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Polyimide surface modification by linear stationary plasma thruster

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ABSTRACT

Compared to the conventional circular type, the horse-track shaped proto-type linear stationary plasma thruster (LSPT) was designed and fabricated. A cathode with LaB6 emitter was adopted for trapped electron motion along ceramic wall as an electron source generally attached in the conventional cylindrical SPT. Nevertheless it has a little lower ion beam current density of 0.5 mA/cm^2 than conventional cylindrical type SPT with 50 mm diameter, it was also proved very effective in surface modification of polymers. Reactive O_2^+ and N_2O^+ ion beam generated from LSPT can reduce the wetting angle 70° of polyimide (PI) down to the small angle less than 10°. 2-layer non-adhesive flexible copper clad laminate (FCCL) with Cu(8 μm)/Cu(200 nm)/Ni–Cr–Mo (20 nm)/PI(38 μm) was fabricated by using LSPT in 300 mm roll-to-roll vacuum coater. Peel strength was 0.66 kgf/cm for as-received sample and 0.42 kgf/cm after thermal test for 168 h at 150 °C, which shows a little higher performance than commercial ones.

1. Introduction

As the number of output channel of IC for LCD monitor with high resolution UXGA is increased, the pitch size of chip on flex (COF) for tape carrier packaging (TCP) to electrically connect active electronic devices is highly required to be smaller than 30 μm for inner lead bonding and 50 μm for outer lead bonding respectively. Non-adhesive flexible copper clad laminate (FCCL) has been adopted as base substrates for COF with high density pitch and fabricated through vacuum sputtering and subsequent electroplating [1,2]. Flexural endurance and long-term reliability of FCCL acting as an electrically connector fundamentally rely on the peel strength of FCCL which is inherently related to adhesion between Cu and PI [3,4]. There have been studies for both improving the adhesion and investigating the chemical bonding mechanism between metal and polyimide surface [5,6]. In the sputtering process, the PI film surface is usually treated by O_2 or N_2 plasma and then subsequently a thin tie layer with thickness below 20 nm such as Ni or Ni alloys and Cu seed layer as much as 150–200 nm are deposited over the PI films. Compared to DC or RF plasma treatment methods, low energy ion beam irradiation in reactive gas environments was reported to be able to change the polymer surfaces into hydrophilic. In particular, direct irradiation of reactive ion beam generated from stationary plasma thruster (SPT) was very efficient for altering PI and PVDF (polyvinylidene difluoride) into superhydrophilic within a few seconds [7,8]. Such a high speed surface modification was considered to result from impinging critical ion beam power (the product of ion beam voltage and current) for surface modification due to its high ion current density. Another advantageous point is that SPT doesn't induce much surface damage due to lower average ion beam energy than 200 eV and invoke surface charging due to self-neutralizing effect by electrons propagating away from the anode's ion acceleration region. From the reference [9], surface wettability was greatly enhanced by reactive ion irradiation than noble gas like argon. That result was closely related to the increase of hydrophilic functional groups on the surface originated from chemical reaction between broken bonds by ion irradiation and active radical ion species. Conventional circular type SPTs with symmetric beam divergence have some limitation in enlarging the beam size, thus they are needed to extend discharge region for large surface modification. In our proto-type SPT conventional circular closed drift region is extended to have horse-track shape. And various gases are able to be discharged as circular type SPTs [7,10]. The objectives of this research are the studying of both the plasma parameters of linear SPT (LSPT) such as plasma density, ion beam current density, and so on, and the feasibility for large area polymer surface modification using LSPT. As one of application, FCCL structured with Cu(8 μm)/Cu(200 nm)/Ni–Cr(20 nm)/PI(38 μm) was fabricated by using LSPT in 300 mm roll-to-roll system and its peel strength was examined.

2. Experimental

2.1. Design and diagnostics of LSPT

Components of linear closed drift ion source are the same as circular one. As shown in Fig. 1, there are 4 main parts; cathode, anode, ceramic channel, and electrical magnetic system [7,10]. Components of linear closed drift ion source are as follows: (1) a cathode with lantanium-hexaboride (LaB_6) emitter, (2) anode which has a role of a gas distributor, (3) a ceramic channel where main ionization and acceleration processes

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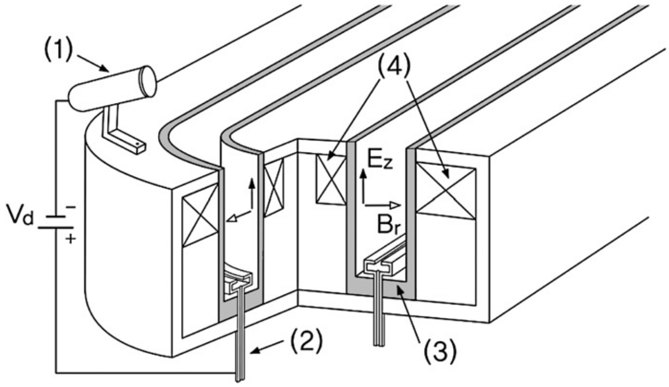

Fig. 1. Schematic cut view of linear stationary plasma thruster. (1) Cathode, (2) anode, (3) ceramic channel, and (4) electromagnet.

take place, (4) a magnetic system consisted of iron magnetic line guide and magnetic coils, which is operated in series with a main discharge.

The plasma is discharged from potential difference V_d between the anode and cathode. Prior to discharge of the main plasma between cathode and anode, cathode discharge is ignited with LaB_6 powder propulsion and high voltage bias of 1.7 kV. Due to radial magnetic field from magnetic coils and electric field from biased anode, electrons move along ceramic channel via $\vec{E} \times \vec{B}$ drift motion. The region inside ceramic channel is called as closed drift region. The ceramic wall has another important role of generating low temperature secondary electrons by collision of electrons and ions with itself. Extended and gradual acceleration process takes place in ceramic channel by low temperature electron and this is the reason why this ion source is called as an ion source with closed drift and extended acceleration region [11]. Gas from gas distributor is ionized by trapped electrons in ceramic channel. Ions move toward outlet and are accelerated due to potential gradation from anode. To discharge plasma along horse-track shape ceramic channel it is essential to generate uniform magnetic field. It is generally known that a performance of closed drift ion source is optimized under a magnetic flux density B_m from 100 G to 200 G. With carefully wounded magnetic coils around iron magnetic field guide it is measured that magnetic field is from 80 G to 105 G across ceramic channel. In that range of magnetic field strength gyro radius 1–2 mm of electron is much less than the length of discharge gap L (distance between inner wall and outer wall inside ceramic channel, about 2 cm) and that of ion is much longer than L. Gas injection system is also fabricated to uniformly flow discharge gas across overall closed drift region. To measure a performance of the SPT source two diagnostic systems were mounted. One is Langmuir probe system which is able to obtain data such as electron temperature, electron density, and plasma potential. Another is Faraday-cup measuring ion beam current density. Main vacuum chamber is initially pumped down by the base pressure of 8.6×10^{-4} Pa using a turbo molecular pump. Plasma discharge and ion beam extraction are carried out at the working pressure from $4–5 \times 10^{-2}$ Pa for Ar, O_2, and N_2O discharge.

2.2. Fabrication of FCCL using roll-to-roll system

As shown in Fig. 2, the roll-to-roll vacuum coater consisted of ion beam surface modification port, unwinding roll, main chilling drum with effective coating area of 300 mm, and 4 magnetron sputter cathodes. This chamber was initially pumped down by the base pressure of low 10^{-4} Pa using a turbo molecular pump and polymer irradiation was carried out at the working pressure from high 10^{-2} Pa to low 10^{-2} Pa. And the roll speed is 0.5 m/min and 0.75 m/min. As a substrate for FCCL, Polyimide (PI) film (Kapton-EN, 38 μm) was used. For tie and seed layer, Ni–Cr (20 nm) and Cu (200 nm) were sputtered in succession respectively. Afterwards thick Cu layer was electroplated up to 8 using vertical type electroplating system (SP-tech). Peel strength of FCCL was examined by 90° peel test (Shimatsu, AG-150) at 50 mm/min speed.

3. Results and discussion

3.1. Diagnostics of linear SPT

Plasma is ignited with a discharge voltage of 90 V and a discharge current of 2.8 A in case of Argon gas and 2.6 A in oxygen. Discharge current is proportional to discharge voltage for both gases and increases up to 16.3 A in Ar and 15.6 A in oxygen at the discharge

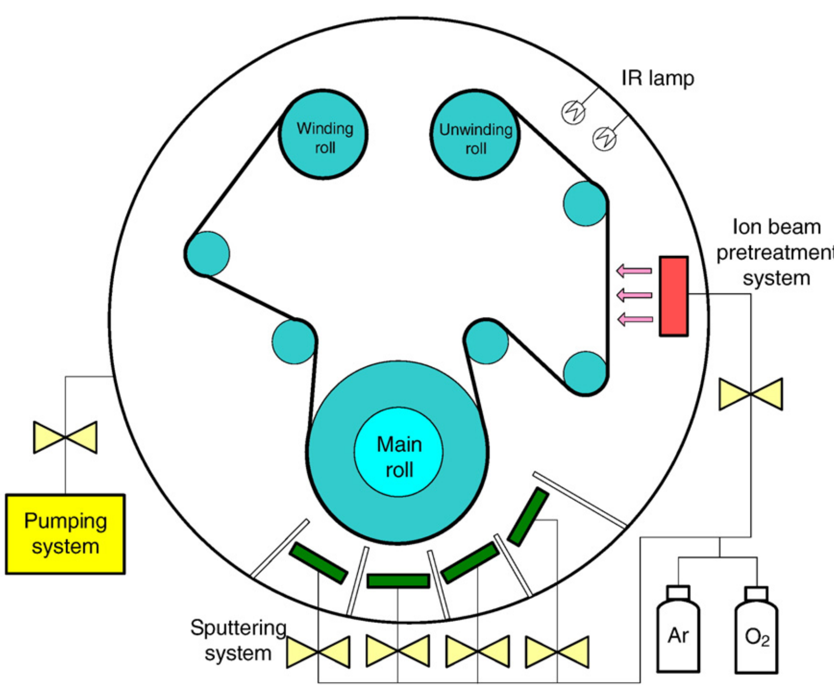

Fig. 2. Schematic diagram of roll-to-roll vacuum coater.