Advances in Arc Spot Travel Speed to Improve Film Characteristics

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Key Words: Arc vaporization, TiN, Adhesion, Surface roughness

ABSTRACT

Various techniques have been developed to improve the qualities of arc vapor deposited films. Many of these processes sacrifice deposition rates in order to achieve high quality, reduced macro-particle coatings. Increased arc spot surface velocities, at constant currents, improve the deposited film qualities and deposition rates. This paper will review the influences of arc spot travel speeds on arc source materials, film quality and operational conditions.

INTRODUCTION

Vacuum arc based coatings have been commercially available in the United States for over 20 years and their applications are well known. Uses of this technique include metallization and reactive depositions of a wide variety of materials for an even wider variety of applications.

Many control devices have been developed to keep the arc discharge on the face of the cathode and away from the insulators and seals. These methods include and are not limited to: extinguishment methods through gap confinement [1], magnetic control of spot confinement [2], active border control to bounce the arc spot back to the cathode face [3], and a myriad of filtered arc devises with a number of degreed bends and twists [4].

Early designs of vacuum arc systems used large area anodes, usually the chamber walls, to provide the electron return path for operation. These anode "envelops" were thought to have control over providing a uniform coating zone to coat large quantities or sizes of substrates.

As coating byproducts build up on the chamber walls or liners, the electron return path of least resistance changes. During one cycle, the best path may exist near the arc cathode. As coatings and their contaminants (oxides, nitrides, etc.) build up on these areas and increase electrical resistance, the electron return path will seek an alternate route, dragging along with them the coating ions, which changes the deposition zone within the chamber.

U.S. Patent 5,037,522 [5] discloses for the first time, switched arc techniques coupled with the use of discrete anodes. These anodes can have surface areas equal to or less than the cathode surface area. By reducing the size of the anodes, the operating voltage of the arc is increased several times higher than if using the chamber as anode. Discrete anodes, being easier to clean than the chamber walls, provide a stable base for the electron return path and a uniform coating zone within the chamber.

Combining the smaller anodes along with switched arc operation reduces the size of the craters formed from the vaporization process and improves coating qualities.

EXPERIMENTS

Investigations were made to study the differences between using the chamber as anode, discrete anodes, no arc switching and switching with different frequencies. Both the cathode surfaces and the resulting films were compared. No magnetic enhancements were used.

The different processes were:
1. Chamber as anode, no switching
2. Discrete anodes, no switching
3. Discrete anodes, 4 hertz switching
4. Discrete anodes, 16 hertz switching

Cathode Surface Tests

New cathodes were used for each of the surface tests. The vacuum chamber was pumped down to 1.0×10^{-4} Torr and the same argon gas flows were used for all tests. The erosion patterns on the cathodes were documented by microscopy and profilometer scans. Two process "on" times of 250 millisecondes and 5 seconds were used to see single arc tracks and total erosion patterns. Figure 1 shows the visual differences between the 250 millisecond, 5 second and 120 hour arced cathodes run at 120 amps. Figures 2 through 5 show the various arc track patterns of a single path.

44th Annual Technical Conference Proceedings—Philadelphia, April 21–26, 2001 ISSN 0737-5921

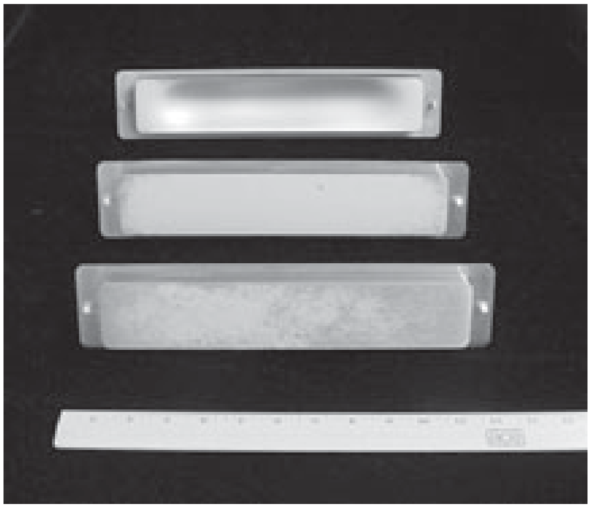

Figure 1: Photograph of 5 milliseconds, 5 seconds, and 120 hours arced cathodes run at 120 amps.

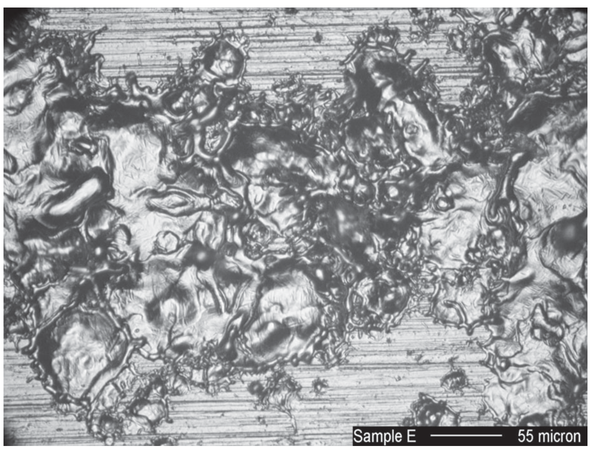

Figure 2: Single arc track of chamber as anode, no arc switching used (random arc)

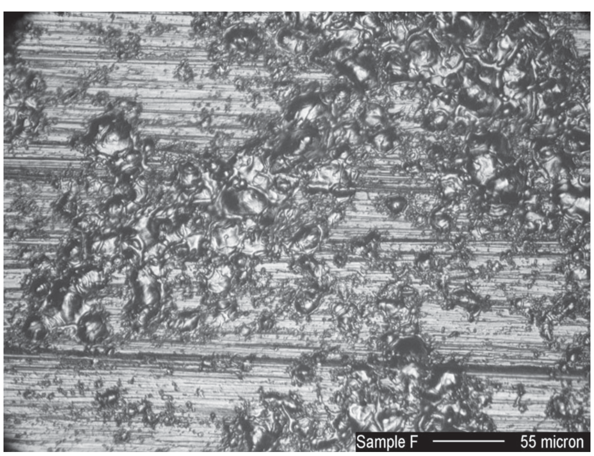

Figure 3: Single arc track of discrete anodes, no arc switching used.

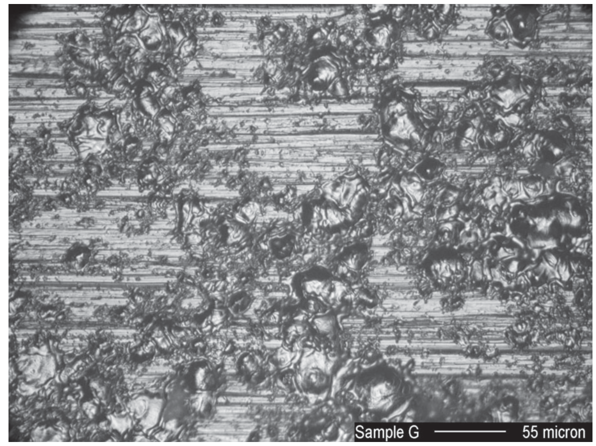

Figure 4: Single arc track of discrete anodes, 4 hertz arc switching frequency

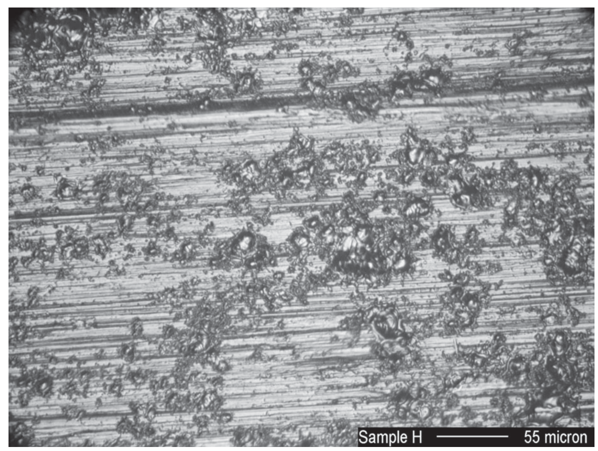

Figure 5: Single arc track of discrete anodes, 16 hertz arc switching frequency

As observed the random arc path of the cathode using the chamber as anode shows the largest crater formation and much macroparticle evidence. Changing to discrete anodes showed a decrease in the size of the crater formation. Increasing the switching frequency also decreased the crater sizes.

A second set of experiments were carried out to observe the total erosion patterns on the cathodes by simply extending the arc on time to 5 seconds and performing the same process cycles as in the 250 millisecond tests. Figures 6 through 9 are micrographs of these resultant surfaces.

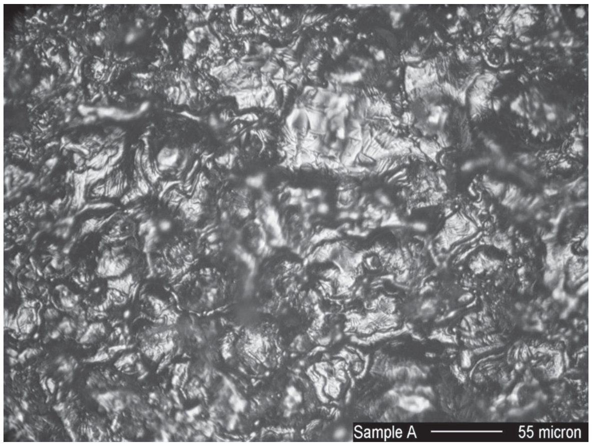

Figure 6: Pattern of 5 second arc operation with chamber as anode and no arc switching.

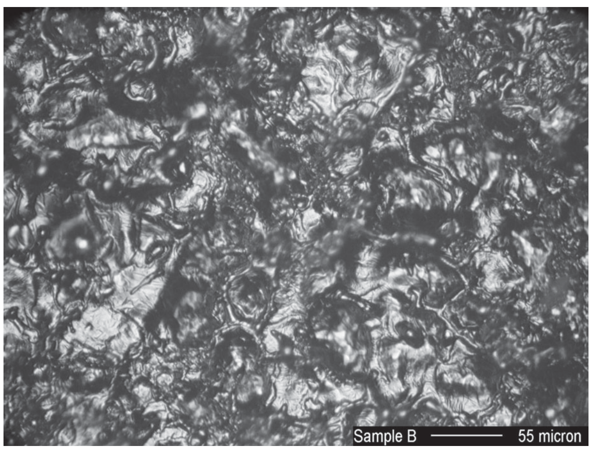

Figure 7: Pattern of 5 second arc operation with discrete anodes and no arc switching.

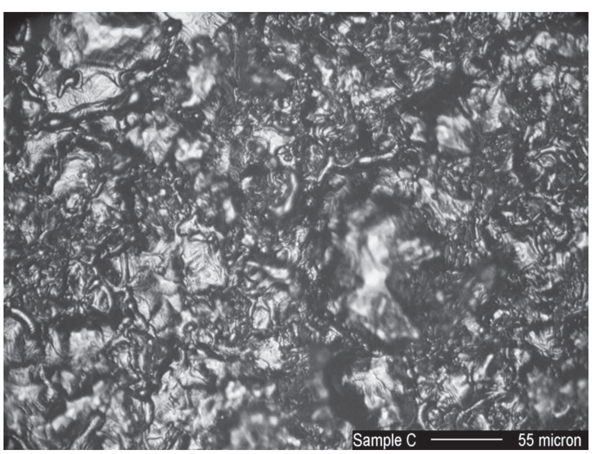

Figure 8: Pattern of 5 second arc operation with discrete anodes and 4 hertz arc switching frequency.

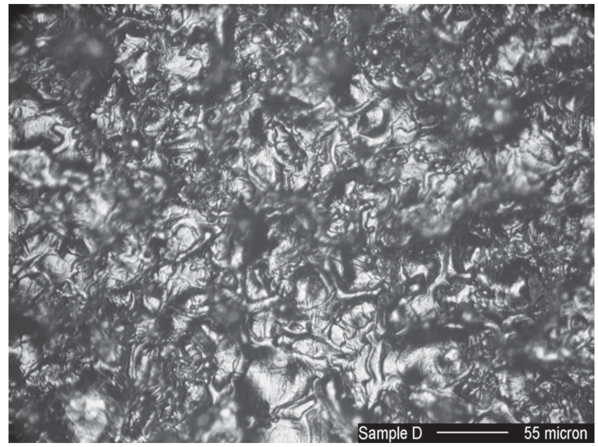

Figure 9: Pattern of 5 second arc operation with discrete anodes and 16 hertz arc switching frequency.

Visually the pattern of the 16 hertz switched cathode appeared slightly smoother than the chamber as anode, unswitched cathode. To more clearly investigate these possible differences, 500 micron length profilometer scans were taken on all 5 second operated cathodes. The results of which are listed below.

Chamber as anode, no arc switching:
Ra 6.7156 µm
TIR 38.7130 µm

Discrete anodes, no arc switching:
Ra 1.3077 µm
TIR 5.9460 µm

Discrete anodes, 4 hertz arc switching frequency:
Ra 1.1126 µm
TIR 5.9140 µm

Discrete anodes, 16 hertz arc switching frequency:
Ra 2.0719 µm
TIR 11.6340 µm

A six-fold decrease in the surface roughness was observed by using discrete anodes in place of using the chamber as anode, which also correlates with the single arc path tests. The nearly doubling of the roughness of the 16 hertz switched arc cannot be currently explained and will be further investigated.

Tests of Deposited Films

Four process sets were run to investigate the titanium nitride films deposited by these various techniques. All processing parameters were repeated in each cycle.

Cathode to substrate distance was 20 inches. The chamber was pumped down to 1.0 x 10^{-4} Torr. Argon gas flows were consistent. Substrate rotation was 6 rpm. Substrate bias used for heating was –600 volts. One 2 x 12 inch arc cathode was used at 120 amps. Maximum temperature was 400°F. Substrate bias used for coating was –100 volts. Nitrogen gas flows were consistent. TiN coating cycle time was 10 minutes.

The substrates used for testing were high speed drill bits, case hardened steel pins and polished stainless steel spring stock. Rockwell C diamond indentations were made on the pins to evaluate adhesion. SEM analysis was performed on the spring stock to compare surface roughness. Coating thickness was measured with SEM, ball crater, and X-ray fluorescence.

Figures 10 through 13 are SEM micrographs of the TiN coatings on the spring steel samples along with the coating thickness. A marked improvement in the reduction of macroparticles was observed with the discrete anode tests. The substrates were not cleaned prior to performing subsequent analysis.

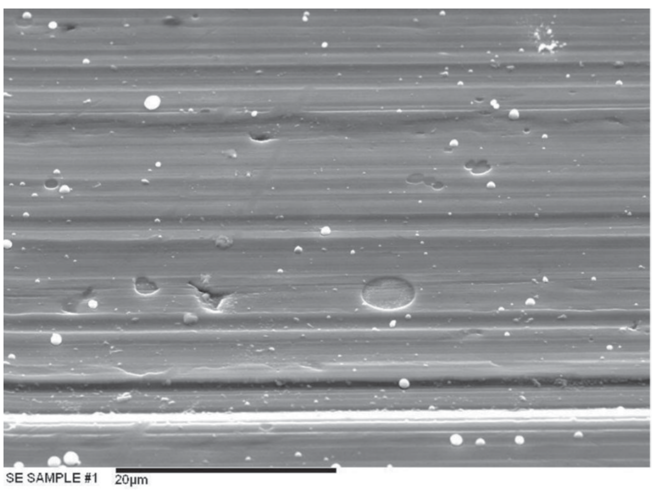

Figure 10: TiN on spring steel, 0.241 microns thick. Chamber as anode, no arc switching.

As observed, the surface of Figure 10 was littered with macroparticles, pop outs and a macro splat. The discrete anode tests also show microparticles and pop outs, but at a lesser degree.

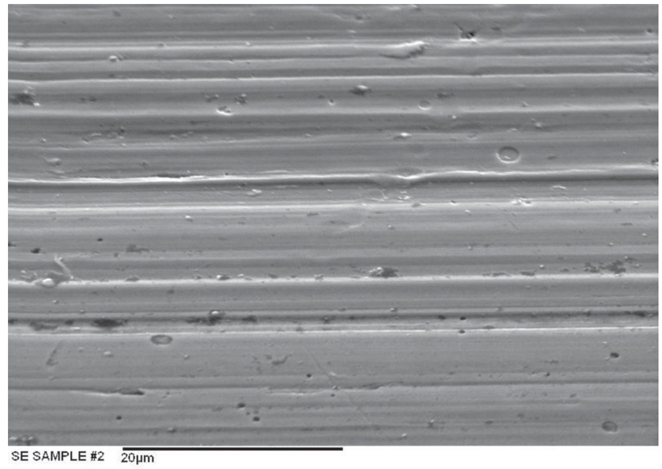

Figure 11: TiN on spring steel, 0.299 microns thick. Discrete anodes, no arc switching.

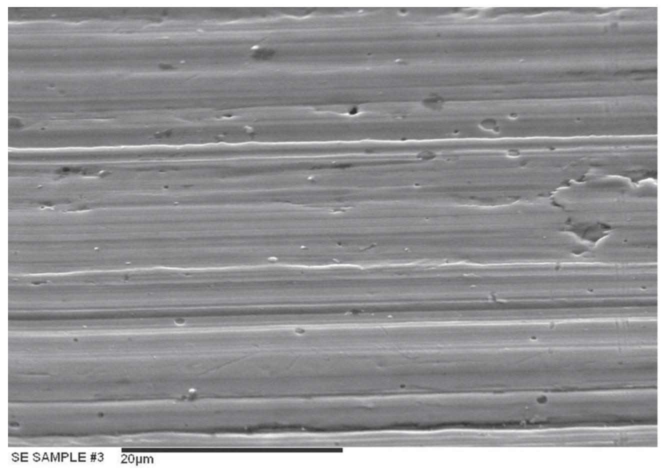

Figure 12: TiN on spring steel, 0.263 microns thick. Discrete anodes, 4 hertz arc switching frequency.

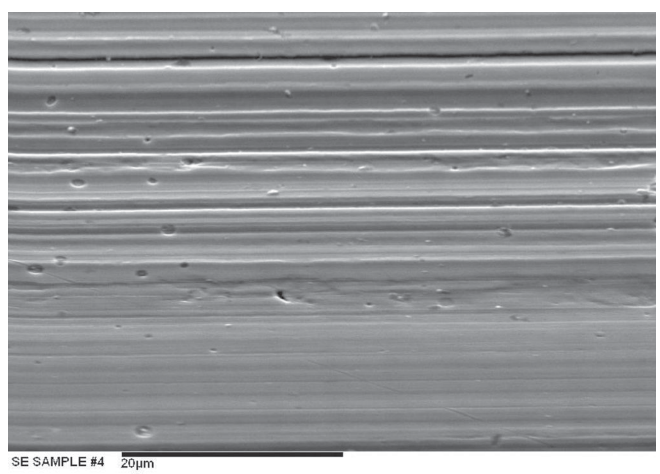

Figure 13: TiN on spring steel, 0.285 microns thick. Discrete anodes, 16 hertz arc switching frequency.

A more dramatic difference was observed on the diamond indented steel pins. The coatings were performed at 400°F to demonstrate the improved adhesion of the discrete anode switched arc process. Operationally, the chamber anode arc process ran at 16 volts during heating and 25 volts during coating. The discrete anode arc process ran at 45 volts during heating and 65 volts during coating. The voltage differences between heating and coating are due to the reactive nature of nitrogen gas on the cathode surface, which increases the cathode surface melting point. Further investigation will be made to quantify the ion energy levels of the two anode set ups for potential plasma differences. Figures 14 through 17 show the 150 kg diamond indentations on the steel pins.

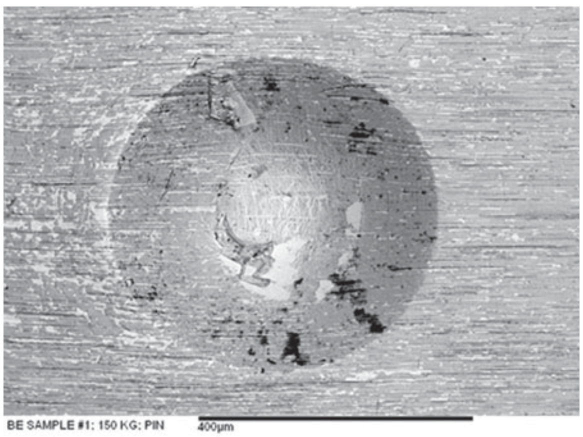

Figure 14: SEM photo of TiN on steel pin. Chamber as anode, no arc switching.

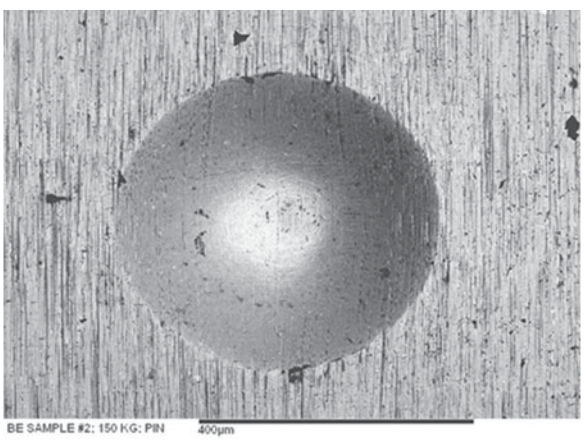

Figure 15: SEM photo of TiN on steel pin. Discrete anodes, no arc switching.

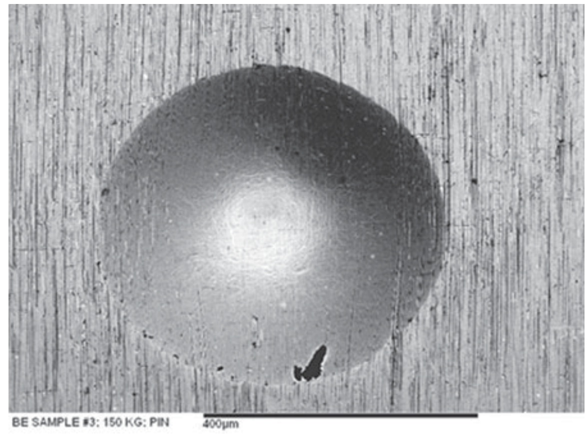

Figure 16: SEM photo of TiN on steel pin. Discrete anodes, 4 hertz arc switching frequency.

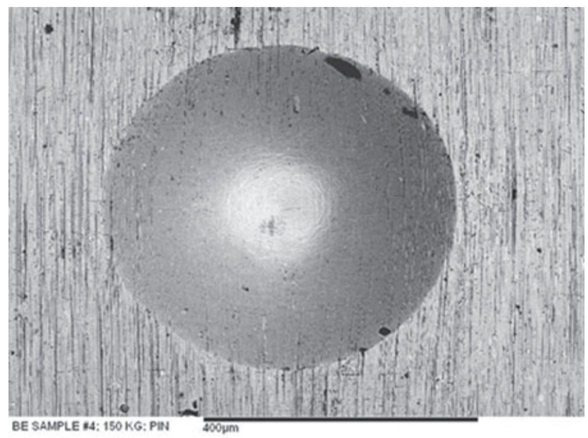

Figure 17: SEM photo of TiN on steel pin. Discrete anodes, 16 hertz arc switching frequency.

CONCLUSION

By using discrete anodes and cathode arc switching, improvements in the deposited films are evident. Coating deposition rates were improved by approximately 15% and the coated surfaces were smoother. Although further studies must be made to fully understand the relationships between cathode and anode surface ratios, influences of gas pressures, and arc switching frequencies, it is clear that coating improvements can be made to existing large area cathode arc coating systems.

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4. Private communication with A. Anders, Lawrence Berkeley Laboratory.
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