (Fig. 6). For a homogeneous dose over the entire substrate surface, it is important that the beam spot hight varies as little as possible in the direction of the substrate movement. For this purpose, the lens potential applied to the deflector can be adjusted to the ion optical effect of the parallelization magnet for each beam deflection angle.

The Al^+ ion dose D(x,z) has been calculated at each point P(x,z) of the substrate surface, using a two dimensional Gaussian beam current density distribution with σ_x and σ_z as FWHM

$$j(x,z) = \frac{I}{2\pi\sigma_x\sigma_z}\exp[-\frac{1}{2}(\frac{x^2}{\sigma_x^2}+\frac{z^2}{\sigma_z^2})],$$

according to

$$D(x,z) \approx \frac{1}{\Delta x \times f}\sum_{z_p=-2\sigma_z}^{2\sigma_z}\int_{-\infty}^{\infty} j(x_p,z_p)dx_p,$$

where a beam scan frequency of f = 33 Hz and a scanning width of Δx = 250 mm was chosen. The calculation is valid for small distances $\Delta z \ll \sigma_z$ between each scanned line, which is satisfied at a substrate velocity of 200 mm/min resulting in Δz = 0.1 mm.

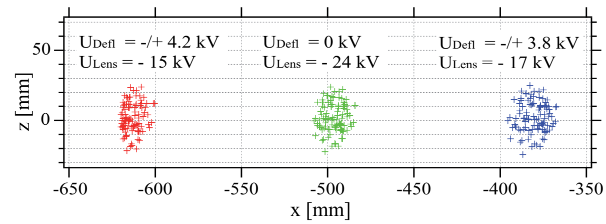

Figure 6: 30 mA Al^+ ion beam spot size on target at $\pm$ 10° beam deflection, tuned with the deflector potential and the deflector lens potential, respectively.

CONCLUSION

A new high current wide area metal ion implantation platform for large surface applications has been developed. It comprises a unique ECR metal ion source, which is equipped with an integrated cylindrical sputter magnetron as metal vapor supply, as well as beamline elements such as an analyzing dipole magnet, an electrostatic deflector, and a beam parallelization dipole magnet. Assuming a perfectly stable current of 30 mA Al^+ ions, an implantation dose of 2.25×10^{16} cm^{-2} can be reached with the facility according to simulations. First experiments concerning the optimization of the implantation platform are carried out at present. A newly designed Faraday cup system is used to measure the metal ion beam current. Its water cooled cup electrode allows the application of a beam power above 1 kW.

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