Applications of High-Power Built-in Plasma Gun

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Introduction

Recently, in the optical thin-film market, customers are increasingly demanding low price and high quality in optical components incorporated in home electric and electronic appliances. To meet these demands, advanced equipment such as our high-density reactive ion-plating system has started to contribute greatly to forming high-quality thin films in a wide variety of industrial areas.

In addition to the demands for introduction of new systems, there has been a gradual increase in another need to modify the existing vacuum-deposition systems to enhance the film qualities (resistance to environmental change, adhesion, and hardness). In this context, the recognition that the ion/plasma technology is indispensable for creating high-added-value thin films is widening.

Achieving both low-price and high-quality optical components is a hard challenge. However, if the technology that adds high value to films is combined with large equipment that provides an enormous throughput per batch (for example, 1800 mm diameter equipment), it is possible to meet the market needs for low-price and high-quality optical components to a considerable extent.

In this context, JEOL has developed a new, built-in plasma gun, the BS-80010 (**Fig. 1**). The BS-80010, designed based on our existing 3 kW built-in plasma gun EPG-3010, features 6 kW plasma output. This development was done with a view to finding applications for large equipment.

Outline of High-Power Built-in Plasma Gun

The new, high-power built-in plasma gun uses the same operating principle as the existing EPG-3010 that has a 3 kW plasma output. **Figure 2** shows a schematic diagram of the BS-80010. First, the argon plasma is generated inside the plasma gun by the direct-current discharge of thermoelectrons emitted from the tungsten filament. The electrons in the plasma are accelerated by the electric field generated by the extracting electrode (anode) and introduced into the vacuum chamber. These electrons irradiate evaporated particles and the introduced argon gas inside the vacuum chamber, efficiently exciting and ionizing them. At the maximum power output rating, the discharge voltage and current are 160 V and 38 A.

Introducing the electron beam into the vacuum chamber diffuses the plasma widely inside the chamber and thereby high-density plasma is generated over the chamber interior. In addition, it is possible to select the direct-beam method or spiral-beam method by changing resistors A and B, which are connected between the chamber walls and extracting electrode.

Irradiation-beam method

In this method, electrons flow into grounded surfaces of the vacuum chamber walls. It can achieve highly efficient ionization. This method is useful for ion-plating substrates with metallic films because it can continue to provide stable discharge while maintaining the conductivity of the grounded surfaces of the chamber walls.

Reflection-beam method

In this method, the reflected electrons flow to the extracting electrode (anode) (**Fig. 3**). That is, the electrons are not only introduced into the vacuum chamber, but also returned to the electrode. During this process, the extracting electrode heats due to the current that flows to it, and this heat cleans its surface. This process can maintain the conductivity of the extracting electrode and stable discharge even in an environment where the grounded surfaces of the vacuum chamber walls are covered with insulating materials. Thus, this method expands the applications of ion plating.

Specifications of Built-in Plasma Gun BS-80010

This built-in plasma gun features the following specifications.

- Plasma output: Up to 6.08 kW
  (discharge voltage: 160 V, discharge current: 38 A)
- Operating pressure: 1×10^{-2} to 1×10^{-1} Pa
- Discharge gas: Up to 20 mL/min (argon gas)
  Cooling water: 7 L/min or more
  (temperature: 25 °C or less)

Applications of BS-80010

The high-power built-in plasma gun BS-80010 is a special-purpose component developed for use as a plasma generator in the optical thin-film industry. In its major applications, this gun is incorporated into existing or new vacuum-deposition systems. It generates high-density plasma in the vacuum chamber and forms thin films by means of the ion-plating method to add high value to those films.

We show examples of the applications using this new BS-80010 gun. Thin films were deposited in an 1800 mm diameter vacuum-deposition system by using the ion-plating method, and the effectiveness of the gun was evaluated. The experiments were carried out with support from an optical-systems manufacturer.

Experimental conditions

The built-in plasma gun BS-80010 was installed on the floor of an 1800 mm diameter vacuum-deposition system. The beam irradiation angle was appropriately adjusted to direct the plasma beam toward the film-deposition space. Then, various film-forming experiments were performed. The experimental conditions such as ultimate pressure, substrate temperature, and film-deposition rate were the

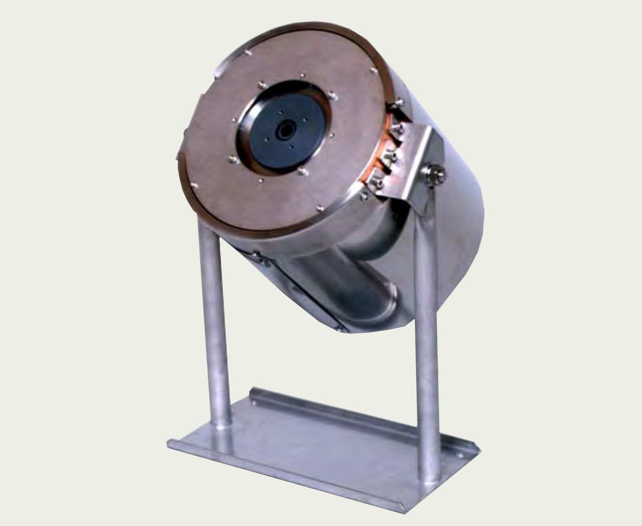


Fig. 1. External view of built-in plasma gun BS-80010.

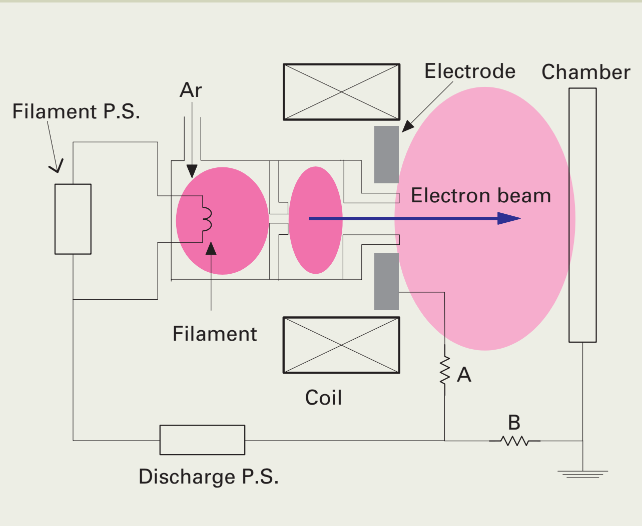


Fig. 2. Schematic diagram of High-Power Built-in Plasma Gun.

Fig. 3. Spiral beam of High-Power Built-in Plasma Gun.

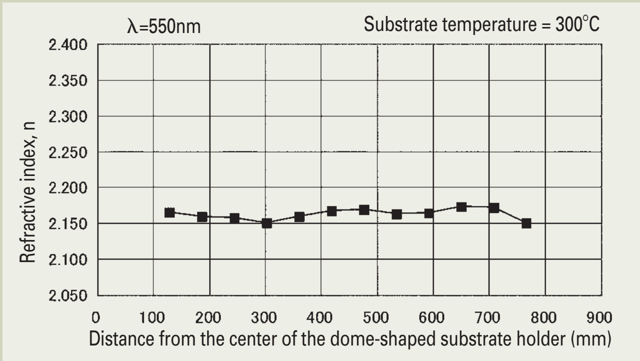


Fig. 4. Refractive indices and distribution of twelve single-layer Ta_2O_5 films.

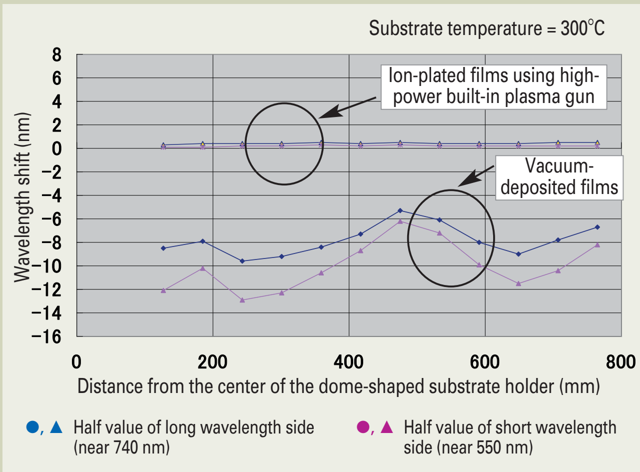


Fig. 5. Wavelength shifts of twelve multi-layer SiO_2/Ta_2O_5 films (19 layers).

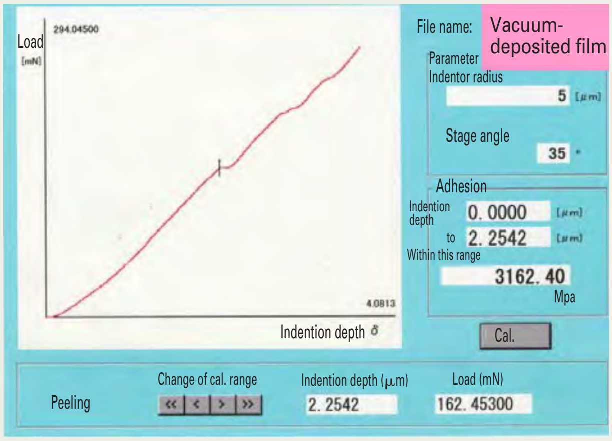
same as those used in the vacuum-deposition method.

Refractive indices of single-layer films

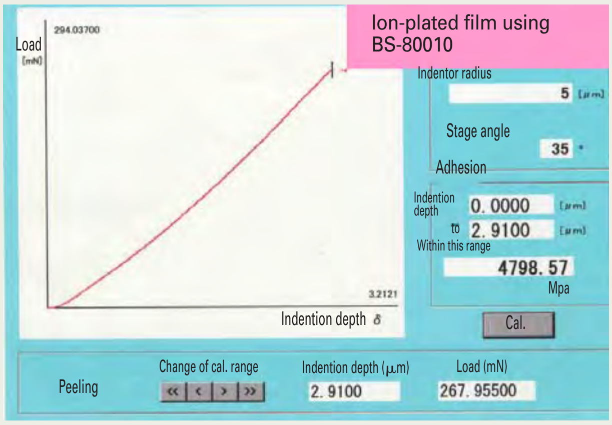
Twelve glass substrates were arranged in a dome-shaped substrate holder, from the center toward the periphery, spaced equally apart. Then, single-layer Ta_2O_5 films were deposited on the glass substrates. **Figure 4** shows the measured results of the refractive index of each Ta_2O_5 film versus the location, although the results do not show the comparison with the data obtained from the vacuum-deposition method. The ion-plating method using the built-in plasma gun BS-80010 can offer refractive indices higher than those obtained from the vacuum-deposition method, and also provide distribution almost the same as vacuum deposition, verifying the high quality of ion-plated films.

Wavelength shift of multi-layer films

Figure 5 shows the wavelength shifts of twelve multi-layer SiO_2/Ta_2O_5 films (19 layers each). The wavelength shift, in terms of the uniformity across the dome-shaped substrate holder of the wavelength of the 50% transmittance point of the long-wave edge, was evaluated by comparing that at room temperature and that obtained under 100°C heating with



Adhesion of vacuum-deposited film: 3162.40 MPa



Adhesion of ion-plated film: 4798.57 MPa

Fig. 6. Adhesion of multi-layer SiO_2/Ta_2O_5 films (19 layers).

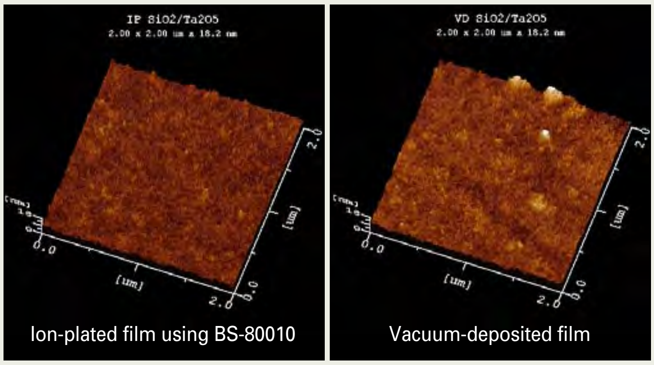


Fig. 7. AFM images of multi-layer SiO_2/Ta_2O_5 Film (19 layers).

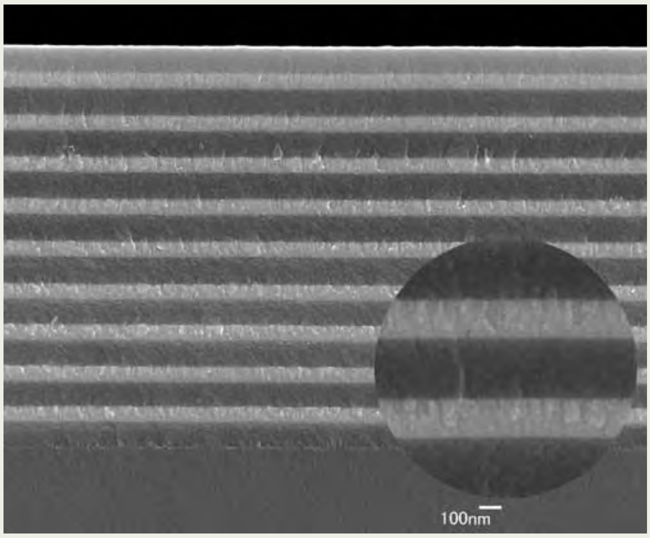


Fig. 8. Cross-sectional SEM image of multi-layer SiO_2/Ta_2O_5 film (19 layers).

hot air. This evaluation shows that the wavelength was shifted toward the short wavelength side by 6 to 13 nm for the vacuum-deposited films, while the wavelength shift was minimal over the entire area of the dome-shaped substrate holder for the ion-plated films using the built-in plasma gun BS-80010.

Adhesion of multi-layer films

The adhesions of the multi-layer film samples discussed were measured with NEC Sanei Instruments Thin Film Physical Property Test Equipment MH4000. **Figure 6** shows the test results. They prove that the ion-plated film using the built-in plasma gun BS-80010 has adhesion higher than that of the vacuum-deposited film.

AFM images

The surfaces of the film samples discussed were observed with a JEOL scanning probe microscope (JSPM-4210). **Figure 7** shows the AFM images of a 2μm square. Several protrusions are visible on the vacuum-deposited film, while no conspicuous protrusions were observed on the ion-plated film using the built-in plasma gun BS-80010. The BS-80010 can offer improved smoothness of the film surface.

Cross-sectional SEM image

The cross section of the ion-plated film sample discussed was observed with a JEOL field emission scanning electron microscope (JSM-6700F). **Figure 8** shows the resulting SEM image. When the vacuum-deposition method is used, the film is likely to grow in a columnar form caused by the adsorption of water into and desorption from the gaps between the columns, thus causing the wavelength shift. On the other hand, Fig. 8 shows that the built-in plasma gun BS-80010 can create a highly dense ion-plated film with a flat interface.

Conclusion

In the evaluations of ion-plated films that were deposited using the high-power built-in plasma gun BS-80010 in the 1800 mm diameter vacuum-deposition system, it was verified that thin films, which have higher quality (for example, reduced wavelength shift and higher adhesion) compared to the conventional vacuum-deposition method, can be formed. Based on the experimental results, we expect that the new, built-in plasma gun will contribute to creating the films which meet the needs of the optical thin film industry.

In the future, we will explore possibilities for new applications of our built-in plasma guns and continually pursue the improvement and development of these guns so that the products will be used more widely in the industrial fields, together with timely report of our research activities. In closing, we would like to express our sincere appreciation to the optical-systems manufacturer who supported us in the experiments of film formation with their 1800 mm diameter vacuum-deposition system.