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Hall current accelerator for pre-treatment of large area glass sheets

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Abstract

A large aperture Hall current accelerator has been developed for cleaning glass sheets before vacuum arc deposition of decorative layers. Hall current source advantages towards Kaufman's one in industrial processes are emphasized. Source 'sputter profiles' are given for silica glass and poly(methyl metacrylate). Sputter cleaning of aluminum has been characterized in terms of roughness and microhardness variation.

Keywords: Plasma processing; Aluminum; Glass; Sputtering; Polymers

1. Introduction

Ion beam processing has become an established method for surface treatment [1]. It includes techniques like sputtering, thin film deposition or ion implantation. Though the principle is the same in all cases [2], a given application requires a specific source design according to the ion energy range and uniformity needed. In glass coating technology, substrate cleaning before coating is of particular importance for the quality of the further deposited layers, especially for their adhesion and corrosion resistance. Ion beam sputter cleaning proved to be an efficient method to produce high quality coatings on glass, metal and plastic sheets. For sputtering purposes, Kaufman sources [3–5] are usually chosen. These sources are very attractive in the sense that a neutralized beam is generated with the ion energy, direction and current density independently controllable. The ion production is also separated from the substrate and target used. This high degree of control and beam uniformity make Kaufman sources very competitive towards plasma processes. However, inherent design considerations limit the use of such sources in production applications [6]. The source cathode and grid optics are critical components which require sometimes an excessive maintenance. The cathode, which emits electrons to ionize the discharge gas, is subjected to erosion due to sputtering by the ionized particles. Depending on the cathode type, the source lifetime ranges from a few 100 to 1000 h. Local heating or the presence of active gases (such as oxygen) reduce dramatically the source lifetime by damaging the cathode. Grid optics, usually a screen grid and an accelerator grid are also subjected to erosion due to the space charge phenomenon or due to the excessive ion beam current. This somehow limits the ion beam current that can be extracted from the chamber. In glass coating applications, the source design must also meet the requirement of a large area treatment.

In this work, a large aperture Hall current accelerator was developed for sputter cleaning of large area glass, metal and plastic sheets. Though less controllable than Kaufman sources, a Hall current accelerator appears better suited to sputter cleaning production requirements [5]. Of greater significance is the lack of any space charge flow limitation on ion current density. Further, the reliability in etching is improved through the absence of any delicate structures like cathode or grid optics. The Hall current accelerator requires little maintenance and sputter cleaning can be performed with active gases such as oxygen, nitrogen and carbon dioxide.

2. Experimental

The Hall current accelerator is shown in Fig. 1 (half view through the middle plane). It has the shape of a very elongated loop. The Hall current accelerator described has a large aperture (1400 mm in the vertical direction) is used it in the multipurpose apparatus 'Nikolay' designed and

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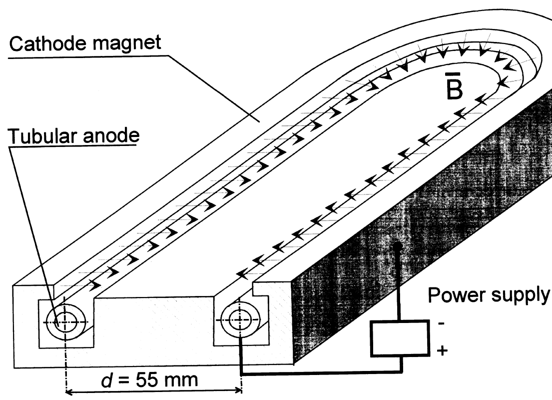

Fig. 1. Hall current accelerator half view.

constructed in SONG Ltd. for deposition on large area glass and plastic sheets by vacuum arc deposition and magnetron sputtering. Generally, such a Hall current accelerator can be used in any apparatus with working vacuum better than 0.1 Pa. The aperture of the Hall current accelerator can be scaled up to 3000 mm without significant changes in design and, therefore, adjusted to a deposition apparatus. The maximum size of the treated sheets in the apparatus 'Nikolay' is 2100×1300 mm. Sheets to be treated are successively transported under the Hall discharge accelerator at a given translation speed, the substrate surface being perpendicular to the ionic flux axis. By changing this speed and the accelerator power, one can control the sputter dose received by the substrate. The sheet is then immediately coated to prevent recontamination. The output capacity for glass is 30 sheets in a production cycle (about 8 h). The source dimensions are 1400 mm in height with a twin aperture made of two slots, 55 mm away from one another. The Hall current accelerator consists of two juxtaposed permanent magnets which act as a cathode. Inside the groove made by the cathode, runs the anode of tubular shape and water cooled. The whole is set under vacuum in the presence of a sputter gas (usually argon). The gas ionization and the subsequent ion acceleration is made through the presence of crossed electric and magnetic fields. The electric field is created by the cathode to anode potential drop whereas a quasi-uniform magnetic field is set between the two pole pieces of the cathode. In the presence of a low pressure gas and the electric field, a glow discharge plasma is initiated. The magnetic field traps the plasma electrons and together with the electric field, causes them to precess circumferentially along the anode surface. Through their cycloid path, they collide with argon atoms and ionize them. The high difference of potential accelerates argon ions away from the anode and towards the substrate to be sputter cleaned. Usual values for the source power are 6 kV and 0.5 A under an argon pressure around 0.01 Pa. The resulting ion beam has an average energy of 6 keV. Therefore, a big progress is achieved since the early Hall current source of 10 cm aperture and ion beam energy of 50–75 eV was designed and fabricated [5]. It has been already quoted [4] that due to the unusual electron movement in Hall current accelerators, a greater energy spread, compared to Kaufman source, should be expected in the accelerated ion beam. This increased energy spread results from both charge exchange and plasma fluctuations.

Though sputter requirements are less demanding in decorative glass industry than in microelectronics, the 'cleaning profile' of the source has to be known in order to estimate the sputter dose received by the substrates. A simple method was used to derive the source cleaning profile. Samples 200 mm wide of silica glass and poly(-methyl metacrylate) were sputter cleaned fixed to the source for different exposition times. Before cleaning, pen marks lines were drawn at a regular spacing interval on the sample surface. The pen marks provide masking against sputter cleaning of the sample surface. After cleaning treatment, they were removed with alcohol leaving a step between the sputtered and non-sputtered parts. The step height was measured using a Taylor–Hobson profilometer. The measures along the width of the sample give the cleaning distribution of the source for a given exposition time.

The source was also characterized with aluminum samples. Cold rolled Pechiney 5182 Al alloy was used containing 4.65 wt.% Mg, 0.37 wt.%, 0.03 wt.% Cu, 0.25 wt.% Fe and 0.1 wt.% Si. In this study, the cleaning distribution was derived from microhardness measurements. $200 \times 100 \times 0.24$ mm aluminum strips were sputter cleaned fixed to the source for different exposition times. Each sample was divided into ten smaller strips 20 mm wide. The initial microhardness was measured. After sputter cleaning, an average microhardness value was computed for each of the 10 strips giving the profile of microhardness variation. Samples in both studies were placed 300 mm away from the source. Hence it gives conservative measures for the glass treatment as it corresponds to the furthest glass position from the source.

3. Results and discussion

Cleaning profiles are shown for silica glass (Fig. 2) and

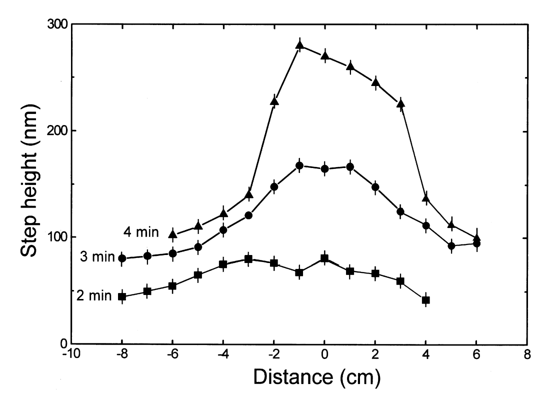

Fig. 2. Source cleaning profile for poly(methyl metacrylate). The experimental points are connected with the guidelines for the eye.

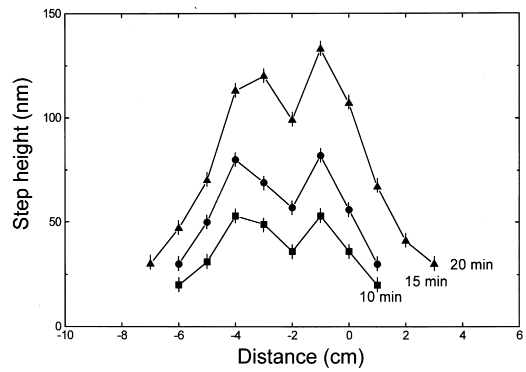

Fig. 3. Source cleaning profile for silica glass. The experimental points are connected with the guidelines for the eye.

poly(methyl metacrylate) (Fig. 3). As would be expected, the profile depends on the material cleaned because silica glass and poly(methyl metacrylate) have different behaviors towards sputtering. Poly(methyl metacrylate) has a lower thermal resistance compared to silica glass. Sputtering times beyond 5 min lead to poly(methyl metacrylate) deterioration. Below this value, the material is sputtered at a maximum rate of a 100 nm/min (Fig. 2). Some reaction occurs with the sample as the surface is covered with a slightly brown layer. The cleaning distribution for organic glass is not simple as a combined physical and thermal sputtering seems to take place. As time is increased, the band of maximum sputtering is getting narrower down to around 20 mm. Silica glass has a more reproducible cleaning profile with time (Fig. 3) than poly(methyl metacrylate). The main difference is the appearance of two distinct peaks in the distribution. The twin construction of the source can hence be resolved in the cleaning profile of silica glass. In the region of maximum sputter cleaning (corresponding to the two peaks), the sputter rate for glass is 7.5 nm/min. For silica glass, longer times are needed to obtain significant and measurable steps. The sputter cleaning of two materials of interest showed that the source cleaning profile is highly non-uniform and material dependent. The source profile for organic glass is difficult to interpret as the ion bombardment produces a combined effect of physical and thermal sputtering on the low thermal resistance polymer. Material deterioration similar to the damage induced by ionizing radiation can be expected [7].

The source cleaning profile for glass shows a distribution in agreement with the twin aperture source design. In the first approximation, the source profile can be modeled with a two-peaks Gaussian profile distribution. At a distance of 300 mm away from the source, the spacing between the Gaussian peaks (30 mm) is smaller than the distance d between the axes of elongated parts of the anode loop (Fig. 1). This shows that the source beam is convergent and that a complete beam description would imply the derivation of the source cleaning profile for different distances from the source. As far as the process is concerned, silica glass substrates, when cleaned, are moved relative to the source at a given translation speed. It ensures a uniform cleaning treatment over the glass panel surface. An estimation of the layer sputtered when moving at a given speed can be obtained by integrating the cleaning profile (expressed in cleaning rate units, e.g. nm/min) along the source width. For the speed range used in the industrial process, the silica glass sputtered layer varies from 13 nm at low speed to 0.6 nm at high speed. At the most widely used speed, the thickness of the removed layer is 2 nm.

Aluminum samples observation after treatment shows a change in the surface finish at the location of maximal sputtering. This 60–80 mm wide area is spotted by a light reflection change, the surface being less reflective in this central part. The roughness in this area is lower than on the edges. For 8 min sputter treatment, the roughness falls down from 400 to 250 nm. The cleaning provides a fine polishing of the surface. This application of sputtering is well known and has been already used for the finishing of optic glasses or the removal of scratches and surface strains after machining of metals [8–10]. For reasonable times (8 and 10 min), a very thin sheet of aluminum looses its initial flatness and distorts itself due probably to the combined effect of substrate heating and relaxation of internal stresses by the partly removal of the superficial layer. Microhardness measurements show a maximal decrease in microhardness of about 40% (initial microhardness of the 5182 alloy is 100 HV). Increasing exposition time does not lower the microhardeness but widens the area of maximal relative change as shown in Fig. 4. For comparison, annealing of the 5182 aluminum alloy was done at different temperatures (200, 300 and 400°C) during 4 and 8 min. The measurements directly after treatment show a 30% decrease in the microhardness for samples annealed at 300 and 400°C. The ones annealed at 200°C did not encounter any change in the microhardness. This softening with temperature is related to the dissolution of β phase precipitates. For an Al–5 wt.% Mg alloy, the dissolution occurs at 260°C which explains that no variation was measured for the samples annealed at 200°C [11]. Cleaning of pure aluminum (99.999 wt.%) does not show any decrease in the microhardness. Annealed samples indi-

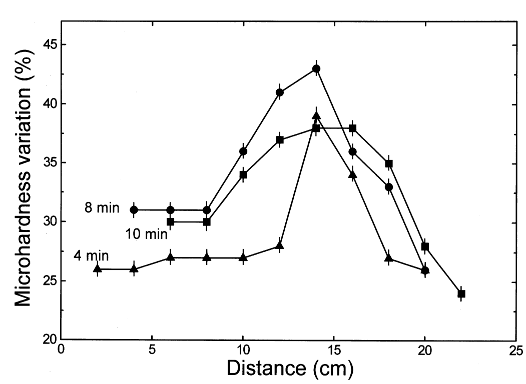

Fig. 4. Source cleaning profile in terms of microhardness variation for Al alloy 5182. The experimental points are connected with the guidelines for the eye.

cate that the microhardness variation is mostly due to temperature elevation. The sputtering of the superficial layer induces a little change in the overall microhardness variation.

4. Conclusions

A large aperture Hall current accelerator was presented. The absence of any lifetime critical components make it very attractive for industrial applications in comparison with Kaufman sources. Little or no maintenance is needed and active gases such as oxygen and nitrogen can be used for sputter cleaning. The source sputter profile under argon was determined for silica glass and poly(methyl metacrylate) treated 300 mm away from the source. In both cases, the cleaning distribution is highly inhomogeneous and presents only a narrow area of maximal sputtering. Poly(-methyl metacrylate) has a cleaning rate 13 times higher than silica glass. For this material physical sputtering is supposed to take place simultaneously with thermochemical reaction of the surface. The cleaning profile cannot be simply interpreted whereas for silica glass the two-peaks distribution induced by the twin aperture source can be resolved. Though this type of characterization does not give the full source behavior, it enables to give an estimate of the sputtered glass layer when the substrate is moved relative to the source at a given speed. Sputter cleaning of Al alloy 5182 induces a polishing effect of the substrate surface and a 40% decrease in the microhardness value. Increasing exposition time allows heat propagation towards the edges of the sample thus widening the area of microhardness variation without inducing a further decrease in the microhardness value.

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