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Design of the Quasi-diffuse Vacuum Arc Source with Cold Cathode in Vacuum Arc Deposition

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Abstract
The work proposed design principles and program of a compact and efficient quasi-diffusion arc source with cold cathode. Movement of arc spot was controlled through diode rotating transverse magnetic field covering the entire target surface, with adjustable frequency and strength. Meanwhile, manufacture of arc source and discharge testing were conducted according to the design principles and program. Results show that: large collective arc spot were gradually decomposed into dispersive arc spot lines with increasing rotation frequency and intensity of transverse magnetic field; arc spot lines gradually pervaded on the entire target surface, presenting morphology of dispersive arcs, thus greatly reducing power density of arc spot. Meanwhile, purified plasma with high density was extracted through axial-focusing guiding magnetic field, thus improving transport efficiency of plasma. In cold cathode target, the quasi-diffusion arc source program had achieved strong disperse arc state fully distributing on the entire target surface, without the need to heat target to high temperature. Through quasi-diffusion arc with cold cathode, discharge types and working stability of arc spot was greatly improved; corrosion uniformity and utilization of target was enhanced to reduce emission of MPs; transmission efficiency of plasma was improved, expanding application of vacuum arc deposition technology.
Keywords: DIODE ROTATING TRANSVERSE MAGNETIC FIELD, ARC SOURCE OF QUASI-DIFFUSION ARC WITH COLD CATHODE, AXIAL-FOCUSING GUIDING MAGNETIC FIELD, MPS, ARC DISCHARGE

1. Introduction

Vacuum arc deposition(VAD) is an advanced plasma coating technology, with advantages of simple structure, high ionization rate, high incident particle energy, excellent diffraction, and low-temperature deposition. VAD technology has achieved wide application and rapid development, especially in decorative plating and tooling plated markets, demonstrating great economic and industrial prospects [1-5]. However, macro-particles(MPs) emission in VAD caused contamination on film surface, resulting surface roughness increased and gloss of film reduced, adversely affecting the quality of the film and its applications in decoration and antifriction; moreover, adhesion between coating and bulk material is reduced, appearing peeling and malconformation [6-11]. High ionization and low-temperature deposition of VAD leads to outstanding advantages in plating of tool and mold compared with other methods of coating deposition. However, MPs of arc discharge become obstacle of tool plating as well as a bottleneck for wider application of VAD.

Currently, magnetic filtration of MPs is an effective measure with wide application and better effects [11-14]. However, deposition rate is greatly reduced due to plasma loss in transmission process, resulting in waste of cathode materials and lower production efficiency. Meanwhile, magnetic filtration technology greatly reduces deposition window, which is not conducive to industrial production. Therefore, MPs problem should be solved from the generation source. Necessary condition for self-maintained arc discharge is continually plenty of effective electron emission. From mechanism of electron emission, the precondition of large-amount electron emission is that a large number of electrons crossing barrier height of metal surface and Fermi level (work function). This happens in two conditions: one is electron divergence of hot cathode, namely metal surface has many upper-state electrons (greater than work function). The number of upper-state electrons increases with rise of temperature of the metal, thus strengthening effects of hot electrons divergence. The other is reduction of surface potential barrier (work function), increasing strength of extra electric field on cathode surface[15]. The reduced height of surface potential barrier increases with rising strength of extra electric field. Density of positive charge near the cathode determines electric field strength at cathode—increase of positive charge density promotes enhancement of electric field strength. In terms of cold cathode, concentrated discharge of current is the most effective way to form efficient electron divergence with arc discharge. On the one hand, cathode can be locally heated to a high temperature by concentrated discharge, increasing the number of upper-state electrons; on the other hand, local positive charge sheath with high density can be formed to increase local electric field strength with reducing work function, thus promoting a large number of electron emission. Generally, arc source used in vacuum arc deposition is cold cathode arc source, and its arc behavior is controlled by highly-bright cathode spots with fast movement on cathode surface. In cathodic arc discharge, only micro cells with highest temperature (by ion bombardment and thermal effects of resistance) and strongest electric field or lowest work function can emit large amount of electrons. Existence of arc spot is maintained through large amounts of most effective electron emission. Therefore, the observed motion of arc spot is the motion at the most effective position. More specifically, movement at the position with maximum density of positive charge results in new arc spot and extinguish of old arc spot, thus leading to motion of arc spot. Cathode spots in vacuum arc deposition have small size and high power density. Therefore, as strong emission source of electron, metal atom and high-speed metal vapor, cathode spots also continually spray liquid macro-particles(MPs). This phenomenon does not exist in large-area arc discharge of hot cathode (low power density has not reached molten state). Large weld puddle is formed in discharge with localized high power density. Emission of MPs cannot be avoided through local pressure and ion bombardment.

From production mechanism of MPs in vacuum arc deposition, partial ion bombardment as well as large and deep arc weld puddle resulted from local overheating of target should be avoided to reduce emission of MPs. Therefore, measures should be adopted to control arc movement, improving discharge types and velocity of arc spot. Meanwhile, residence time of arc should be shortened, with reduction of local power density and ion bombardment of high density. The principle of internationally controlled vacuum arc deposition is to control and improve movement velocity of cathodic arc on cathode surface through appropriate magnetic field. In other words, power density is changed from local point state to line state (in the same time period), thereby reducing amount and size of droplet with enhancement of film lifetime. Moreover, vapor deposition that could not be achieved by ordinary vacuum arc deposition (also known as random vacuum arc deposition, with arc spot moving randomly on cathode surface) can be achieved by controlled arc. Controlled vacuum arc is further development and inevitable direction of vacuum arc deposition.

Controlled vacuum arc deposition can achieve effective control of arc spot, limiting arc spot trajectory to partially reduce MPs emission. However, arc spot are limited at certain positions, leading to pathway due to long-term corrosion, resulting low utilization rate of target. Currently, there are some designs of arc source using dynamic magnetic field to control arc movement [16, 17], mainly divided into electromagnetic type and mechanical type. The main principle is to dynamically transform local distribution of magnetic field on target surface, thereby changing distribution of maximum value of transverse component in magnetic field; the area of transverse component in magnetic field is dynamically expanded to increase arc spot corrosion area, thus improving utilization of target material. Mechanism of mechanical type is the movement of magnet or target, where movement is divided into rotating form and reciprocating form. Dynamic magnetic field can achieve homogeneous corrosion of arc spot on target with simple structure and large area. However, this approach requires additional set of complex electromagnetic or mechanical control means. The expansion of arc spot distributing on target surface only partially improves target utilization through position change of transverse component of magnetic field, but arc discharge have not been fundamentally improved, arc spot still locally move with changes of magnetic field configuration, presenting arc discharge of concentrated current, with problem of MPs. Moreover, the intensity of magnetic field is constantly changing, while arc spot is fluctuating with unstable velocity. Thus, MPs cannot be effectively reduced, which is not conducive to homogeneous coating. All of these arc sources are cold cathode arc sources with fragmented cathode spots, which is the root cause of MPs. This arc source cannot effectively improve discharge forms of arc spot; meanwhile, it has not reached requirement for preparing film with precise function.

Based on mechanism of arc spot movement in magnetic field as well as previous researches [18, 19], structure of traditional arc source is improved in the work, breaking through conventional design ideas of cold cathode arc source. Design principles and program of a compact and efficient cold cathode arc source of quasi-diffusion arc was proposed for circular target with diameter of 60-150mm, to improve discharge forms and working stability, increase corrosion uniformity and target utilization, reduce mission of MPs and improve transmission efficiency of plasma. Meanwhile, manufacture of arc source and arc discharge testing were conducted according to the design principles and program. Analysis on arc discharge of this arc source under different conditions will be described in another paper. The work focuses on technical principle, programs and structure of quasi-diffusion arc source with cold cathode as well as test results of quasi-diffusion arc discharge.

2. Technical Principles

Based on physical characteristics of vacuum arc plasma, discharge and movement of arc spot as well as transmission characteristics of plasma will be improved with electromagnetic field on arc source. Numerous studies have indicated that: vacuum arc spot conduct retrograde motion against Ampere-force in transverse magnetic field parallel to cathode target surface [20-23], where the motion direction is opposite to that of current force ($-I \times B$). Figure.1 shows transient topography of arc spot with increase of magnetic field strength under transverse magnetic field with low-frequency (10Hz) rotation. It is observed that when transverse magnetic field strength is zero, namely the absence of magnetic field, arc spot presents random motion as collective large spots on target surface due to self-generated magnetic compression of arcs. In absence of magnetic field, redistribution of front dense plasma of arc spot is entirely decided by random factors (such as target surface roughness, and direction of impact force in metal vapor, etc.); presence of position with maximum-density of positive charge n+ (position of the most effective electron emission) entirely results from random interference of in-stable factors. Therefore, the movement of arc spot is random. With increase of transverse magnetic field strength, arc spot morphology is gradually transformed from collective large bright spots into straight long fine lines; trajectory of arc spot becomes longer and finer. Elongating trajectory of arc spot with increase of magnetic field strength indicates that velocity of arc movement is proportionally accelerated at the same exposure time; trajectory becoming finer indicates short residence time of arc spot; strait-long-fine lines of trajectory shows that arc spot conduct linear motion along certain direction under effect of transverse magnetic field. However, rotation of transverse magnetic field results in slightly curve and twists of arc trajectory. Under magnetic field with large strength, direction of arc motion is changed with direction variation of transverse magnetic field when arc spot move to the edge of target in line. Arc spot conduct motion with high velocity, while magnetic field has lower rotational frequency. Thus, movement of arc spot is less influenced by rotation frequency, but more greatly influenced by strength of magnetic

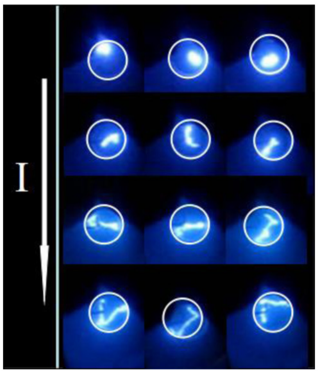

Figure 1. Transient topography of arc spot with increase of magnetic field strength under transverse magnetic field with low-frequency (10Hz) rotation

field. Therefore, morphology of arc spot just presents simple liner-curved variations with low-frequency rotation of transverse magnetic fields. Discharge of arc spot have not been greatly changed; instead, only moving velocity is enhanced with increase of magnetic field strength, reducing residence time at a point, with finer arc spot. After formation of new arc spot, high-density space charge layer is formed near cathode target surface. Then, a strong electric field is generated combined with cathode target surface, maintaining electron emission away from cathode as well as bombardment movement with positive ions toward cathode. Distribution of bombardment movement is symmetric without magnetic field, and random motion of arc spot can be caused under influence of random factors. If transverse magnetic field is applied on target surface, density of positive charge n+in negative direction will be larger than that n+of negative direction, so new arc spot is more easily formed in negative direction. Repeatedly, continuous formation of new arc spot in negative direction with extinguish of old arc spot results in observed linear motion of arc spot in retrograde direction.

With increase of transverse magnetic field strength, parabolic relationship exists between velocity of arc spot movement and strength of transverse magnetic field [24, 25]. Thus, velocity of arc spot movement can be enhanced through transverse magnetic field, which is a very important rule of arc spot motion in magnetic field. Currently, most arc source designs adopt static or dynamic magnetic field to form a certain magnetic configuration on target surface, restricting arc motion using law of acute angle [26]; transverse component is used to improve arc velocity [27]. It is indispensable to integrate the two laws, although there are various forms of magnetic field. In order to achieve improvement of target utilization and reduction of MPs, area and strength of transverse component should be expanded; meanwhile, movement of arc spot should be restricted. Static magnetic field is relatively stable, thus it can improve arc velocity and discharge stability while reducing utilization of target. In dynamic magnetic field mode, distribution of maximum value in transverse component of magnetic field on target surface is primarily changed through dynamical variation of local distribution of magnetic field; meanwhile, the area of transverse component is dynamically increased to achieve expansion of corrosion area in arc spot. However, current designs of static or dynamic magnetic field do not fundamentally improve arc discharge. Arc spot still locally move with changes of magnetic field configuration, presenting arc discharge of concentrated current, with problem of MPs. Moreover, the intensity of magnetic field is constantly changing, with fluctuating arc spot in unstable velocity. Thus, MPs cannot be effectively reduced, which is not conducive to homogeneous coating.

Based on the above analysis, movement of arc spot controlled through diode rotating transverse magnetic field covering the entire target surface, with adjustable frequency and strength, was proposed. Transverse magnetic field caused retrograde rectilinear motion of arc spot along vertical direction of magnetic field, going against Ampere Law. Transverse magnetic field is limited in a certain range in traditional designs of controllable arc source. According to acute angle rule, arc spot conduct retrograde linear motion in part areas of transverse magnetic field, with random motion along direction of transverse magnetic field within a certain range of target surface. Arc spot rapidly rotate in the circle of transverse magnetic field, thus increasing velocity of arc spot, and reducing residence time of arc spot at one point. Random motion of spot is transformed into lines distribution, reducing power density of arc spot and emission of MPs. However, long-time corrosion easily results in corrosion tunnel. Through diode transverse magnetic field covering entire target surface, arc spot conduct retrograde linear motion along vertical direction of transverse magnetic field, with random motion along direction of transverse magnetic field. Transverse magnetic field covers the entire target surface rather than being limited within a certain range. Therefore, arc spot with random motion along direction of transverse magnetic field also moves along the entire target surface. Meanwhile, high-frequency rotation of diode transverse magnetic field leads to superimposed rotary motion of arc spot. Therefore, arc spot will be distributed throughout the entire target surface under combined effects of certain magnetic field strength and rotation frequency, greatly reducing power density of arc spot. Rotary transverse magnetic field can constrain plasma in the front of target surface, restricting movement of electrons and ions. Thus, electron density near target surface is greatly increased, promoting inter-particle collisions, with increase of ion density and ionization rate; bombardment effect of ions can be further strengthened on target surface (the enhancement of bombardment effect is distributed on the entire target surface); electron emission of thermal field on target surface is promoted, thus increasing amount of effective electrons. Emission of high power density (cause of MPs) focusing on one point is transformed into uniform thermal-field electron emission with low power density on the entire target surface. Quasi-state diffusion arc can be achieved, greatly reducing emission of particles with improvement of evaporation effect and ionization effect. Meanwhile, purified plasma with high density was extracted through axial-focusing guiding magnetic field, thus improving transmission efficiency of plasma.

3. Technical Program

Based on the above technical principles, Figure.2 shows two-dimension diagram of overall structure of a compact and efficient quasi-diffusion arc source with cold cathode. Figure.3 shows three-dimension diagram of overall internal structure of the arc source without flange shield. It is observed that, compact and efficient quasi-diffusion cold cathode arc source is composed of arc source and controlled magnetic field group. Arc source includes target, target base, shield of target base, target chassis, arc initiation device and permanent magnet device. Controlled magnetic field group includes flange sleeve, flange insulation sleeve, diode TRMF (transverse rotating magnetic field) generating device, axial FGFM (focusing guiding magnetic field) generating device, coaxial focusing magnetic yoke and flange plate. Arc source is connected with the bottom of flange sleeve through target chassis, forming an integral structure of arc source. Flange plate in the front of flange sleeve is connected with furnace, controlling focusing magnetic field device in controlled magnetic field group to generate focusing lines of magnetic force.

Flange sleeve was equipped with flange insulation sleeve. At the outer side of insulation sleeve, there are diode TRFM generating device, axial FGFM generating device, and coaxial focusing magnetic yoke. Cooling water channel was set in flange sleeve, with flange water outlet and inlet at its bottom. One end of cooling water channel was equipped with annular flange plate, with connecting hole at its edge.

Target was installed in target base through connecting thread; diode TRFM generating device and axial FGFM generating device encircled flange sleeve, coaxially placed with the target and protected from flange sleeve through insulation sleeve. Diode TRFM generating device was placed around the target, with movable position and its center slightly higher than target surface. Axial FGFM generating device was placed at the front of diode TRFM generating device, with coaxial focusing magnetic yoke at the bottom as well as opening slots at inner side. Outer side of flange sleeve was equipped with flange shield, protecting inside magnetic field generating

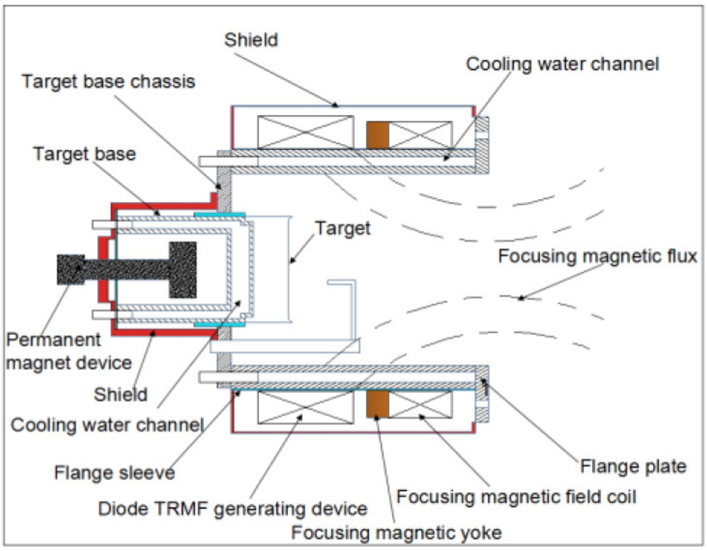

Figure 2. Two-dimension diagram of overall structure of compact and efficient quasi-diffusion arc source with cold cathode

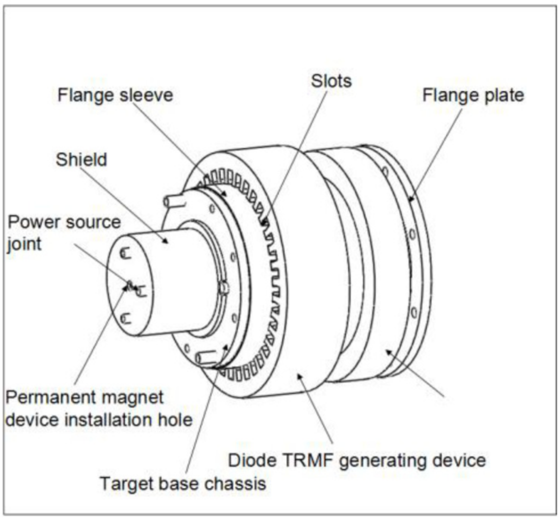

Figure 3. Three-dimension diagram of overall internal structure of compact and efficient quasi-diffusion arc source with cold cathode without flange shield

device. Target base chassis was nested outside the target base, conducting seal protection through insulating sleeve of target base. Permanent magnet device was mounted inside the hollow space of base target, joint with the bottom of target by permanent magnet installation hole. Target base was equipped with a shield at the periphery to protect inner part, as well as a cooling water channel communicating with water inlet and outlet. An installation hole of arc generating device was opened at target base chassis near target base. Then, arc initiation device was set in this hole with one end towards target. Rim of target base chassis opened joint holes to be connected with flange sleeve.

Figure.4 shows top view, side view and cutaway view of diode TRFM generating device structure. The diode TRFM generating device was composed of a multi-pole (12n, n are integers, and n≥2) iron-core skeleton with slots at inner side and varnished wire windings. The iron core consisted of annular overlying silicon steel sheets with high permeability (2000-6000H/m) and 0.5mm thickness. Inside circle of iron core opened slots of embedded winding coils. The slots had half-closed shape with slot number of 36. Inner diameter of iron core was slightly larger than outside diameter of flange sleeve; outer diameter of the core was selected according to selection criteria, enclosing flange sleeve by insulating sleeve. Surface of silicon steel sheet was coated with against-high-voltage insulation varnish, while cold-rolled silicon steel was used as iron core material. Varnished wire winding coil of diode TRFM generating device adopted high-strength polyurethane enamelled copper wire (QZY-2), using double-speed winding of double ultima-ratio normal distribution and △/2Y connection. There were 6 outgoing lines of the winding. End lines 2U, 2V and 2W of three-phase center tap were unconnected with vacancy. Power source was introduced through 4U, 4V and 4W to form diode transverse magnetic field. Figure. 5(a) shows three-dimensional structure and winding distribution of magnetic field generating device; Figure.5(b) shows cross-sectional transient magnetic field distribution of diode transverse rotating magnetic field. It is observed that, on cross-section of diode TRFM generating device, magnetic field was diode transverse magnetic field completely covering the entire target surface, with uniform magnetic field strength as well as adjustable frequency and intensity.

Varnished wire winding of diode TRFM generating device adopted three-phase variable-frequency sinusoidal AC excitation with phase difference of 120°. Current frequency and voltage can be individually adjusted, with voltage range of 0-380V and frequency

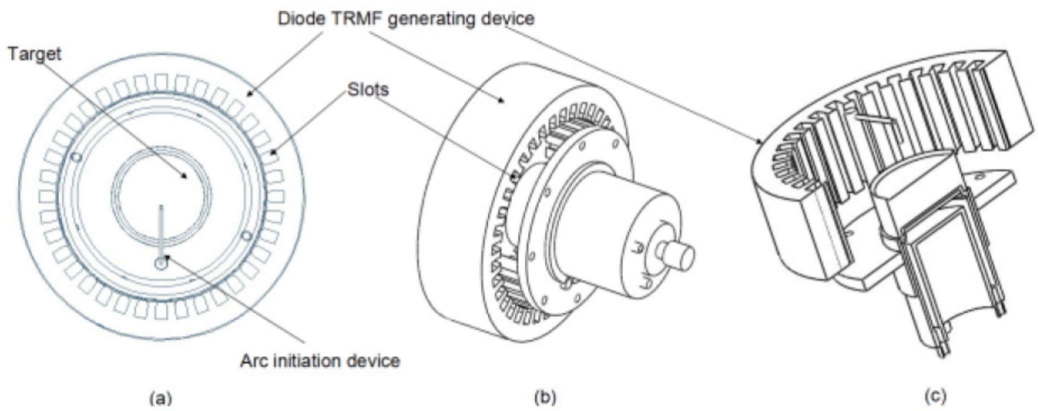

Figure 4. Top view, side view and cutaway view of diode TRFM generating device structure

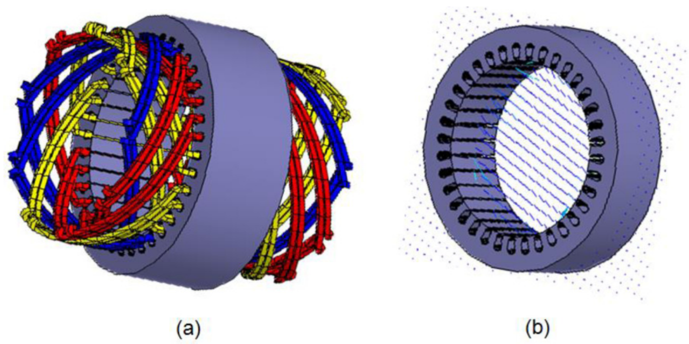

Figure 5. Three-dimensional structure and winding distribution of magnetic field generating device (a). Cross-sectional transient magnetic field distribution of diode transverse rotating magnetic field(b)

range of 10-500Hz. Strength of diode TRFM was adjusted through voltage, while its rotational speed was adjusted by current frequency.

Variable-frequency power source was manufactured with the core of microprocessor in mode of PWM (Pulse Width Modulation); module design of active component IGBT was adopted, using technologies of digital divider, D/A conversion, instantaneous feedback, and sinusoidal pulse width modulation, with protection functions from short circuit, over current, overload, and overheating.

Arc spot movement was controlled through diode rotating transverse magnetic field covering the entire target surface, with adjustable frequency and strength. Transverse magnetic field caused retrograde rectilinear motion of arc spot along vertical direction of magnetic field against Ampere Law, with random motion along direction of transverse magnetic field. Transverse magnetic field covered the entire target surface rather than being limited within a certain range. Therefore, arc spot with random motion along direction of transverse magnetic field also moved along the entire target surface. Meanwhile, high-frequency rotation of diode transverse magnetic field resulted in superimposed rotary motion of arc spot. Therefore, arc spot were distributed on the entire target surface under combined effects of magnetic field strength and rotation frequency, greatly reducing power density of arc spot. Rotary transverse magnetic field could constrain plasma in the front of target surface, restricting movement of electrons and ions. Thus, electron density near target surface was greatly increased, promoting inter-particle collisions, with increase of ion density and ionization rate; bombardment effect of ions was further strengthened on target surface while the enhancement of bombardment effect is distributed throughout target surface; electron emission of thermal field on target surface was promoted, thus increasing amount of effective electrons. Emission of high power density (cause of MPs) focusing on one point was transformed into uniform thermal-field electron emission with low power density on the entire target surface. Quasi-state diffusion arc was achieved, greatly reducing emission of MPs with improvement of evaporation effect and ionization effect. However, transverse magnetic field restricted plasma diffusion. In order to further improve transmission efficiency of plasma, purified plasma with high density was extracted through axial-focusing guiding magnetic field. Axial focusing guiding magnetic field generating device was composed of electromagnetic coil winded by varnished wire. Focusing guiding magnetic field coil achieved insulation protection through insulation sleeve and flange sleeve, placed in the front of diode TRFM generating device. The bottom of axial FGMF generating device could be connected with coaxial focusing magnetic yoke with high permeability (2000-6000H/m), avoiding influence of axial focusing magnetic field on rotating transverse magnetic field. Coil of axial FGMF generating device was energized with direct current. Strength of focusing guiding magnetic field was adjusted through current. Figure.6 shows transient distribution of diode rotating transverse magnetic field on target section, as well as transient distribution of coupling magnetic field in plasma transport space. Figure.6(a) to Figure.6(d) were situations with and without focusing guiding yoke, under a certain strength of axial focusing magnetic field. It is observed that, axial focusing guiding magnetic field has changed distribution of magnetic field in plasma transport space. Strength of magnetic field was increased, thus achieving coating technology of non-equilibrium quasi-diffusion arc. Discharge power density was declined to reduce emission of MPs; meanwhile, constraint of plasma on target surface was reduced, improving transmission efficiency and density of plasma in transport space. Thus, discharge stability was improved to achieve diffusion arc, with enhancement of transmission efficiency of plasma.

Therefore, the program provides a design of arc source with compact structure, high transmission efficiency of plasma, stable discharge, and quasi-state diffusion arc. It can greatly improve discharge and

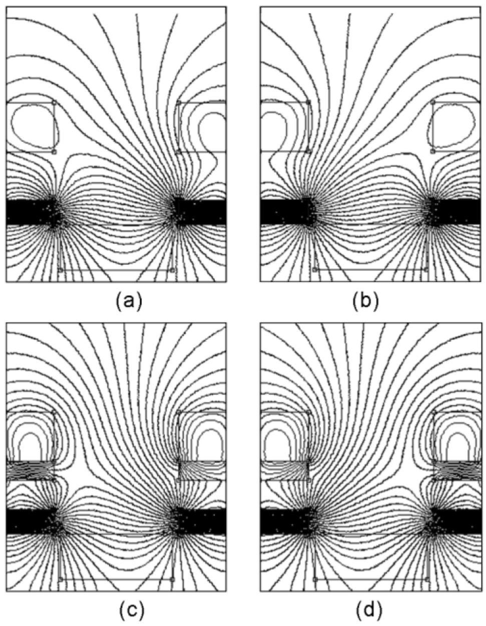

Figure 6. Transient distribution of the coupling magnetic field between diode rotating transverse magnetic field and axial focusing guiding magnetic field

working stability of arc spot, and enhance corrosion uniformity and utilization of target. Meanwhile, emission of MPs can be reduced to improve transmission efficiency of plasma. Furthermore, the program is beneficial to design of overall equipment and suitable for promotion, thus promoting development of tool coating and decorative coating.

Programs of coupled magnetic field were also provided. Figure.7(a) to Figure.7(c) show transient distribution diagrams that diode rotating transverse magnetic field was coupled with axial magnetic field of permanent magnet at the back end of target. Figure.7(a) shows transverse distribution of diode rotating transverse magnetic field on target section without coupling of axial magnetic field at the back end of target. Without effect of other magnetic field, diode transverse magnetic field was completely parallel to target surface, forming an acute angle toward inside edge of target. Figure.7(b) shows transverse distribution diagram of diode rotating transverse magnetic field on target section with coupling of axial magnetic field. Figure.7(c) shows transverse diagram of diode rotating transverse magnetic field with opposite direction of the transverse magnetic field in Figure. 7(b), under coupling of axial magnetic field at the back end of target. It is observed that, certain variation has occurred in distribution of diode transverse rotating magnetic field under strength of axial magnetic field. The magnetic field was no longer exactly parallel to the target surface. Instead, a magnetic field with certain angle toward target was formed. The sharp-angled magnetic field formed an acute angle with one orientation toward the entire target surface, rather than two orientations of acute angle as that of arched magnetic field. Thus, diode sharp-angled magnetic field was formed on target surface. Parallel component of sharp-angled magnetic field was still transverse, thus arc spot conducted liner retrograde motion along the direction perpendicular to transverse component. Meanwhile, under the law of acute angle, arc spot were superimposed with motion trends along guiding direction of transverse component. The motion of arc spot was controllable movement rather than random motion, improving controllability and stability of discharge. Meanwhile, diode sharp-angled magnetic field had rotation with high frequency, so arc spot were also superimposed with rotary motion. Therefore, arc spot conducted motion under certain strength of axial magnetic field and diode transverse rotating magnetic field, as well as integrated coupling with certain rotation frequency. Then, arc spot would be distributed on the entire target surface as quasi-diffusion arc, greatly reducing power density as well as emission of MPs; meanwhile, magnetic field coupling increased stability of discharge.

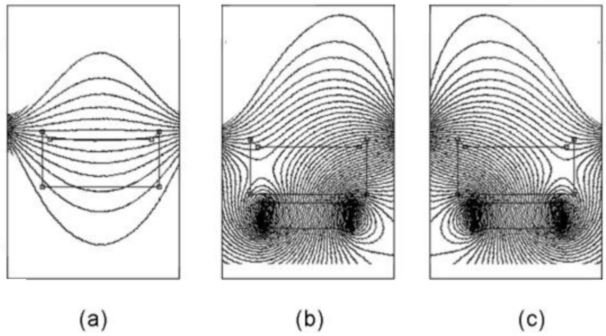

Figure 7. Transient distribution that diode rotating transverse magnetic field was coupled with axial magnetic field of permanent magnet at the back end of target

Conclusions

Cold cathode arc source of arc ion plating has arc spot with concentrated discharge, thus MPs have become an obstacle for deeper application of arc ion plating technology. Large and deep weld puddle as well as local ion bombardment resulted from local overheating should be avoided in order to reduce emission of MPs. Therefore, measures should be adopted to control arc spot movement, improving discharge types and velocity of arc spot. Meanwhile, residence time of arc spot should be shortened, with reduction of local power density and ion bombardment of high density. Traditional arc source designs adopt static or dynamic magnetic field to form a certain magnetic field configuration on target surface, restricting arc motion using law of acute angle; transverse component is used to improve arc spot velocity. Modes of magnetic field are relatively stable, thus easily reducing target utilization and discharge stability while improving arc velocity. At the same time, arc discharge have not been fundamentally improved. arc spot still locally move with changes of magnetic field position, presenting arc discharge of concentrated current, with problem of MPs.

Based on mechanism of arc spot movement in magnetic field as well as relevant researches, the work proposed design principles and program of a compact and efficient quasi-diffusion arc source with cold cathode. Meanwhile, design of arc source and discharge testing were conducted according to the design principles and program. Rotary transverse magnetic field can constrain plasma in the front of target surface, restricting movement of electrons and ions. Thus, electron density near target surface is greatly increased, promoting inter-particle collisions, with increase of ion density and ionization rate; bombardment effect of ions is further strengthened on target, while the enhancement of bombardment effect is distributed on the entire target surface; electron emission of thermal field on target surface is promoted, thus increasing amount of effective electrons. Collective spots with high power density (cause of MPs) are gradually transformed into stronger disperse arc floccules with large-area distribution on target surface. Finally, they become strong disperse arc lines distributing on the entire target surface, with intensified division of arc spot. At the same time, arc spot motion distributed over the entire target surface, leading to uniform heating of entire target surface as well as sharp decline of current density. Quasi-state diffusion arc was achieved, greatly reducing emission of MPs with improvement of evaporation effect and ionization effect. Purified plasma with high density is extracted through axial-focusing guiding magnetic field, thus improving transmission efficiency of plasma. The proposed arc source of quasi-diffusion arc with cold cathode makes full use of combined effects of intensity and rotation frequency of transverse magnetic field. Strong diffusion state of arc spot distributing throughout the entire target surface is completely achieved on cold cathode target, without the need to heat target to high temperature. Through quasi-diffusion arc source with cold cathode, discharge types and working stability of arc spot can be greatly improved; corrosion uniformity and utilization of target can be enhanced to reduce emission of MPs; transmission efficiency of plasma is improved, thus expanding application of arc ion plating technology.

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Effect of multi-mode dynamic coupling magnetic field on arc spots movement in arc ion plating

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Abstract
The work investigated the movement characteristic of arc spots under direct current coupling magnetic field, triangular wave coupling magnetic field and rectangular wave coupling magnetic field with different frequency. The results showed that reversed polarity focusing magnetic field combined with an axial-symmetric magnetic field forming an arched magnetic field with a proper curvature under direct current mode, which could accurately