OPTIMIZED THIN FILMS DEPOSITION SYSTEM

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Abstract: A thin films deposition system using a combination between magnetron sputtering deposition technique and deposition from hydrocarbon gases in rf discharge (glow discharge) is presented. The installation was developed in Bacau University laboratories in order to optimize the deposition process. With the studied system, the high energy of the substrate incident species, specific to sputtering deposition, is combined to the high methane decomposition from glow discharge process.

Keywords: magnetron sputtering, plasma, glow discharge

1. INTRODUCTION

The development of protective thin carbon films exhibiting low friction coefficients, high wear and corrosion resistance, and excellent optical transparency is of great importance to several leading technologies, such as hard disk drives and microelectromechanical devices. Various deposition techniques and characterization methods have been used in previous studies dealing with the growth mechanisms and mechanical properties of amorphous carbon (a-C). Among the different film deposition techniques discussed by Lifshitz [1] such as ion beam, cathodic (vacuum) arc, pulsed laser ablation, ion assisted evaporation and sputtering deposition techniques, filtered ion beam and cathodic arc depositions are especially suitable for producing high-quality carbon films. Nevertheless, sputtering of thin a-C films is the most common technique for high-volume production in various industries, such as magnetic heads and hard disks for high-density proximity recording.

Common to all these methods is the deposition of a-C from particles whose energy is within the range of about 100 eV up to several kilo-electron volts. It appears that the most critical process parameter determining the film properties is the ion bombardment occurring during deposition. Different models for describing the interaction of energetic ions with the amorphous network, such as preferential sputtering or displacement and the subplantation model, have been suggested [2]. In addition to sputtering technique, which is capable of providing the requisite high energy density during film, deposition from hydrocarbon gases in rf discharges has also become widely used. During growth, the layers are subjected to ion bombardment controlled by the potential drop between the plasma potential and the negative dc bias voltage (V_b) at the film surface. With increasing bombarding energy the film transforms from a soft polymer-like (V_b<100 V), to a hard diamond-like (100 V<V_b<600 V) and finally to a soft graphite-like (V_b>600 V) material [3].

The process of thin film deposition by sputtering comprises three main stages: (a) sputtering of film-forming materials from the target surface, (b) transport of sputtered atoms (or clusters of atoms) through the target–substrate space, and (c) adsorption of film-forming precursors and film growth on the substrate surface. Consequently, to study the dependence of the growth and mechanical properties of thin *a*-C films on the radio frequency (rf) sputtering deposition conditions, it is essential to study the characteristics of low-pressure rf discharges and the effects of rf power, working pressure, substrate bias voltage, and substrate surface temperature on the film deposition.

In this work, we study an optimized deposition process, using a combination between magnetron sputtering deposition technique and deposition from hydrocarbon gases in rf discharge (glow discharge).

2. EXPERIMENT

Hydrogenated amorphous carbon films were deposited by combined magnetron sputtering /glow discharge technique, using a pure graphite target, 7.5 cm in radius and 99.99 % pure Ar/CH_4 gas mixture. The magnetron installation shown in fig.1 was built in our laboratory in order to deposit thin films by dc and rf planar and circular magnetron sputtering. In an unbalanced magnetron, the plasma extends over both the target and the substrate, so that the Ar ions provide both the sputtering flux to the graphite target and the ion plating flux on the growing film. The energy and the flux of the ions (mainly Ar^+ and CH_n^+) reaching the growing film surface was varied by applying an external bias voltage (from –400 V to +400 V) to the substrate. The plasma must also decompose the methane gas, for a better hydrogenation of films and a major contribution of glow discharge process in the film growth. A high flux of neutral C atoms is achieved by placing the magnets as close as possible to the graphite target. The configuration of the magnetic field is a critical parameter controlling the deposition rate and the ion plating intensity and is a particular property of the magnetron.

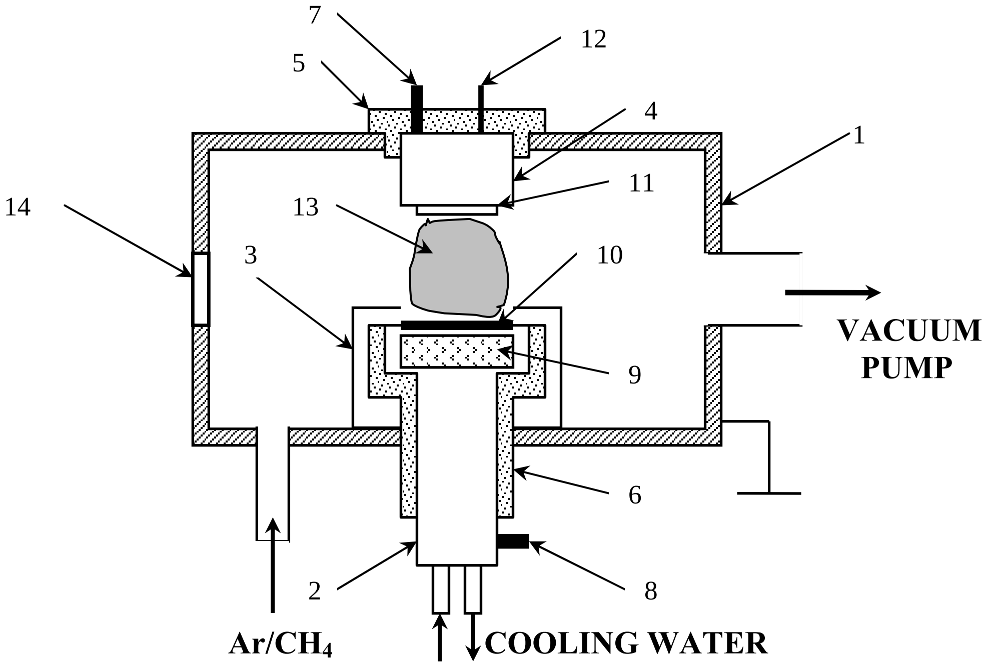

Fig.1. The deposition system: 1-cylindrical stainless-steel chamber; 2-cathode; 3- circular anode; 4-planar anode; 5,6-isolators; 7,8-electrodes; 9-magnets; 10-target; 11-substrate; 12-temperature sensor; 13-plasma; 14- window

The deposition system is shown in figure 1. The deposition chamber (1) is made from stainless-steel material and has three observation windows (14). A window is used for spectroscopic plasma analysis. Inside, we find a magnetron cathode (2) and two anodes, a circular one (3) and a planar one (4), who also is the substrate (11) holder. The stainless-steel cathode (2) is water-cooled and contains a magnet system (9). The graphite target (10) is in electrical contact with cathode surface. The plasma discharge is powered by a rf source at 13.56 MHz coupled at electrode (8) and is controlled by a stabilized dc power supply with maximum ratings 500 V and 140 mA connected at electrode (7). The dc power supply is used to negative or positive substrate polarization.

The volumetric proportion between Ar and methane was maintained constant at 1/1. The pressure during deposition was between 0.2 and 0.01 Torr. The substrate temperature remains below 100°C for all samples. During deposition the substrates are partially masked so that thickness measurements can be made by Tolansky instruments. The reactive radicals in plasma were identified and analyzed by optical emission spectrometry (OES).

The obtained films are transparent, smooth, colorless for high deposition pressures and soft yellow for less deposition pressures. For positive substrate polarization the color is varying to dark brown or black. The thinner films (bellow 1 micron) exhibit a good substrate adherence. For thicker films, the adherence is bad because of the internal intrinsic stress.

The main deposition parameter is the substrate polarization potential because of the control on the energy of the substrate incident species with direct influence on the deposition rate and physical properties of the films.

3. RESULTS AND DISCUSSION

First, we present the discharge parameters. Figure 2 shows the I-V discharge characteristics for three different gas pressures in 1/1 Ar/methane atmosphere. As we see, the system acts like a diode, with a high increase of the current density when the positive substrate bias increases. Indeed, the films deposited in these conditions are nontransparent, with a dark color, because of the backsputtering process (the sputtering of the substrate deposited material because of the high bombardment).

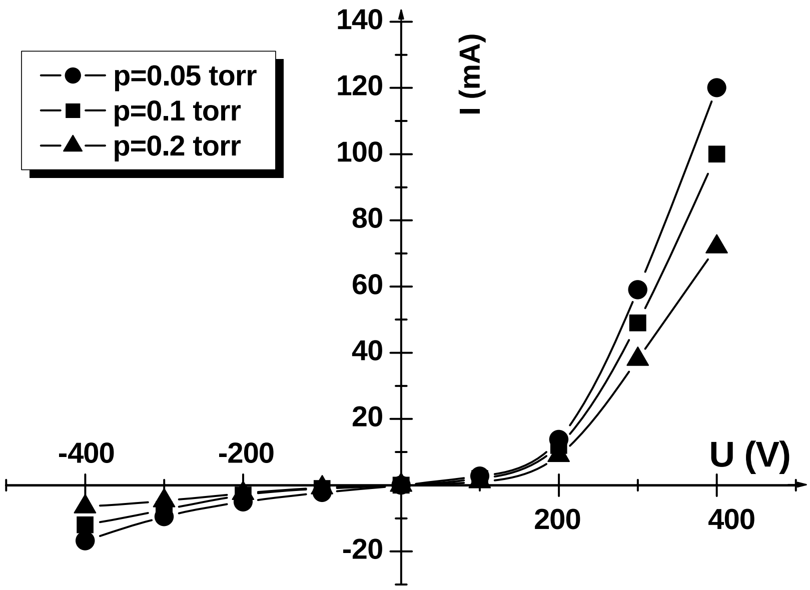

Fig.2. I-V discharge characteristics for three different gas pressures in 1/1 Ar/methane atmosphere

An other deposition system main parameter is the dependency between the discharge power, for a given constant radiofrequency signal, and the discharge pressure. In Figure 3 the dependencies are presented for three different substrate biases. The increase of the substrate bias lead to a slow increase in discharge power because of the electric field produced by the anode-substrate applied potential. When the deposition pressure increase, the discharge power decrease because of the increasing of the plasma interactions.

The deposition rate is an important parameter for method and installation evaluation. Figure 4 shows the dependence of deposition rate on the deposition gas pressure, for three different bias voltages. A rf power between 70 W for 0.01 Torr gas pressure and 40 W for 0.2 Torr gas pressure was used. The value of the discharge power was imposed by the gas pressure, for a constant rf signal generated by the source. The dc power for –200 V bias voltage was 3 W and 6 W for +200 V bias voltage. The deposition rate decrease with rising pressure and the shape of curve is given by the variation of discharge power. This variation of deposition rate with pressure is different from that found for a-C:H deposited from glow-discharge, where the growth rate increase when the gas pressure increase [4]. Figure 5 illustrates the increase of the deposition rate proportionally to the rf discharge power.

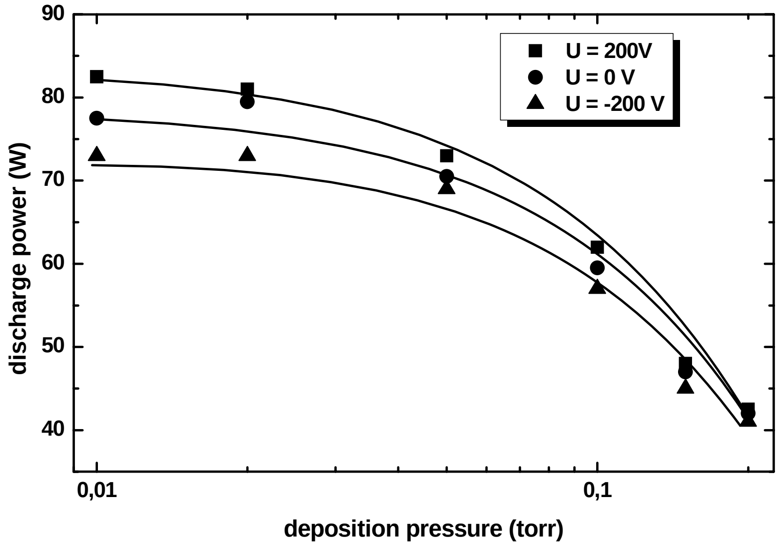

Fig.3. Dependence of the discharge power on the deposition pressure, for three different bias voltages

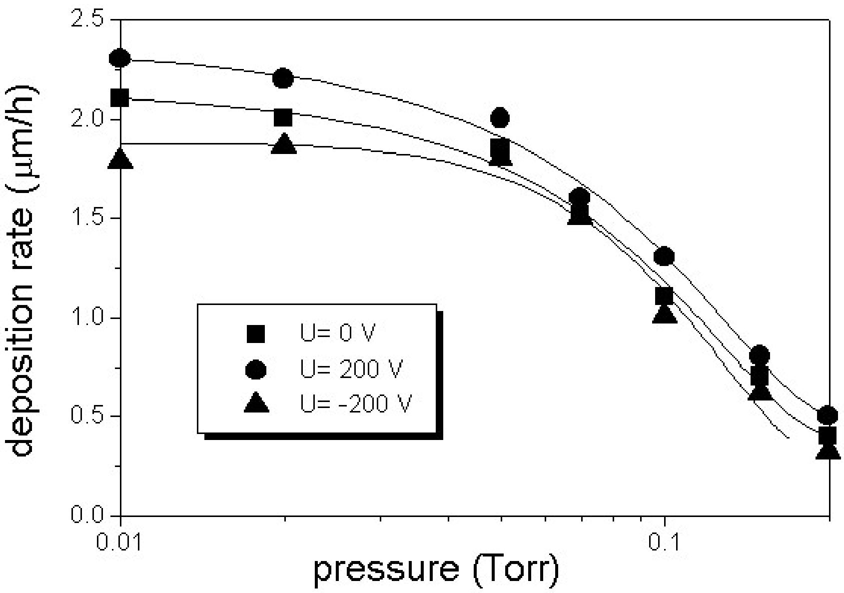

Fig.4. Dependence of deposition rate on the deposition gas pressure, for three different bias voltages

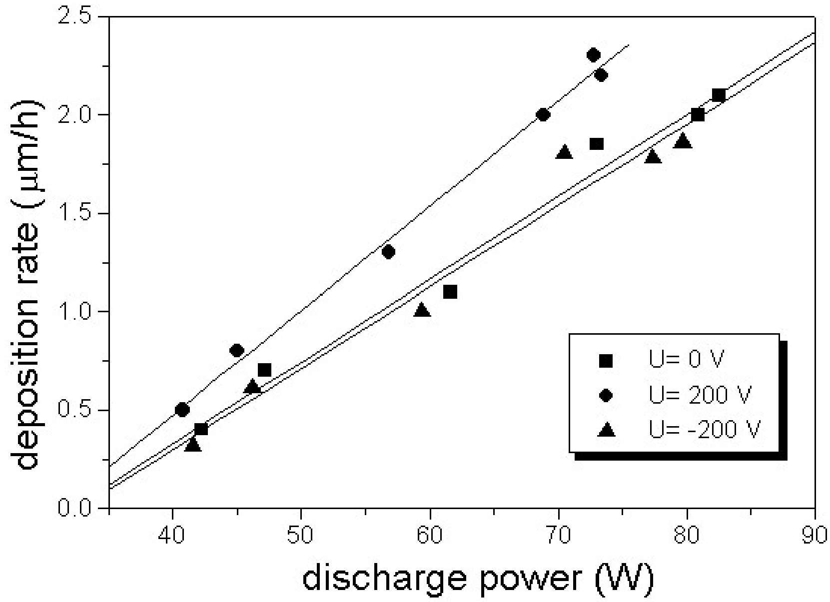

Fig.5. Deposition rate depending on discharge power

Figure 6 shows an increasing of growth rate with increasing bias voltage. The dc power increase from 0 to 40 W for positive biasing and from 0 to 8 W for negative biasing. We explain this increasing of the deposition rate by two effects: (a) for positive bias on the substrate, the combined rf - dc power of the discharge increase when bias voltage increase; (b) for negative bias on the substrate, the backsputtering yield increases according to Sigmund's theory [5] proportional to bias voltage. This is in contradiction with the results found for films prepared by rf plasma decomposition of hydrocarbon gases [6], but, in the rf plasma decomposition method, the negative bias on the substrate increases with the rf power. The rising of deposition rate in this case is determinate not by the increase of negative bias, is determinate by the increasing of rf power.

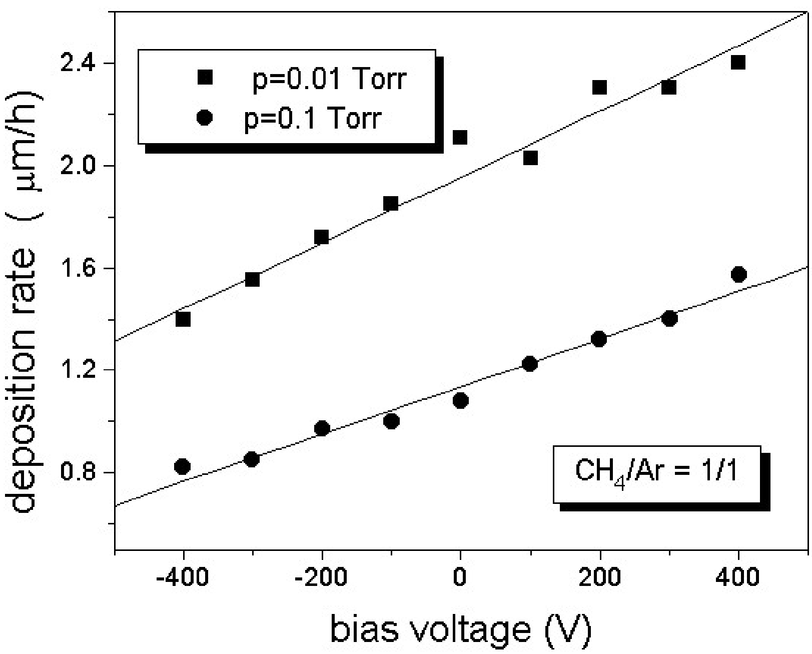

Fig.6. Deposition rate depending on bias voltage

The experimental results obtained for deposition rate using rf magnetron sputtering are similar with results obtained for pulse laser deposition [7] or by hot-filament chemical vapour deposition [8] and greater than usual values indicate for rf plasma decomposition, 0.3 μm/h-0.8 μm/h [4, 9, 10]. In the work [11] greater deposition rates are reported for amorphous carbon deposited by magnetron sputtering, but with greater discharge powers and lower deposition pressure.

4. CONCLUSIONS

A thin films deposition system using a combination between magnetron sputtering deposition technique and deposition from hydrocarbon gases in rf discharge (glow discharge) was presented. With the studied system, the high energy of the substrate incident species, specific to sputtering deposition, is combined to the high methane decomposition from glow discharge process. The discharge parameters that can be modified in order to find the optimum deposition conditions are the pressure, substrate bias voltage and discharge power. The higher deposition rate is obtained for high discharge powers, low pressures and high positive biases, but the films quality decrease when the substrate bias increase. In conclusion, the best quality/growth rate ratio is obtained for films deposited at 0.01 torr, with 70-100 W discharge bias and below 200 V substrate bias.

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