Deposition of Tungsten Nanoparticles for Potential Use in Dispenser Cathodes

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Abstract: *Dispenser cathodes have attracted attention in both industrial and academic research for a long time, due to their application as high-brightness electron sources. Since most modern cathodes utilize tungsten as the base material, it is useful to investigate how novel forms of tungsten can influence a cathode. In the present study, nanoscale tungsten particles were generated by physical vapor deposition and deposited onto substrates, to gauge the effectiveness of generating a tungsten coating that can enhance electron emission. These nanoparticles were characterized by scanning and transmission electron microscopy. The tungsten particles formed a continuous nanoporous structure, along with discrete larger particles on the substrate.*

Keywords: Characterization; Cathode; Tungsten; Nanoparticle; Physical Vapor Deposition

Introduction

Cathodes are used extensively as electron sources in vacuum electron devices, which are important for several critical application spaces in defense and communications [1]. These cathodes have a micron-scale porous structure that utilizes a refractory metal as the base material and alkaline metal oxide(s) as impregnant materials [2]. Research on cathodes has addressed impregnant materials, but less work has been done on tungsten itself. Tungsten has served as the standard base material for most cathodes since the development of dispenser cathodes around 1950 [3]. More recently, it was reported that nanoscale impregnant materials contribute to cathode performance [2]. However, it is still unknown whether nanoscale base materials, such as tungsten, can improve the emission properties of a cathode. Physical vapor deposition is a versatile method for depositing thin films and can also be used to fabricate nanoscale metal particles under different processing conditions. The current study involved deposition and characterization of nanoscale tungsten particles using a custom-built nanoparticle generator, followed by electron microscopy, to better understand the fabrication of tungsten in a form that could enhance dispenser cathodes.

Experimental Procedure

Samples were fabricated using a custom-built nanoparticle generator (Fig. 1) for physical vapor deposition (PVD). The source target was 99.95% purity tungsten (AJA International, Inc.), with diameter of 38.1 mm (1.50 inch) and thickness of 3.18 mm (0.125 inch).

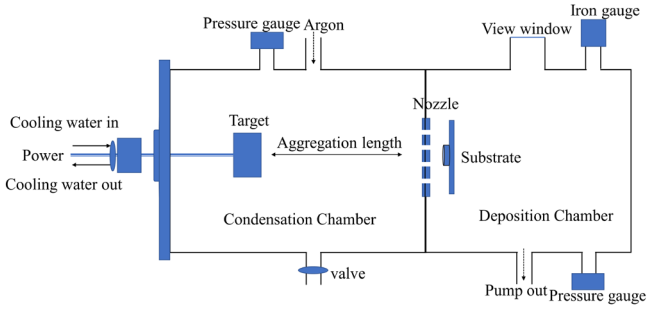

FIG. 1 Schematic of nanoparticle generator used for deposition.

The main parameters that influence nanoparticle size are aggregation length (distance between sputter target and nozzle plate) and the ratio of pressures between the two chambers. Deposition was performed at ambient temperature with a base pressure before deposition of 10^{-7} Torr. During deposition, the pressures in the condensation chamber and deposition chamber were 0.9 Torr and 10^{-3} Torr, respectively, using argon as the process gas. Sputtering power of 125 W was applied for 40 min. The aggregation length was 15 cm, and the substrate was copper foil. Sample morphology and composition were characterized by scanning electron microscopy (SEM) and x-ray energy dispersive spectroscopy (EDS). An electron-transparent lamella was extracted for imaging and EDS in the transmission electron microscope (TEM).

Results and Discussion

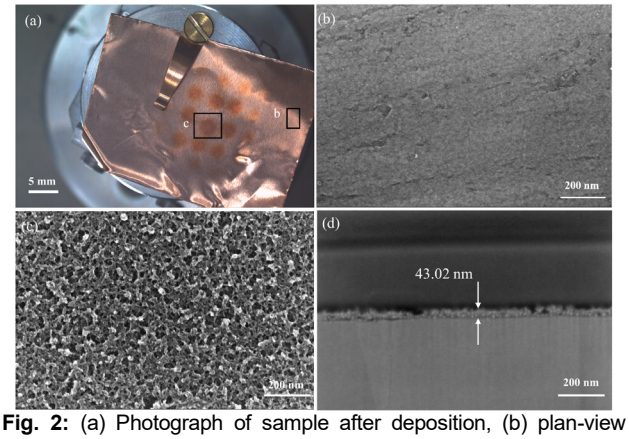

Fig. 2: (a) Photograph of sample after deposition, (b) plan-view SEM image of substrate at position *b*, (c) plan-view SEM image at position *c*, and (d) cross-section at position *c* showing thickness of deposited nanoparticle layer.

As shown by the discolored spots in Fig. 2a, deposition on the substrate occurred in an array pattern corresponding to the nozzle plate. Positions *b* and *c* are at the substrate edge and within the central spot, respectively, and their microstructures are shown in Figs. 2b and 2c. Fig. 2c indicates that a nanoporous network of nanoparticles was deposited at position *c*, while at position *b*, the substrate remained bare. Fig. 2d shows a cross-section at position *c*, revealing the thickness of the deposited layer to be 43 nm. Most tungsten nanoparticles were ~10 nm in diameter.

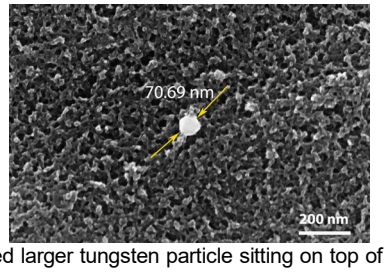

Fig. 3 Isolated larger tungsten particle sitting on top of nanoparticle layer.

In addition to the network of ~10 nm nanoparticles, larger individual particles were observed on the nanoparticle layer surface, with particle size ranging from 20 nm to 100 nm. Fig. 3 shows a discrete, larger particle (71 nm in diameter) sitting on top of the continuous porous network. EDS analysis shown in Fig. 4 confirms that both the larger particle and the continuous nanoparticle network are tungsten. This phenomenon suggests that nanoparticle deposition may not be completely uniform.

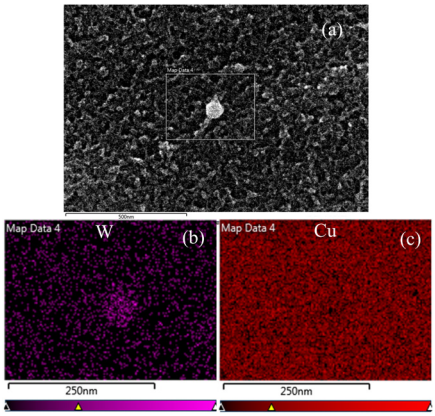

Fig. 4 Image and EDS elemental maps of discrete, larger tungsten particle on top of nanoparticle network: (a) SEM image, (b) tungsten distribution, (c) copper distribution.

Fig. 5 shows TEM observations of the extracted lamella that represents a cross-section. The TEM image in Fig. 5a indicates that the lamella includes three layers: the copper substrate, the deposited layer of tungsten nanoparticles and a carbon layer deposited during the extraction process. Fig. 5b is a high-angle annular dark field (HAADF) image recorded in scanning TEM (STEM) mode, showing atomic number contrast (higher atomic number is brighter). As seen in Figs. 5a and 5b, the deposited layer has a nanoporous structure that results from smaller nanoparticle agglomeration. Fig. 5c is a STEM-EDS map confirming the deposited layer consists of tungsten nanoparticles.

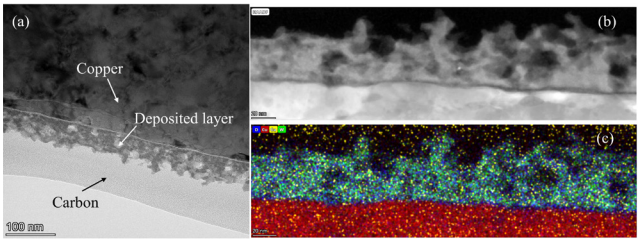

Fig. 5 TEM results: (a) TEM image, (b) HAADF-STEM image, (c) STEM-EDS map showing distribution of elements throughout the cross-section.

It is noted that the tungsten surfaces are oxidized. The nanoscale dimension of the deposited tungsten particles provides enhanced surface area and small radii of curvature, which should facilitate broader barium coverage in a tungsten-based dispenser cathode. In turn, this should improve the electron emission capability of such cathodes. Finally, for cathodes that experience tungsten surface diffusion during activation, in order to form preferred crystallographic facets, the nanoparticle layer may serve as a source of mobile tungsten.

Conclusion

A porous layer consisting of tungsten nanoparticles was fabricated using a PVD method. This layer consisted of nanoparticles with diameter ~10 nm, as well as larger discrete tungsten particles on top of the nanoparticle layer. This nanoscale tungsten may facilitate formation of a preferred surface morphology during activation and lead to enhanced electron emission capability.

Acknowledgment

We gratefully acknowledge extended use of the nanoparticle generator equipment provided by Prof. M.E. Kordesch, as well as helpful discussions.

This work was financially supported by the Defense Advanced Research Projects Agency (DARPA) Innovative Vacuum Electronics Science and Technology (INVEST) program, under grant number N66001-16-1-4041. The views, opinions, and/or findings expressed are those of the author(s) and should not be interpreted as representing the official views or policies of the Department of Defense or the U.S. Government.

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