Automatically reigniting dc vacuum arc plasma source

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A spark reignition system designed and produced to enhance vacuum arc deposition is presented. The system, in which the metal arc can be automatically reignited so as to minimize film contamination, not only initially ignites the arc by means of a spark component, but also reignites the spark automatically when the arc is near extinguishing. This automatic reignition system can effectively curb the pressure fluctuations induced by arc extinction and thus enhance the deposition procedure. © 2002 American Institute of Physics. [DOI: 10.1063/1.1494868]

I. INTRODUCTION

Vacuum metal arc deposition offers high-deposition rates and produces dense coatings by the use of dense, energetic plasmas of electrically conducting elements. The high-ion flux is created from minute, extremely hot, and discrete locations on the arc cathode known as cathode spots.1 In order to ignite the arc, a mechanical metal trigger can be used, but the process may generate contamination2 that must be avoided especially in semiconductor applications. Frequently, the arc plasma extinguishes during the deposition process.2–4 In dual plasma deposition involving both gaseous and metallic elements, the chamber pressure can surge significantly within a few seconds after the arc extinction5 because a large amount of gas is bled in to react with the metallic ions in the cathodic plasma to produce the film. It is in practice very difficult to immediately adjust the gas flow after the arc extinction, and the sudden burst of gas may result in inhomogeneity in the composition and structure of the film. Thus, rapid reignition that can minimize this problem is desirable in many applications. We have designed and produced a spark autoreignition system in which by using one spark component, the arc can be automatically reignited in a time shorter than in conventional vacuum arc sources (several to tens of seconds for manual operation and $\geq 1/2$ second for mechanical autoigniter), thereby reducing the fluctuation in the gas pressure and the corresponding deleterious effects.

II. HARDWARE AND EXPERIMENT

The hardware implementation and experiments were conducted on a vacuum arc system fitted with a 90° magnetic solenoid filter as shown in Fig. 1. The water-cooled vacuum arc plasma source consisted of a cathode 60 mm in diameter, an ignition electrode, and a spark component. The arc was initiated on the side surface of the cylindrical cathode, and copper, titanium, and graphite were used as cathode materials. The focusing coils produced a magnetic field in the range of 0–75 mT, and the filter coils produced a filtering magnetic field up to 20 mT in the center of the coils. The stainless steel quarter torus had an internal duct with an inside diameter of 125 mm. Argon was introduced at a flow rate of 40 sccm as a background gas and the pressure was $9.3 \times 10^{-2}$ Pa. The main power supply could provide up to 300 A of arc current at 30–40 V. The open-circuit voltage of the power supply was 70 V.

Figure 2 exhibits schematically the structure of the arc autoreignition system. The energy storage unit that is recharged repetitively by the high-voltage cell, which includes a high-voltage transformer, rectifier, and energy-input resistor, produces the sparking energy. If the feedback unit detects that the main power supply is ready at the beginning or when the arc is extinguishing, a square wave signal is sent to the pulse generator by a sensing cell and high-frequency pulses are sent to the thyristor grid. When the gate of the thyristor is excited, high voltage is supplied between the igniting electrode and cathode. The spark generated by the spark component subsequently ignites the cathodic arc and the thyristor switches off automatically when the current drops below the holding value.

III. ANALYSIS

The key component in the autoreigniting device is the sensing cell. Because different cathode materials possess different optimal operating voltages, the sensing cell must allow for both automatic and manual operation. In addition, in order to accommodate the rapid pressure change, the sensing cell must have a high response speed. Considering that the
main power supply typically resembles a traditional welding power supply having a high-electrical inductance, the arc current cannot go to zero abruptly and the arc voltage has a finite ramp rate.

In our special design, the sensing cell sends an ignition signal when the arc voltage increases to \( fV_w \), where \( V_w \) is the working voltage, \( f \) is the arc voltage increase with a value between 1 and \( V_i/V_w \), and \( V_i \) is the idle voltage of the main power supply. Hence, the reignition signal can be sent to the cathode just before the arc completely extinguishes. Consequently, with the implementation of this hardware, the deposition process is much smoother and arc extinction can hardly be noticed in most cases.

Figure 3 displays the sequence of wave forms of the main power supply and the autoretrigger system. When the main power supply is switched on at time \( t_0 \), the high-voltage cell is also switched on at the same time, and the energy storage unit is charged. Line 3 in Fig. 3 produces the energy storage voltage wave form. The sensing cell and pulse generator are automatically switched on after a delay time of \( t_1 - t_0 \) (lines 4 and 6). At \( t_1 \), the pulse generator begins to produce stable pulses (line 6) for the whole deposition process. When the sensing cell detects that the voltage of the main power supply is at a voltage that is over a given voltage \( fV_w \), the pulse control unit switches to high (line 4). It adds the oscillating signals to the thyristor grid as shown by line 5 in Fig. 3. The capacitor in the energy storage unit keeps discharging until the current drops to a value low enough to switch off the thyristor at time \( t_2 \). After \( t_2 \), the energy storage unit is recharged and the recharge–discharge states alternate. The igniting pulses do not disappear unless the voltage of the main power supply drops below \( fV_w \). That is, the spark component keeps sparking to sustain the arc if the voltage of the main power supply is higher than \( fV_w \). At \( t_3 \), the output of the control unit switches to low, and the oscillation signals are filtered.

During the deposition, if the arc shows sign of extinguishing, the voltage of the main power supply will increase. As soon as the sensing cell detects that it is higher than \( fV_w \) (for example, at time \( t_4 \)), the output of the control unit becomes high and lets the ignition signal go through. The ignition pulses are sent to the spark component again. If the arc is reignited by a pulse at time \( t_5 \), the voltage of the main power supply decreases again, and at time \( t_6 \), the output of the pulse control unit switches to low. This essentially completes one autoreignition cycle. When the deposition process is over at time \( t_7 \), the entire deposition system is switched off, and the energy storage unit discharges slowly.

**IV. DISCUSSION**

To enhance dual-vacuum arc deposition, the resistance of the “energy-input” resistor and the “energy-output” resistor is important. The energy-input resistor determines the charging speed of the energy storage unit and so the resistance cannot be too high. The energy-output resistor determines the discharging speed of the energy storage unit, and its resistance should not be too high either. However, the total electrical resistance of the energy-input resistor and the energy-output resistor should not be so low that the thyristor cannot be shut down automatically. In addition, a high-voltage filter must be added to the system to avoid a breakdown of the rectifying components in the main power supply due to the high-voltage pulses. Using a careful design as described in this article, the arc can be automatically reigned before extinguishing completely. The time for which the arc voltage and arc current fluctuate is limited to the
interval $t_6-t_4$. Thus, the fluctuation in the vacuum pressure induced by arc extinction and the subsequent detrimental effects can be effectively avoided.

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