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Characteristics and design of metal vacuum arc plasma source power supply for pulsed-mode plasma immersion ion implantation

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Metal vacuum arc plasma sources enhance the capability of plasma immersion ion implantation (PIII) by providing a convenient and efficient means by which to introduce metallic ions into the plasma for metallic ion implantation and/or thin film deposition. The power supply of a metal vacuum arc plasma source is usually based on the artificial transformation line design, but it has several drawbacks. For instance, the pulse width cannot be adjusted conveniently and the pulsing frequency cannot exceed a predefined value. These restrictions make process optimization and synchronization with the sample high voltage modulator complicated in pulsed-mode PIII operation. In this work, we experimentally investigate the voltage–current characteristics of our metal vacuum arc plasma source. Our results suggest two different power supply designs. By adopting the design incorporating a gradual voltage–current decline, we successfully construct a simple and reliable power supply that works in a stable manner for a prolonged period of time. *© 2000 American Institute of Physics.* [S0034-6748(00)02001-9]

I. INTRODUCTION

Plasma immersion ion implantation (PIII) is a proven surface treatment technique for industrial components, especially those possessing an irregular shape.[1–4] In early PIII equipment, the plasma source was very simple, and only gaseous plasma could be generated. With the advent of metal vacuum arc plasma sources,[5–10] the capability of PIII has been extended considerably, particularly in the area of functional film fabrication on an irregular surface.[11,12] In metal ion PIII experiments involving large specimens, irregular-shaped samples (with sample rotation preferable in some cases), and thick film formation, the metal ion flux must be quite large in order to ensure a reasonably high throughput. The large implant current places stringent demands on the power supply. If the metal vacuum arc plasma source works in a constant current mode, the power supply is very large. In most PIII equipment, the metal vacuum arc plasma source works in a pulsed mode in synchronization with the sample high voltage power supply in order to conduct independent ion implantation, deposition, and ion beam induced deposition (IBED) experiments. Therefore, the design of a metal vacuum arc plasma source suitable for PIII is different from that of a constant current one in other applications.

In a traditional pulsed metal vacuum arc plasma source, an artificial transmission line is used as the main arc power supply. The artificial transmission line can provide a large current to the main arc of the metal vacuum arc plasma source. However, the pulse width cannot be adjusted, and the frequency must be smaller than a predefined value. In PIII, it is imperative that the pulse width, frequency, and main arc current be adjustable independently to cater to the needs of different processing and materials requirements. In our efforts to design an appropriate metal vacuum arc plasma source power supply, we investigate the voltage–current characteristics of our metal vacuum arc plasma source. Based on the results, we have designed and constructed a simple power supply that has been demonstrated to be stable in prolonged operation in our laboratory.

II. VOLTAGE–CURRENT CHARACTERISTICS OF METAL VACUUM ARC PLASMA SOURCE

In an artificial transmission line power supply, the initial voltage to which the artificial transmission line is charged is relatively high, and the current in the main arc is limited by the internal resistance of the transmission line. In general, the main arc can be regarded to be a simple resistor, and the voltage–current relationship is linear. However, in reality and as indicated by our experimental results displayed in Fig. 1, there are two distinct stages in the voltage–current curve: a rapidly decreasing phase in which the voltage is high prior to arc initiation and a relatively flat stage in which the voltage is lower, typically ~20 V or so, when the arc is on. In the first stage, the metal vacuum arc plasma source is initiated using a relatively high voltage. In our experiments, it is found that the pre-arc power supply voltage must be higher than 50 V in order to ignite the arc and to bring it to stable operation. However, it should be noted that the main arc

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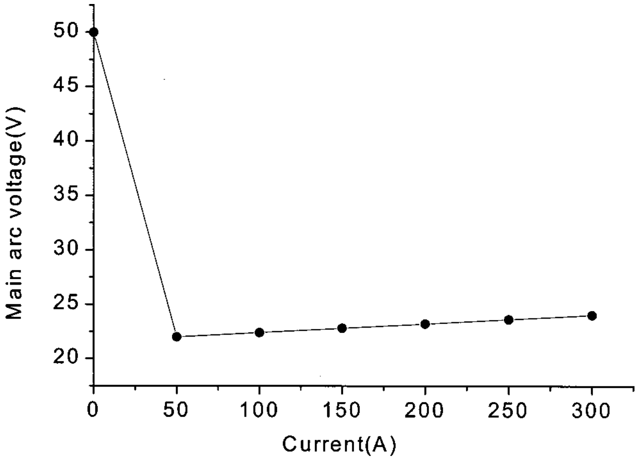

FIG. 1. Voltage–current characteristic of the main arc of metal vacuum arc plasma source.

cannot work in this stage steadily. After the arc between the cathode and anode of the metal vacuum arc plasma source has been established, the main arc voltage decreases rapidly, as shown by the second phase in Fig. 1. In our experiments, after the arc has been ignited, the voltage should be decreased to about 23 V for stable operation.

III. POWER SUPPLY DESIGN

Since the characteristic of the main arc of the metal vacuum arc plasma source is quite complex, the power supply must be designed specifically to ensure stable and prolonged operation. There are two types of power supplies that can fit the scheme. The first one possesses a fast dropping V–I characteristic as depicted in Fig. 2. In this configuration, when the current of the main arc is zero, the voltage is higher than 50 V. After the arc between the cathode and anode has been triggered, the voltage diminishes quickly, and the power supply is essentially transformed into a constant current one. The intersection is the common working point of the power supply and main arc of metal vacuum arc plasma source. The current setting of the power supply can be adjusted to obtain different arc currents. This kind of power supply meets the requirements of the main arc and provides steady operation. Unfortunately, since the metal vacuum arc plasma source works in a pulsed mode in PIII experiments, designing such a power supply is quite difficult.

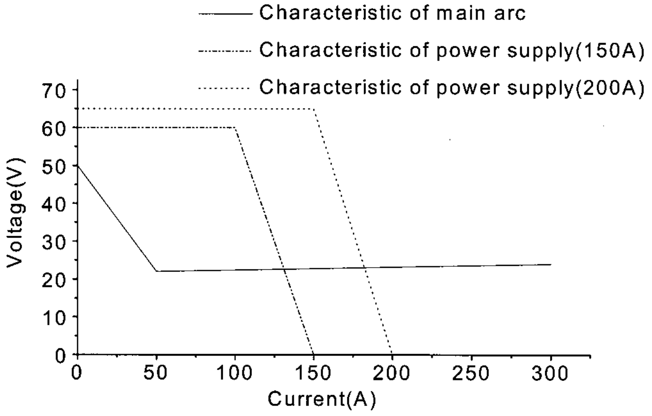

FIG. 2. Matching between a power supply with a rapidly decreasing V–I characteristic and the main arc.

The alternative is to adopt a design in which the V–I characteristics show a gradual decline as shown in Fig. 3. In this case, the current is determined by the initial voltage. When the initial voltage is increased, the intersection point between the power supply and the characteristic line of the main arc will shift, and the current of the main arc can be increased. This design also meets the requirements of the main arc. In addition, this design allows easy adjustment of the current of the main arc by varying the initial voltage. Since a power supply with this characteristic is easier to build, we have adopted the latter design for the metal vacuum arc plasma source in our laboratory.

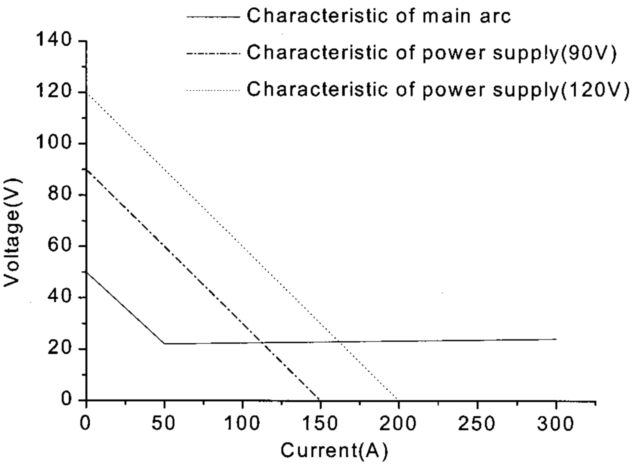

FIG. 3. Matching between a power supply with a slowly declining V–I characteristic and the main arc.

IV. MAIN ARC POWER SUPPLY

By employing the design that incorporates a gradually decreasing voltage–current characteristic, we have constructed a simple power supply to power our metal vacuum arc plasma source in our laboratory. A schematic of it is exhibited in Fig. 4. The IGBT is used as a current switch, and the V–I property is achieved using a 0.6 Ω resistor. When the voltage of the capacitor is 115 V, the current of the main arc can be as high as 150 A. In this circuitry, the current cannot rise indefinitely even if the cathode of the metal vacuum arc plasma source is connected to the anode. There-

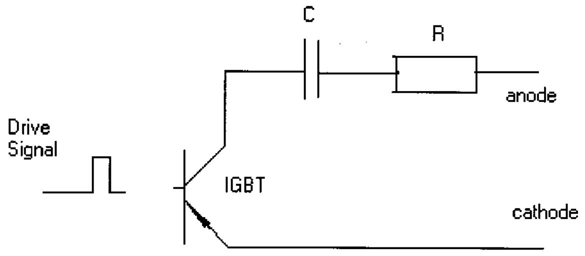

FIG. 4. Schematic of the power supply possessing the V–I property shown in Fig. 3.

fore, the IGBT is protected by the resistor. The pulse width and modulating frequency can be adjusted easily by varying the drive signal parameters of the IGBT. This is in contrast to an artificial transmission line in which the pulse width has a predefined value and the pulsing frequency cannot exceed a certain value. In our tests, with proper cathode feeding speed, the metal vacuum arc plasma source works steadily until the trigger fails to work. The reliable and stable operation achieved in our laboratory proves that the new power supply is suitable for a metal vacuum arc plasma source in PIII experiments.

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[1] J. R. Conrad, J. L. Radtke, R. A. Dodd, F. J. Worzala, and N. C. Tran, J. Appl. Phys. **62**, 4591 (1987).

[2] P. K. Chu, B. Y. Tang, Y. C. Cheng, and P. K. Ko, Rev. Sci. Instrum. **68**, 1866 (1997).

[3] S. Y. Wang, B. Y. Tang, J. F. Sun, X. F. Wang, P. K. Chu, and X. C. Zeng, Phys. **26**, 362 (1997).

[4] B. Y. Tang, P. K. Chu, S. W. Wang, K. W. Chow, and X. F. Wang, Proceedings of the 10th International Conference on Surface Modification of Metals by Ion Beams (SMMIB-97), Gatlinburg, Tennessee, 1997, p. 153.

[5] I. G. Brown, Rev. Sci. Instrum. **65**, 3061 (1994).

[6] I. G. Brown, J. E. Galvin, and R. A. MacGill, Appl. Phys. Lett. **47**, 358 (1985).

[7] Z. M. Zeng, P. K. Chu, X. B. Tian, B. Y. Tang, and D. T. K. Kwok, IEEE Trans. Plasma Sci. **28**, 394 (2000).

[8] Z. M. Zeng, B. Y. Tang, S. Y. Wang, X. B. Tian, X. F. Wang, P. K. Chu, and T. Zhang, Chin. J. Vac. Sci. Technol. B (to be published).

[9] T. Zhang, J. D. Hou, B. Y. Tang, T. K. Kwok, Z. M. Zeng, I. G. Brown, and P. K. Chu, Chin. J. Phys. (Taipei) **9**, 279 (2000).

[10] T. Zhang, B. Y. Tang, Q. C. Chen, Z. M. Zeng, P. K. Chu, M. M. M. Bilek, and I. G. Brown, Rev. Sci. Instrum. **70**, 3329 (1999).

[11] L. P. Wang, B. Y. Tang, X. B. Tian, Y. X. Leng, and P. K. Chu, International Symposium on Materials Science and Technology (ISMST) 2000, Harbin, China, 2000.

[12] Q. Y. Zhang, L. P. Wang. X. B. Tian, Y. X. Leng, B. Y. Tang, and P. K. Chu, Proceedings of the 7th Sino-Korean International Symposium on Thin Film Materials: Emerging Techniques for Thin Film Materials, Dalian, China, 2000, p. 8.