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Exploration of the nonideal behavior observed in engineered, multilayer MgO/Ag/MgO photocathodes

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ABSTRACT

Improving photocathode performance by increasing electron emission while lowering the angular spread of emitted electrons can improve particle accelerator performance, expanding the reach of both fundamental and applied science. Materials science expertise is needed to design new photocathodes with these desired properties. In this work, we have undertaken a study of the electronic structure of the interfaces in a multilayer photocathode structure consisting of MgO/Ag/MgO to explore how the fabrication process can lead to nonideal interfaces compared to those constructed in simulations. To study how the fabrication affects the interfaces, hard x-ray photoemission spectroscopy was used to probe the chemistry of the buried interfaces within the thin film multilayer structure of Ag and MgO. In these multilayer structures, we observed that the silver layers were predominantly metallic. A small high binding energy ($\Delta E = 0.69$ eV) peak was also observed in the Ag 3d core level in the samples. This peak is shifted in the opposite direction of the binding energy shift in silver oxides, suggesting that this peak is not due to formation of silver oxides at the interfaces with the MgO. Two possible explanations for the origin of this peak then are charge transfer at the interface from the Ag to the oxide monolayer or the formation of silver nanoparticles during the growth process. Based upon simple depth profiling analysis, we postulate that the former is the more likely explanation but cannot rule out the latter. In addition, the O 1s and Mg 1s core level indicated the presence of $Mg(OH)_2$. The MgO layers react with H_2O in the vacuum chamber or ideal gas used as a buffer during sample transfer. Since the theory predicts strong dependence upon the number of MgO layers surrounding the Ag, the formation of $Mg(OH)_2$ likely contributes to the nonideal behavior, even given the similarity in the electronic structure to MgO (large bandgap insulator) and $Mg(OH)_2$. The speed at which this reaction occurs would significantly limit the lifetime and the utility of the MgO/Ag multilayer photocathodes. In order to custom engineer multilayer photocathodes, complete control over the growth process will be needed to ensure that the ideal surfaces are formed. Using nonreactive materials would greatly increase the lifetime of the engineered photocathodes.

I. INTRODUCTION

In a 2010 paper, Németh *et al.*[1] proposed that emission properties of a photocathode could be tuned by placing ultrathin magnesium oxide (MgO) films on metals, such as silver. The work function for such structures has been calculated to decrease with increasing number of monolayers of the MgO thin film layers. Velázquez *et al.*[2] showed that the experimentally grown multilayer heterostructures do exhibit variable emission properties with increasing MgO layer thickness except that the work function did not drop as rapidly as predicted. The band structure for the case of the 3 ML MgO/4 ML Ag/3 ML MgO was also observed to have a different behavior from that predicted by the model.