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SYNTHESIS OF ULTRA-THIN SINGLE CRYSTAL MgO/Ag/MgO MULTILAYER FOR CONTROLLED PHOTOCATHODE EMISSIVE PROPERTIES

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Abstract

Photocathode emission properties are critical for electron beam applications such as photoinjectors for free electron lasers (FEL) and energy recovery Linacs (ERL). We investigate whether emission properties of photocathodes can be manipulated through the engineering of the surface electronic structure. The multilayers described here have been predicted to have emission properties in correlation with the film thickness. This paper describes how ultra-thin multilayered MgO/Ag/MgO films in the crystallographic orientations (001) and (111) multilayers were synthesized and characterized. Preliminary results of work function measurements are provided.

Films were grown by pulsed laser deposition at 130 °C for the (001) orientation and 210 °C for the (111) orientation at a background pressure of ~ 5×10-9 Torr. Epitaxial growth was monitored in-situ using reflection high-energy electron diffraction, which showed single crystal island growth for each stage of the multilayer formation. Photoelectron spectroscopy was used to track the chemical state transition from Ag to MgO during the deposition of successive layers. The Kelvin probe technique was used to measure the change in contact potential difference, and thus work function, for various MgO layer thicknesses in comparison with bare single crystal Ag(001)and Ag(111) thin films. The work function was observed to reduce with increasing thickness of MgO from 0 to 4 monolayers as much as 0.89 eV and 0.72 eV for the (001) and (111) orientations, respectively. Photoelectron spectra near the Fermi level revealed electron density shifts toward zero binding energy for the multilayered surfaces with respect to the clean Ag surfaces.

INTRODUCTION

Much of the development of photocathode materials has been aimed to the growth of photoemissive thin films with low work function (WF), and high quantum efficiency (QE) [1]. It has been shown, in some cases, that metal-insulator junctions can lead can lead to the modification of the WF for coverages of a few monolayers of metal oxides on metallic substrates, both theoretically and experimentally [2-5]. Reduction of WF and increase of QE can be achieved simultaneously by coating metal surfaces with Cs or CsBr [6,7]. Cs ion implantation on Cu, Ag and Au has also been shown to also reduce the WF and increase QE while still retaining the robustness of a metal, nonetheless, sacrificing the crystalline quality of the substrate [8]. However, the production of electron beams suitable for new photoinjector technologies in many instances requires low emittance beams from the cathode itself [2]. Therefore, the cathode intrinsic emittance plays an increasingly important role in new electron beam source designs [1].

A theoretical model by Nemeth et al. [2] describes the density functional theory (DFT) simulation of a multilayered structure MgO/Ag(001)/MgO in the configuration of 4 monolayers of Ag(001) flanked by n monolayers (ML) of MgO, where n is a small integer. This model indicates that it is possible to reduce the emittance of a photoemitted electron beam as the surface band structure exhibits a narrowing the density of states near the Γ-point neighboring the Fermi level when the thickness n of the MgO layers is 2 or 3 monolayers. In addition, this and other similar model [3] predict a work function drop of 1 eV to 1.5 eV from that of a bare Ag(001) surface. Measurements using atomic and Kelvin probe force microscopies (AFM and KPFM) show that even the deposition of MgO on a Ag(001) single crystal substrate produces a work function drop of 1.1 eV (1 ML) and 1.4 eV (2 ML) from the work function of the silver substrate, for 1 and 2 monolayers respectively [4,5].

More recently, an effort to quantify the effect on the emittance of 4 monolayers of MgO deposited on a Ag(001) substrate was carried out by Droubay et al. [9] who used Angle Resolved Photoelectron Spectroscopy (ARPES) to show that there was an enhancement of the photoemission intensity at the Γ-point near the Fermi level for the MgO coated Ag(001) in comparison with the uncoated Ag(001) substrate. Nonetheless, the ARPES spectrum for the MgO coated surface also exhibited the presence of sharp side bands near the Brillouin Zone boundaries which had the effect of increasing the total intrinsic emittance to 0.97 μm/mm from 0.47 μm/mm for the bare Ag(001) surface.

In this paper we present test results of multilayered MgO/Ag/MgO films as photoemitters. These multilayers were synthesized by Pulsed Laser Deposition (PLD) and characterized by Reflection High-Energy Electron Diffraction (RHEED) and Photoelectron Spectroscopy (PES) to show the formation of the crystalline and chemical structure of the multilayered films. It was found that there was a gradual decrease of the relative work function for MgO coated Ag surfaces in the (001) and (111) crystallographic orientations with respect to that of uncoated surfaces as the thickness of the flanking layers increased.