Ionized plasma vapor deposition and filtered arc deposition; processes, properties and applications

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Recent innovations in vacuum arc deposition have resulted in the development of the filtered arc source as a deposition tool for a range of technologically important materials. The vacuum arc was recognized early on as a potentially useful source of energetic, ionized material and a practical high rate method for depositing thin films with bulk properties and the deposition of new materials. The inherent problem of microdroplet contamination was overcome by several approaches, the toroidal magnetic duct being the most prevalent. The present state-of-the-art of filtered arc deposition is discussed in terms of the current understanding of the emitted fluxes, the properties of the materials deposited by these devices and new applications. © *1999 American Vacuum Society.* [S0734-2101(99)01204-X]

I. INTRODUCTION

The vacuum cathodic arc has been extensively used as a method of thin film deposition with origins that can be traced back as far as 1877 and a patent of Edison in 1892.[1] It was recognized early that the emission products of the vacuum arc have properties that are highly desirable for the deposition of high quality thin films. The process has found major application in the deposition of wear resistant coatings applied to tools and other machine parts primarily in the synthesis of nitrides. The attraction of the technique is due in part to the simplicity of the source in comparison to other technologies, the ability to mount multiple sources in any orientation, the high rate of evaporation achievable, and the properties of the deposition films. Industrial scale arc deposition systems have been commercially available for the past two decades and currently play a dominant role in plasma vapor deposition (PVD) tool coating.

II. CHARACTERISTICS OF EMISSION PRODUCTS

The vacuum arc is a plasma discharge between two metallic electrodes in vacuum where the current is concentrated at 1–10 micron sized sites on the cathode called cathode spots. The current density in the spot is of the order of 10^6-10^8 A cm^{-2} and the spots move rapidly and randomly across the surface of the cathode.[2] The plasma generated by the arc has a concentration of metal ions and the positive ion current is a constant fraction of the arc current, $I_{\text{ion}}=\epsilon I_{\text{arc}}$, where ϵ is in the range of 0.06–0.12. The charge state of the emitted ions has been measured by several groups[3–9] with the average charge depending upon the element, ranging from 1.0 for Li to 3.18 for U. Charge states as high as 7^+ are detected for W. Anders[10] has recently developed a theoretical model for the calculation of charge state distributions (CSD) from vacuum arcs under the assumption that local thermodynamic equilibrium conditions occur in the region of the cathode spot. Excellent agreement with experimentally observed CSDs has been obtained. Furthermore, the model can also predict the enhancement in the average charge, state due to the presence of an external magnetic field. The average charge for W, for example, is increased from 3.18 to 4.17 in a magnetic field of 3.75 mT.

Apart from the multiplicity of charge states in the emitted ions, the intrinsic ion energy is considerably higher in comparison to that of evaporated or sputtered atoms. Ion energy measurements have shown energies of the order of 5 eV for Cd, 37 eV for Al, and 45 eV for Ti.[11] More recent measurements[9] have confirmed the presence of high energy ions from Ti and TiAl alloys in high vacuum and partial pressures of N_2 and O_2 up to 5 Pa. A high deposition energy in the condensing atoms is essential in film growth to promote adhesion and also to disrupt columnar growth.

The most undesirable aspect of arc evaporation is the presence of microdroplets of cathode material in the plasma stream. These particles range in size from submicron to tens of microns and are emitted primarily at low angles to the cathode surface. While these may be tolerated in simple metallurgical coatings or tool coatings, they prevent the application of the arc evaporation process to the more demanding areas of precision optics and electronics. For this reason considerable efforts have been made in recent years to reduce or eliminate droplets using various forms of macroparticle filters.

III. MACROPARTICLE FILTERS

The various types of filters reported in the scientific and patent literature have been described in detail previously.[1,12] The basic objective in macroparticle filtering is to prevent line-of-sight of the particle to the substrate and to guide the plasma efficiently to the substrate, generally using plasma

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