TOWARDS A MULTIALKALI DISPENSER PHOTOCATHODE: EXPERIMENT AND THEORY*

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Abstract

High performance FELs demand photocathodes with high quantum efficiencies (QE), kHr life, kA/cm^2 peak and A/cm^2 average current, and ps response. In harsh accelerator vacuum conditions, having delicate cesium-based coatings, efficient photocathodes face shortened life. The UMD dispenser photocathode extends lifetime by resupplying cesium from a subsurface reservoir through a porous substrate such as sintered tungsten [1], and recesiation can rejuvenate cesiated cathodes (Cs:Ag) after contamination [2]. These studies have validated theory that can presently treat both coated metals and semiconductors [3] [4]. Other alkali metals (Na, K) may also be deposited singly or together for better QE (e.g., Cs2KSb and other high QE multi-alkalis). Towards that end and to refine the Jensen coated-metal photoemission theory, we here report fabrication and testing of K:Ag, Cs:W, K:W, and Na:W, complementing the previously cited Cs:Ag and Cs:W work. Models of coating-dependent QE analyze the alkali data on polycrystalline metal surfaces. The status of an effort to incorporate these models into PIC beam simulation codes such as MICHELLE [5] shall also be indicated.

EXPERIMENT

Motivation

Past dispenser photocathode tests at UMD have involved cesiated metal surfaces. These characteristically have QE of order 0.1% in the UV. High efficiency photocathodes for future high average current FELs will require QE of order 1% using a green drive laser [6]. This QE can be achieved using multialkali antimonides, as was demonstrated in both the genesis of the photoinjector-driven FEL at Los Alamos [7] and the high average power laser experiment (APLE) at Boeing in the 1980s [8]. Unfortunately these cathodes are sensitive to vacuum conditions and contamination and do not exhibit extended lifetime in the harsh vacuum environment of an FEL.

With a view towards incorporating highly efficient photoemissive coatings such as the alkali antimonides into the already-demonstrated cesium dispenser at UMD, we incorporated evaporative sources of Cs, K, and Na into our photoemission test apparatus (described below). This afforded us the opportunity to refine formerly discussed [4] models of QE as a function of fractional-monolayer surface coverage of a metal substrate with an alkali coating. What follows is the experimental data and theoretical analysis of alkalis adsorbed on silver and on

dispenser-type sintered tungsten substrates, in comparison to previously reported work with cesium.

Apparatus

Quantum efficiency as a function of surface coverage is measured using a low-voltage (though not space-charge limited) DC-biased cathode illuminated through the center of an annular anode by five diode lasers outputting of order 10 mW CW. Thus QE is measured for modest field and laser intensity across the visible range and into the UV at 375, 405, 532, 655, and 808 nm. The cathode surface can be coated by any of four co-mounted cathode-facing alkali vapor sources from Alvatec (which utilize intermetallic bismuth compounds sublimating pure alkali metal when resistively heated). The approximate thickness of alkali deposited is monitored with a quartz crystal with 0.1 Å resolution. The metal surface is cleaned between subsequent experimental runs using a 6.4 keV argon ion beam.

Data

The data for alkalis on tungsten is shown in Figs. 1-3, deferred until after the discussion of the theoretical curves which appear also in those figures. The data for potassium on silver is shown in Fig. 4.

THEORETICAL MODEL

The theoretical model used in this analysis has been detailed earlier [4], but here is improved in one significant aspect. Formerly, the f-factor (f, defined in Eq. 1) arising from the Gyftopoulos-Levine treatment of surface coverage [9] was considered a parameter of the model, unrelated to the thickness measurements from which coverage is experimentally inferred. Here we consider f is related integrally to surface coverage of the cathode, and as such, can (a) be better matched with the existing experiment via an informed fit with the data and (b) be used to more appropriately scale data values of thickness to values of percent-monolayer-coverage. The fit is justifiable since it is clear that a polycrystalline or nonuniform surface such as is exhibited by a dispenser substrate may easily have an f-factor not well-characterized by a single crystal face. The latter (scaling) effect is an important advance over previously reported comparisons of alkali-coated metal photoemission experiment and theory, without which, smaller adatoms such as K and Na cannot have the proper monolayer definition.

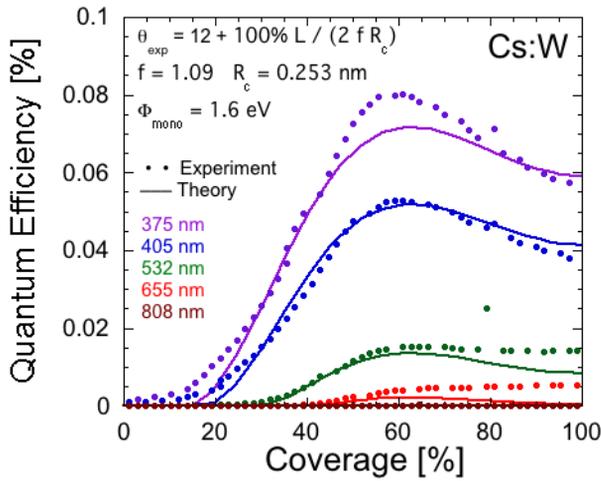The definition of the f-factor as used here, following Gyftopolous-Levine, is
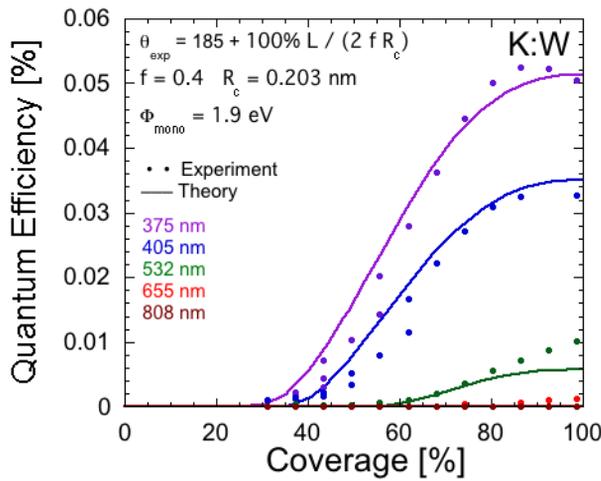
Figure 1: Cesium on tungsten.
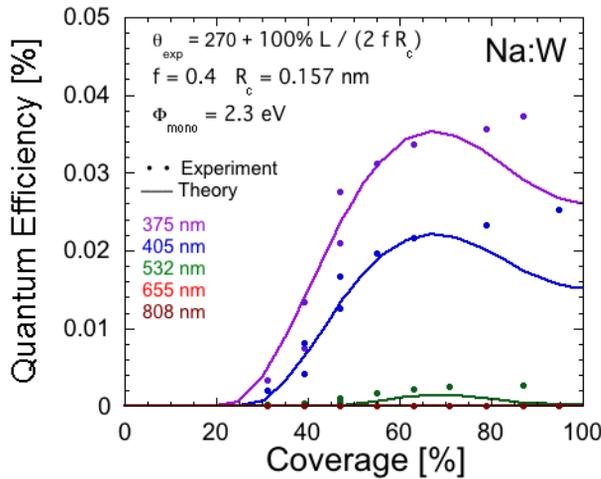

Figure 2: Potassium on tungsten.

Figure 3: Sodium on tungsten.

$$f \equiv \theta_{monolayer} / F_{monolayer} = 1 / F_{monolayer} \qquad (1)$$

where $F_{monolayer}$ is the fraction of the surface covered by the adsorbate.

When comparing to experimental data where the amount of alkali on the surface is given in effective thickness (Å) as read from the deposition monitor, it is necessary to convert from this linear scale to percent monolayer coverage. Previously [4] this was done by scaling by the bond length of the bulk material (twice the covalent radius). However, because adsorbate atoms may not be arranged in bulk the same as on the surface of the metal, it is necessary to include the f-factor as in Eq. 2,

$$\theta = \theta_0 + L / (2 f R_c) \qquad (2)$$

where L is the measured effective thickness, f is as defined in Eq. 1, R_c is the alkali covalent radius, and θ_0 is an offset accounting for nonzero initial L and the actual workfunction of the surface prior to an experiment (which may differ slightly from the bare metal value).

THEORY-EXPERIMENT COMPARISON

The procedure for comparing theory and experiment was as follows: find the appropriate f by matching the slope of the initial data while using the scaling of Eq. 2, with electronic workfunction at monolayer coverage set by literature, if available, or by best fit (in the case of Na:W).

Shown in Fig. 1 is quantum efficiency of cesium on tungsten. Note that the f-factor is nearly unity, which is why our previous work overlooked its importance in scaling to surface coverage. In Fig. 2 is potassium on tungsten and in Fig. 3, sodium; note that in both cases f is now 0.4, which reflects the much smaller atomic size of these atoms while adsorbed on a substrate where they pack sparsely. In all three cases experiment and theory
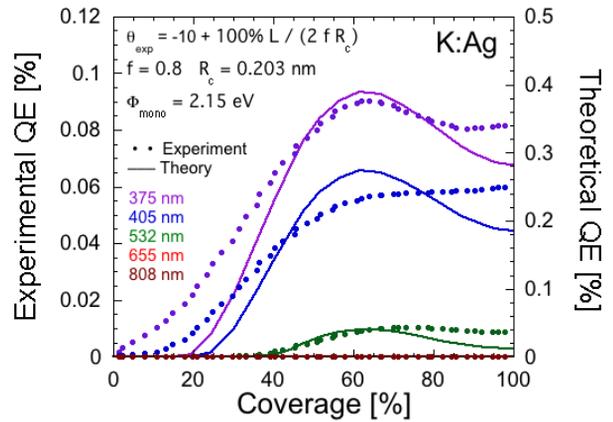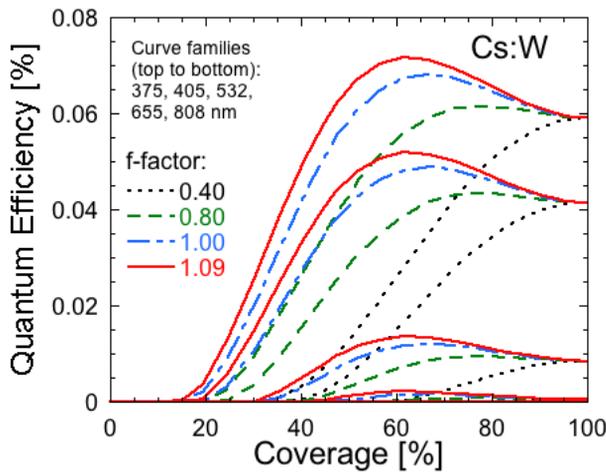

Figure 4: Potassium on silver.
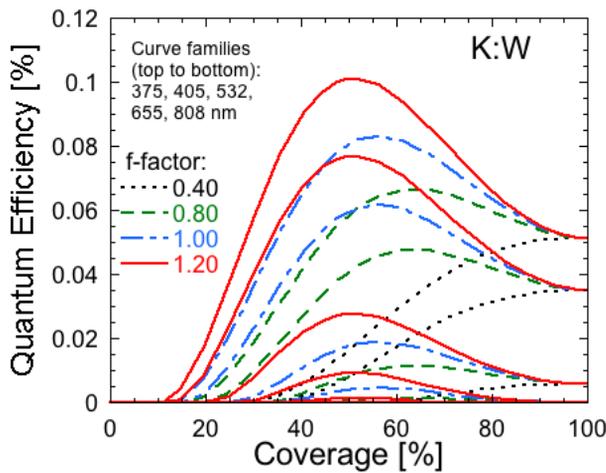
Figure 5: Cs:W study of f-factor. (f_{actual} = 1.09)
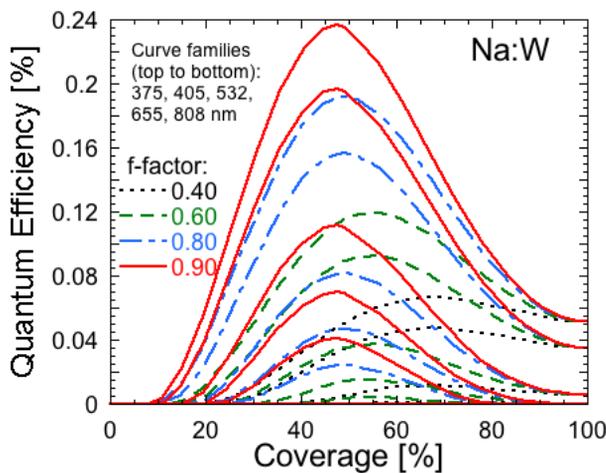
Figure 6: K:W study of f-factor. (f_{actual} = 0.40)

Figure 7: Na:W study of f-factor. (f_{actual} = 0.40)

demonstrate very good agreement.

In Fig. 4 is the case of potassium on silver. This is particularly interesting because the f inferred from fitting the data is 0.8, twice that for potassium on tungsten. The difference is attributed, in the most general sense, to the relative size of the adsorbate atoms and the size of a unit cell in the metallic substrate. K has a covalent radius of 4.06 Å, compared to a lattice constant of 3.16 Å for W and 4.09 Å for Ag. Hence adjacent bonding sites are speculated to be half filled for tungsten compared to silver. Also of note in Fig. 4 is the different scale of the theoretically predicted QE. It is characteristic for theory to predict somewhat higher QE than is found experimentally, particularly when given experimental limitations on polishing and cleaning metal surfaces. Therefore, differences of a factor of 2-4 might be expected and are not therefore considered a critical issue.

A further study of the effect of f-factor in the theory was performed for the three alkalis on tungsten, as shown in Figs. 5-7. One should note that for Cs, because of the already large f, the family of curves shows the effect of *reducing* the modelled value of f, whereas with the small f of K and Na on W, the family of curves shows the effect of *increasing* the modelled value of f. We see that when more closely packed in the monolayer on the surface, the alkali adatoms exhibit a more pronounced peak QE at submonolayer coverage, as initially indicated by Gyftopoulos and Levine. In addition, the magnitude of the maximum QE also improves with larger f, or closer monolayer packing. Finally, the initial turn-on of QE is shifted to slightly smaller coverages with closer monolayer packing, simply reflecting the fact that the requisite workfunction lowering by the average surface dipole of the adatoms is more quickly achieved when atoms adsorb closer together.

SUMMARY

Theory-Experiment Comparison

We have discussed recent photoemission data on dispenser-like substrates for alkali coatings of Cs, K, and Na in preparation for future multialkali antimonide cathodes. Refined theory compares well with the data. The analysis yielded an important modification to existing models of coated metal photoemission: the f-factor needed to be included in any conversions between percent monolayer coverage (used in the theory) and effective coating thickness (measured experimentally).

Incorporation into beam codes

On a related note, the effort to incorporate appropriate models of photoemission into PIC codes such as MICHELLE is progressing. We are now including not only the aforementioned coated-metal photoemission models but also recently reported semiconductor photoemission models [3]. The latest PIC simulation results using these models are deferred to a future work.

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