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SCIENCE DIRECT
Vacuum 78 (2005) 435–438
VACUUM
SURFACE ENGINEERING, SURFACE INSTRUMENTATION & VACUUM TECHNOLOGY
www.elsevier.com/locate/vacuum

Application of laser ion source for ion implantation technology

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Abstract

The subject of this contribution is a study of the application of laser-produced ion streams for implantation into different materials. The laser-produced plasma has been used as a source of ions with different charge states and with different kinetic energies for ion implantation into various materials: metals, polymers and semiconductors, in order to modify their properties. The implantation depth was measured using Rutherford backscattering spectroscopy (RBS).

Keywords: Laser-matter interaction; Laser ion source

1. Introduction

In current material research and development, high priority is given to the surface modification techniques for improving surface properties for specific application requirements. Ion implantation is an important tool for producing improved materials. Its major advantage over other surface modification techniques is that the newly created layer is in, not on, the surface; thus there are no adhesion problems and problems with dimension change are much smaller. The implanted layer can be the final goal or the substrate for additional layers. Conventional ion implantation using currently available plasma ion sources (electron–cyclotron resonance microwave discharges—ECRIS, electron beams—EBIS or metal-vapor vacuum arcs) can only produce moderate average currents of normally gaseous materials or low currents ($\leqslant 100\,\mu A$) of normally solid, especially metallic materials [1–7].

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0042-207X/$ - see front matter
doi:10.1016/j.vacuum.2005.01.064

In comparison, a laser ion source (LIS) seems to have several advantages over the conventional ion implanters. The first of these is the greater depth of implantation due to higher charge states. The second is that LIS can ionize any solid material. A third advantage is the greater ease of biasing the ion source to positive high voltage, which is important for moving substrates. With LIS, several variables can and must be controlled. The proportions of ions and neutrals (current densities, charge state, angular and energy distributions) are determined by the target material and the laser energy, pulse duration and intensity on the target [8–12].

During collaborative experiments performed at the PALS Research Centre in Prague (e.g. [13–16]), an effective implantation of different laser-produced ions into metals, dielectric materials as well as polymers and fabrics was demonstrated. The quantity and depth of ion implantation were analyzed using Rutherford backscattering spectrometry (RBS). The dose of ions implanted into samples was up to $10^{16}\,cm^{-2}$. The maximum implantation depths for Ag and Ta ions implanted into carbon and aluminum substrates were several hundreds of nanometers [15,16]. In this paper, we discuss and compare the efficiency of the implantation of laser-generated ions performed under different conditions.

2. Apparatus and methods

In recent studies, the PALS high-energy iodine laser system [17] (energy up to 1.2 kJ in a 0.4-ns pulse, intensity up to $10^{15}\,W/cm^2$ at a fundamental frequency and energy up to 0.25 kJ at 0.438 μm) was used. The laser-generated ions were investigated using ion diagnostics based on the time-of-flight method [18,19]: ion collectors (ICs) and an electrostatic ion-energy analyzer (IEA) equipped with the windowless electron multiplier. The ion collectors were located at different angles with respect to the target normal and at different distances of 30–60 cm from the target surface. The IEA and a ''ring'' ion collector (ICR) were placed far from the target at distances of ~ 290 cm and ~ 150 cm, respectively, perpendicular to the target surface or at an angle of 30° to the target normal. The scheme of the exemplary experimental chamber equipped with the diagnostic devices and illumination system is presented in Fig. 1.

From the ion current measured by the ICs, the velocity and energy distributions of the ion charge were obtained. By integrating them, the total and mean ion energy as well as total number of ions were calculated. IC signals show several, more or less pronounced maxima, the position and amplitude of which may reflect not only the mechanisms of ion production but also variations of laser parameters. The IEA made it possible to determine the mass-to-charge ratios, energies and abundances of the observed ion species.

The targets irradiated by the laser beam were used for generation of ion streams destined for implantation into substrates located at distances of 10–30 cm from the target. About 10 laser shots, each with the same energy, were used in order to accumulate sufficient amounts of ions implanted into the substrates. The depth profiles of the implanted ions were measured using the Rutherford backscattering (RBS) method [20] with 1.7 or 2.2 MeV alpha particles. The depth profiles were transformed into ion energy spectra using energy vs. depth dependence [20] calculated for a particular target.

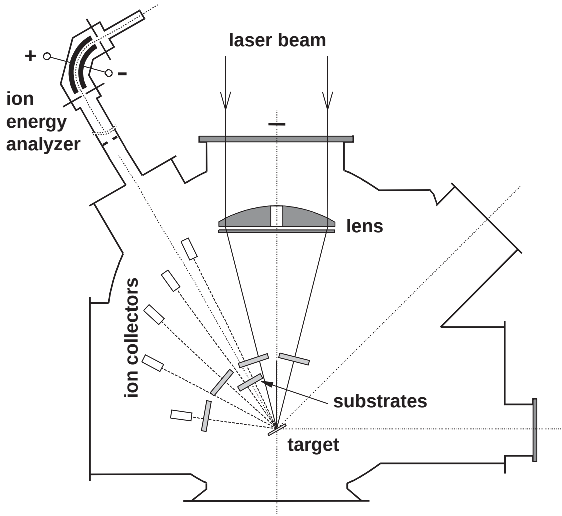

Fig. 1. Experimental setup.