Investigation of Ion Penetration in Silicon during Plasma-Based Ion Implantation

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Abstract – Ion implantation in plasma immersed samples has been applied to surface modification of inner and outer surfaces of 3D metallic and plastic samples, for sterilization of medical equipment, etc. In this paper an evaluation of energy distribution of ions generated during Plasma-Based Ion Implantation (PBII) process based on self-excited N-plasma is studied. The experimentally measured energy distribution of the implanted nitrogen ions was obtained by SIMS deep-profile analysis (specifically by the layer-by-layer ion etching of the target, then bombarding with Cs 2 keV ions and measuring N signal each time). Experimental conditions of the presented study of PBII process are: gas pressure in the technology chambre – 2.4 Pa; pulse voltage (peak) – 15 keV; pulse current (peak) – 3.5 A; pulse width – 5 μs; pulse repetition rate – 300 pulses/s and exposure time - 5min. The energy distribution of the implanted ions, estimated by computer simulation, is almost the inversely proportional of the quadrate of the ion energy (from 2 keV to energy respective to the pulse voltage peak).

1. Introduction

When a negative voltage pulse is applied to a target immersed in plasma, ion implantation and deposition of the plasma species occur. Such technology, called plasma-based ion implantation (PBII) is a rapidly advancing surface-modification technique [1–5], leading in the implantation of the ions into the target over all surfaces at normal incidence [1, 2]. The advantages of that method are: (i) a simplification of needed equipment, (ii) an ability to treat 3D metal or plastic samples (including internal surface) with uniform ion bombardment, which is not possible using the conventional beam-line ion implantation, (iii) an ability to treat grooving thin films and combination of layers, (iv) an ability to obtain a high quality surface modification at room temperatures.

In that way, deposition of carbon coatings including amorphous or diamond like films [1, 3, 4] was proposed. The implantation and the deposition of the films, aiming enhancement of adhesion could be carried out simultaneously or alternatively. Plasma BII is an effective method for modifying the surface characteristics of thin films and mixing layers. This process was applied for modification of polyethylene terapthalate surfaces, specifically for improvement of plastic bottles by creating an oxygen barrier at the same time keeping low processing cost and good recycling [5, 6, 7]. New approach has been studied and implemented for rapid and safer sterilization of medical equipment, instruments and containers [8].

In this paper an evaluation of the energy distribution of ions generated during Plasma BII process based on self-exited N-plasma at application of a negative 15 keV pulse and 2.4 Pa pressure of the nitrogen gas in the technology chamber is given. Due to the not rectangular shape of the applied short negative voltage pulse, the different conditions (specifically shape and plasma density at the plasma boundary) of the extraction of the plasma ions, the difficult evaluation of the plasma density and probably the nonsteady plasma boundary and parameters in the voltage affected plasma region during the time of the ion extraction, theoretical prediction of the ion energy distribution at Plasma BII process is difficult to be made. We used an experimental evaluation, based on SIMS deep analysis of the implanted nitrogen atoms (penetrated ions) distribution in a well studied material such as silicon. Si targets were immersed in the plasma and treated by Plasma BII process, which is identical to the plastic bottles treatment or the medical sterilization by N ions.

2. Experiment

The scheme of the PBII apparatus is given in ref. [5]. The chamber is electrically grounded. Its dimensions are 450 mm in height, 590 mm in width, and 470 mm in depth. In this study the authors examine the PBII case at which the target is enshrouded in self-excited plasma, generated by applying a high negative voltage to the target. The ions extracted from the gas discharge plasma bombard the target at normal incidence with high energy, providing effective and uniform ion implantation of the target with ionized gas particles.

A water cooled stainless-steel electrode (substrate) insulated from the chamber supports the silicon samples at the center of the chamber. The target chamber was evacuated to a base pressure of $7.0 \cdot 10^{-4}$ Pa using a diffusion pump. The gas pressure of order 2–3 Pa was maintained during the ion bombardment. The substrate was cooled to room temperature (about 20 °C) during processing. A summary of the experimental conditions is shown in Table 1.

Table 1. Experimental conditions

Sample	1	2	3
Gas	N_2	N_2	N_2
Gas pressure [Pa]	2.4	2.4	2.5
Pulse voltage [kV]	15	12	8
Pulse current [A]	3.5	2	1
Pulse width [μs]	5	5	5
Pulse rate [pps]	300	300	300
Exposure time [min]	5	5	5

The gas pressure used was chosen as a compromise of the discharge impedance, permitting to apply a higher peak voltage at big enough ion current (the maximum voltage modulator current was 10 A). The gas used – Nitrogen, is chosen because this gas is used during investigations for modification of plastic films [7] and ion sterilization [8].

3. Results and discussions

Fig. 1 shows SIMS deep profiles of the implanted N^+ ions in the silicon targets. The sample bombardment for that analysis was done using Cs ions with energy 2 keV and current 140 nA for approximately 2000 sec. The attenuation down of the N^{14} concentrations is in a quality agreement with the voltage peaks of the used negative pulses for respective samples. In purpose to evaluate the ion energy distribution of the bombarding ions we simulate the ion penetration, using our well-tested computer code TRIMVD [9, 10].

Fig. 2 presents two energy distributions (curve 1 and curve 2) of the implanted nitrogen particles, which show results that are similar to the experimentally observed deep profile (see Fig. 3). It could be seen, that evaluated ion energy distribution is approximately:

$$\frac{\Delta N}{N}(E) \approx \frac{N}{E^2},$$

where E is the ion energy, N is the total ion number.

The shown features (the character of which is not well demonstrated) at the higher energy tail-end of the energy distribution curves (shown in Fig. 2) could result from the time dependent plasma boundary shape and place, as well as from the plasma density, the implantation of molecular ions N_2^+, or from the channeling effect.

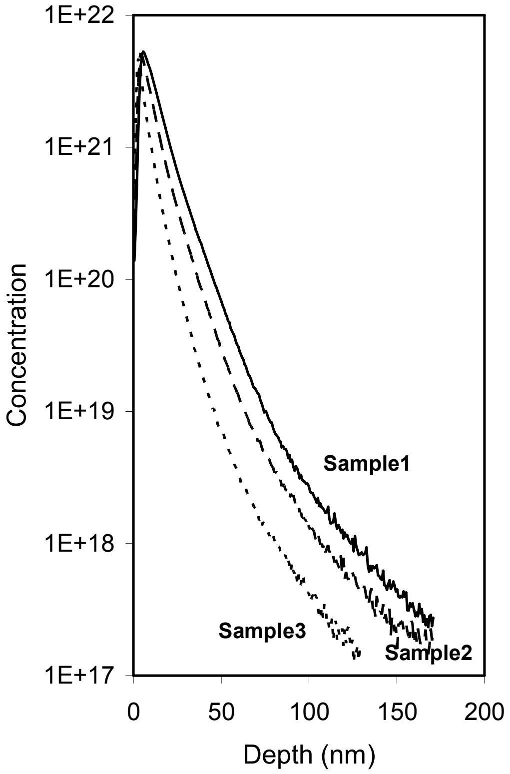

Fig. 1. SIMS deep profiles of the implanted N^+ in three samples at the conditions shown in Table 1

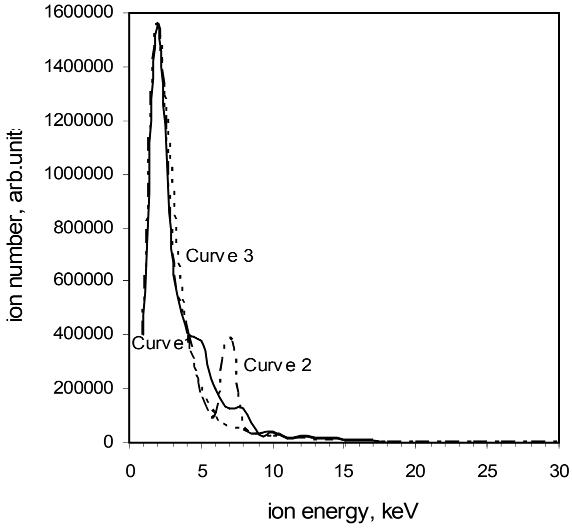

Fig. 2. Energy distributions of the implanted nitrogen particles for pulse voltage 15 keV. Curve 3 presents N/E^2 for $E \geq 2$ keV

4. Conclusion

A pulse voltage with negative polarity was applied to a target, which was in a target chamber on a water cooled sample-holder. The grounded chamber was filled with Nitrogen gas of pressure 2.4 Pa. Self-ignited abnormal glow discharge plasma is generated around the target, which was the plasma source for ion extraction and implantation. These ions had energy distribution inversely proportional to the E^2, (in the region from about 2 keV to the energy, corres-

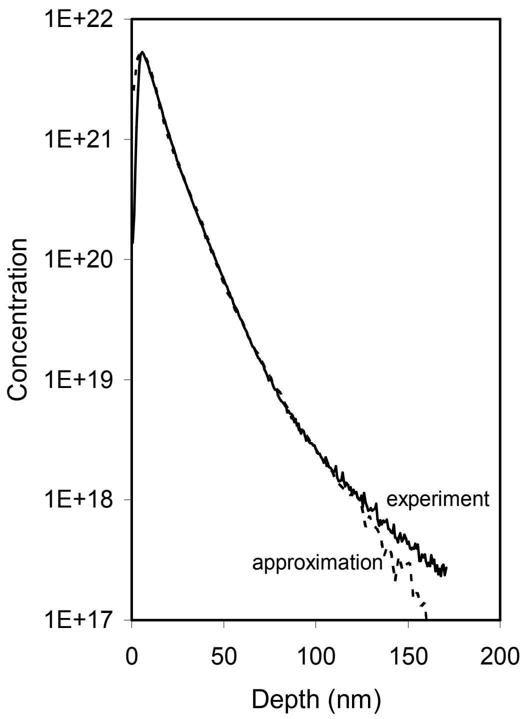

Fig. 3. Comparison between experimental data for sample 1 and calculated results using data presented by curve 1 and curve 2 from Fig. 2

ponding to the peak extracting voltage 15 keV) which is typical for a glow discharge cathode bombardment. The evaluation was done through SIMS deep profiling and computer simulation of penetration of the ions with suitable energy distribution.

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