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Helium Ion Microscope Analysis of Used JLab Photocathode Samples

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Degradation of the photocathode materials in accelerator-based photoinjectors represents a challenge for sustained beam delivery in proposed fourth generation light sources. The quantum yield in most existing photocathodes degrades over time leading to machine downtime for quantum yield replenishing and in some instances to photocathode replacement. Several photocathode degradation processes have been proposed including ion back bombardment, photochemistry of surface adsorbed species and irradiation-induced surface and bulk defect formation. At present, no consensus exists within the user community as to the mechanisms of photocathode damage. Better understanding of degradation mechanisms of existing photocathode materials could lead to improved emission properties and longer operating lifetime. Existing photocathode materials range from metallic (e.g. copper) to semiconducting (e.g. GaAs) with various structures, dopants, and surface preparations. Photocathode emission requirements include high electron yield and low thermal emittance at high repetition rate. The goal of this work is to thoroughly characterize the used photocathode samples obtained from Jefferson lab using helium ion microscope (HIM), Rutherford backscattering spectrometry (RBS) in channeling and random directions, secondary ion mass spectrometry (SIMS), atom probe tomography(APT) and atomic force microscopy (AFM) to understand the degradation mechanism.

Four different GaAs samples (two control including one as prepared and the other as annealed but not used, and two used to delivered 1000 and 7000 Coulombs) were analyzed using these techniques. Specifically, on control samples, the measurements were made at their geometrical center, while on the used samples, the measurements were made at two different points; one at the damaged spot and the other at a point below the damaged area. HIM images obtained at the damaged spot from the 7000 C sample are shown in Figure 1. Two different fields of view (950 μm and 50μm, from left to right) are shown in this figure. These images were collected in the normal direction. It can be clearly seen from these figures that the surface at this spot is severely damaged. In addition, some cracks are clearly visible on the surface. HIM images (figure 2) collected at the tilt angle of 20o clearly show that these damage features are protruding above the surface of the photocathode samples at the center region of the spot. Stylus profilometer measurement on this spot reveals that the spot has peaks and valleys; the height of the main peak is around 7000 nm while the depth of the valleys ranges from 1000 to 3000 nm. It appears that the material in this area is melted and turned into a feature shown in these figures.

HIM images collected from all four samples (below the damage area on the used cathodes) with a field of view of 1 μm are shown in Figure 3. AFM images obtained from these samples are consistent with these results. The average roughness obtained from AFM measurements on control, 1000 C and 7000 C samples are 0.1 nm, 8.5 nm and 2 nm respectively. It is clear from these results that there is a systematic variation in the topography of the samples as a function of prolonged use of the photocathodes. The larger the usage time the smaller the structures are. Detailed analysis of these samples using RBS, SIMS together with HIM will be discussed.

Figure. 1 HIM images of 7000 C sample at the damage location (normal direction)

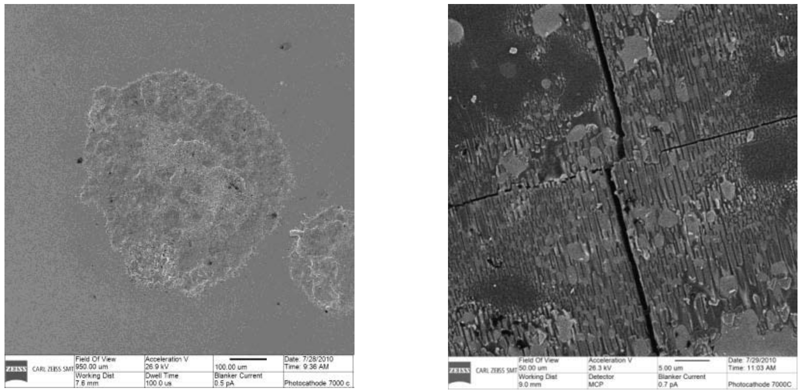
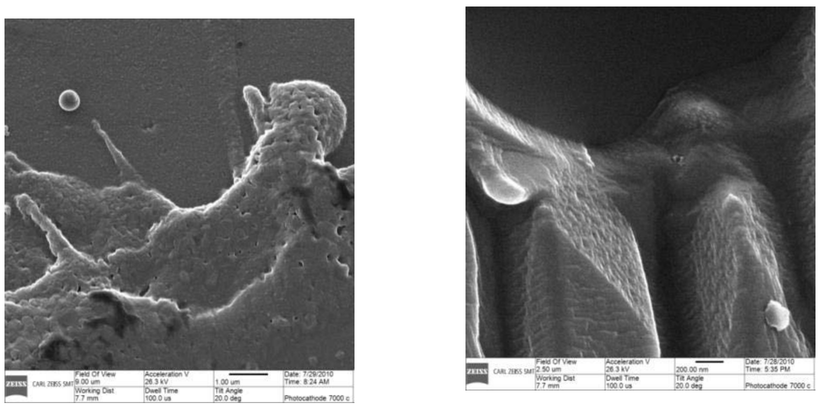


Figure. 2 HIM images of 7000 C sample at the damage location (tilt angle =20o)



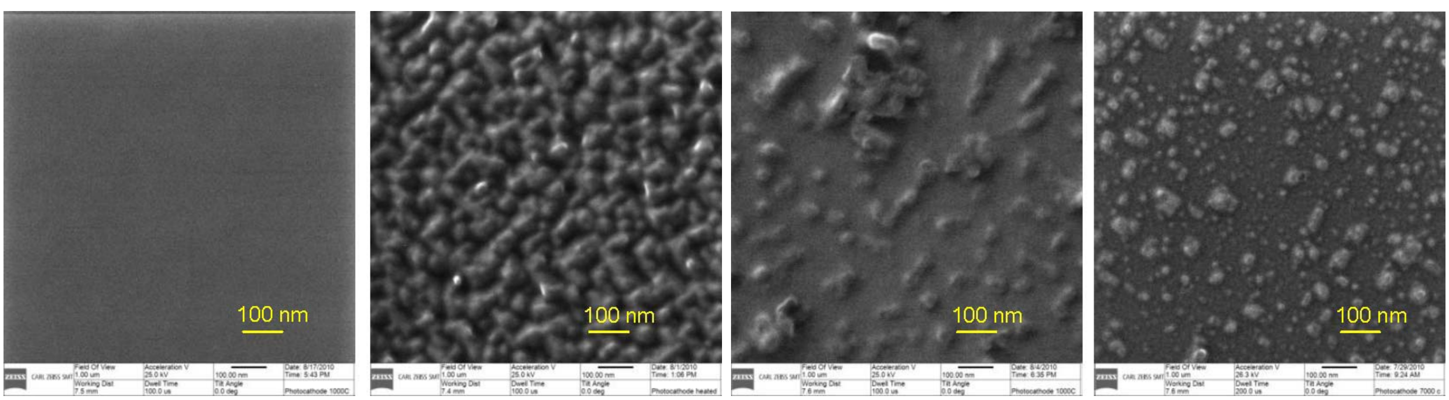


Figure 3. Comparison of HIM images collected from all four samples

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