

## MECHANISM OF PHOTOSTIMULATED EXOELECTRON EMISSION

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### ABSTRACT

This paper discusses the changes in photoyield of pure aluminum and binary aluminum alloys due to fatigue induced surface roughness in the energy range 5 to 11 eV. As evidenced by a surface replication technique, the roughness is caused by dislocation slip steps forming a near perfect grating on the surface. The grating causes a resonant coupling of incident photons to surface electromagnetic waves in the material, the decay of which can eject electrons if the resonance energy exceeds the material's work function. The theory of this roughness induced photoyield will be briefly reviewed. The effects of fatigue softening and hardening, of oxide layer thickness, and of alloying on the photoyield as a function of photon incident energy will be reported.

The term "exoelectron emission" is used in several different contexts. The phenomenon of interest is the mechanism by which fatigue increases the photoyield of aluminum. Typical results<sup>1</sup> are shown in Fig. 1 for work hardened and well annealed Al 1100. The photocurrent (electrons/incident photon) was measured with an electrometer to ground; the intensity of the incident light was measured by measuring the photocurrent from a gold sample and using the literature value for its photoyield. For both the well-annealed sample (for which internal stresses are increasing) and the work-hardened (for which internal stresses are decreasing) the effect of fatigue is to increase the photo-yield over the range of photon energy 5.7 to 8.5 eV, but the increase occurs much more rapidly with fatigue for the well-annealed sample.

Since photoemission is a surface effect (because the escape depth of the photoelectrons is only about 5nm), one expects changes in surface character with fatigue are responsible. Surface replicas of the two kinds of Al sample described above were prepared and examined in the transmission electron microscope. The results are shown in Fig. 2. Several conclusions can be drawn. Cracks are evidently not a factor, since none are visible on this scale, so any cracks must be much less than the wavelength of the light (about 0.16  $\mu\text{m}$ ). The most important result is that the slip steps are much greater on the well-annealed surface than they are on the work-hardened sample, suggesting that they are the source of the increased photoyield. Note that these slip steps have an approximate periodicity of about 50 nm.

The essential ingredients of the photoemission process are shown in schematic fashion in Fig. 3a. The calculations we present below demonstrate that there is a resonant coupling to the surface plasmon by the slip steps which increases the absorption of light, and that this increased absorption is sufficient to account for the increased photoyield without invoking any additional mechanism such as changes in the transport (oxide depth, for example) or escape probability (a change in work function, for example). The surface plasmon is a surface electromagnetic wave at the oxide-metal interface. It cannot couple to external radiation with a flat surface because it is impossible to match both the spatial phase ( $2\pi \sin \theta x/c$ ) and the temporal phase

( $ft$ ) across the boundary. However, the presence of the slip steps produce a weak spatially periodic term in the dielectric function, and this term results in induced fields containing (from the sum and difference of the incident field period with that of the dielectric function) long wavelength terms which can couple to incident light. The coordinate system for this model is shown in Fig. 3b. To test this conjecture, the absorption was calculated from Maxwell's equations.

The results of the theoretical calculation<sup>2</sup> are shown in Fig. 4. Figure 4a shows the absorption of p-polarized light by the oxidized aluminum for different values of the amplitude of the slip steps. The largest value considered,  $h=1.5\text{nm}$ , represents a slip step height of 3.0nm, or about 7-8 lattice constants, a reasonable maximum value. The effect of different slip step spacings is shown in Fig. 4b. The experimental value is about 50nm. The calculation shows that 80nm is inconsistent with the effect observed that 40 and 60nm are both consistent with the general wavelength dependence of the observed increase in photoemission, with 40nm in somewhat better agreement.

Figure 5 shows the experimental data of Fig. 1 replotted to show the change with fatigue and normalized by the calculated photoyield for a perfect surface<sup>2</sup>. That is, this curve shows the photoyield after N fatigue cycles minus that at zero cycles, both divided by a normalizing factor. The spacing and magnitude of the two peaks seen here agrees well with theory for steps 2-3nm high and 50nm apart.

The preceding does not explain the gradual nature of the change with fatigue, but this can be understood from the micrographs shown in Fig. 6a and 6b. These show well-annealed Al at different stages in fatigue at different magnifications. Fig. 6a shows the development of slip on a 2 $\mu\text{m}$  scale, demonstrating that there is little change in the nature of the slip steps. Figure 6b, the same samples on a 40 $\mu\text{m}$  scale, shows that the area covered by plastic deformation does increase with fatigue. The change in photoyield is plotted against this increased area in Fig. 6c, demonstrating a linear growth.

The overall mechanism then is as follows. The photon beam used in these experiments covered a relatively large area of the sample. Those portions of the sample which had experienced plastic deformation permitted resonant coupling to the surface plasmon, increasing the photoyield by an amount proportional to the area covered by slip steps. These plasma oscillations then decayed to electrons which then had sufficient energy to escape, thereby increasing the photoyield.

#### Acknowledgement

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#### References

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2. W. J. Pardee and O. Buck, submitted to Appl. Phys.

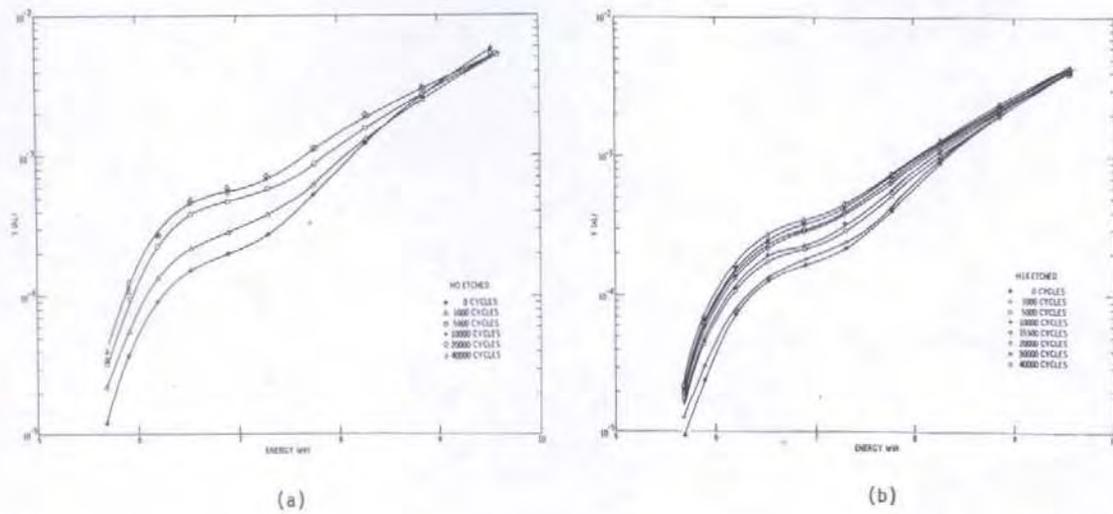


Figure 1. (a) Photoyield (electrons/incident photon) of well-annealed oxidized (12 nm oxide) Aluminum 1100 as a function of photon energies for various states of fatigue (4000 cycles = 10% fatigue life. (b) Photoyield (electrons/incident photon) of work hardened oxidized (12 nm oxide) Aluminum 1100 as a function of photon energies for various states of fatigue (4000 cycles = 10% fatigue life).

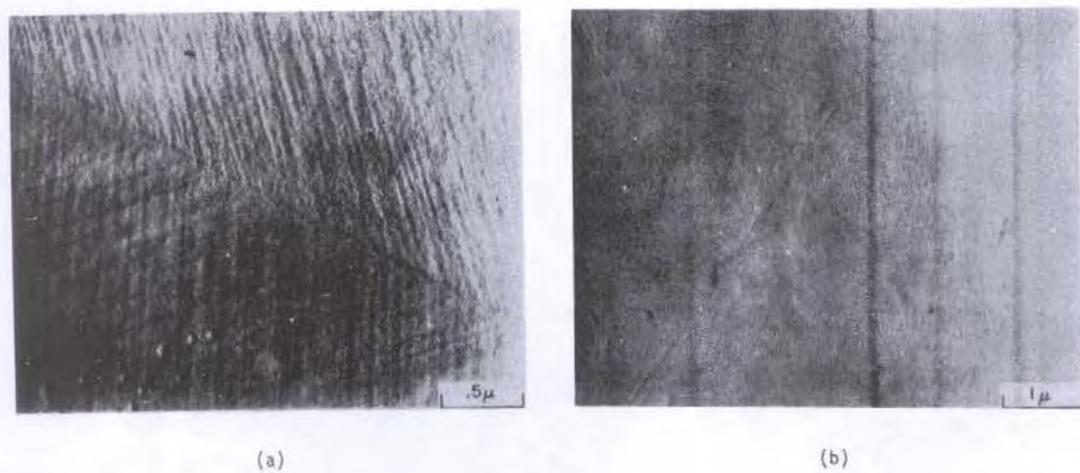


Figure 2. (a) TEM micrograph of well-annealed Aluminum 1100 at 10% life; (b) TEM micrograph of work hardened Aluminum 1100 at 10% life.

PHOTOEMISSION semi-classical & schematic

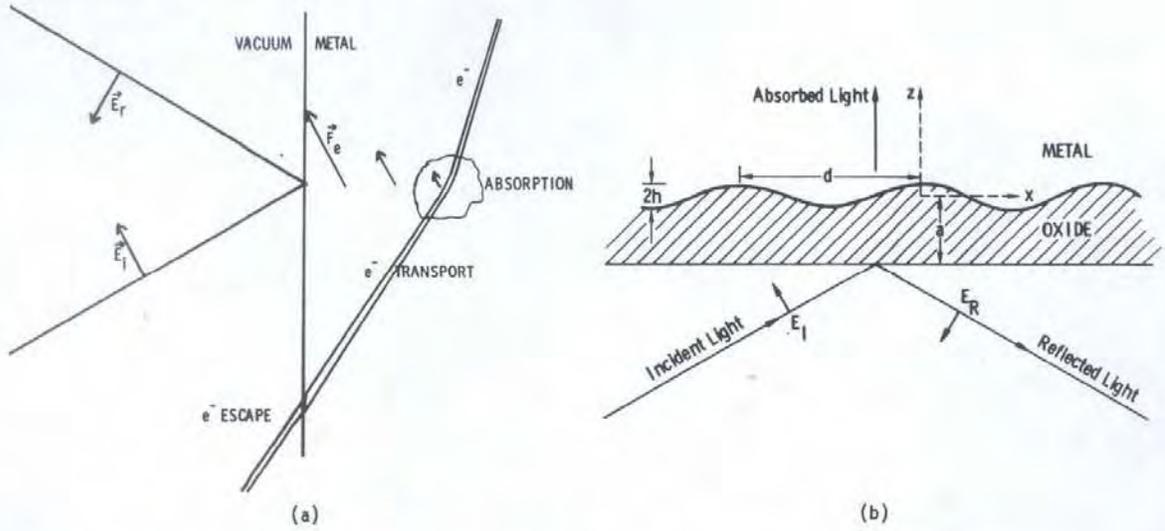


Figure 3. (a) A semi-classical illustration of the essential processes involved in photoemission. (b) Diagram (not to scale) of the model for which Maxwell's equations were solved (to leading order in  $h$ ).

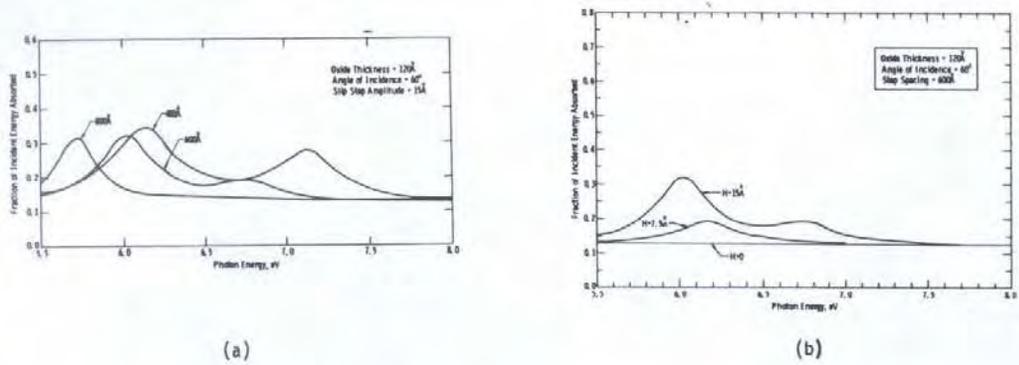


Figure 4. (a) Theoretical absorption of p-polarized light as a function of photon energy for various slip step amplitudes. (b) Theoretical absorption of p-polarized light for various slip step spacings.

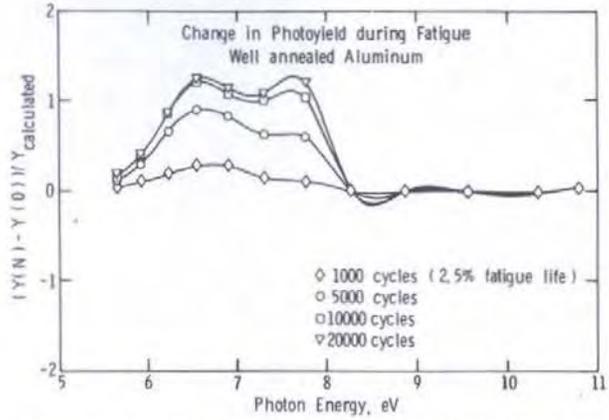


Figure 5. Experimental change in photoyield with fatigue, normalized by theoretical photoyield for a flat surface.

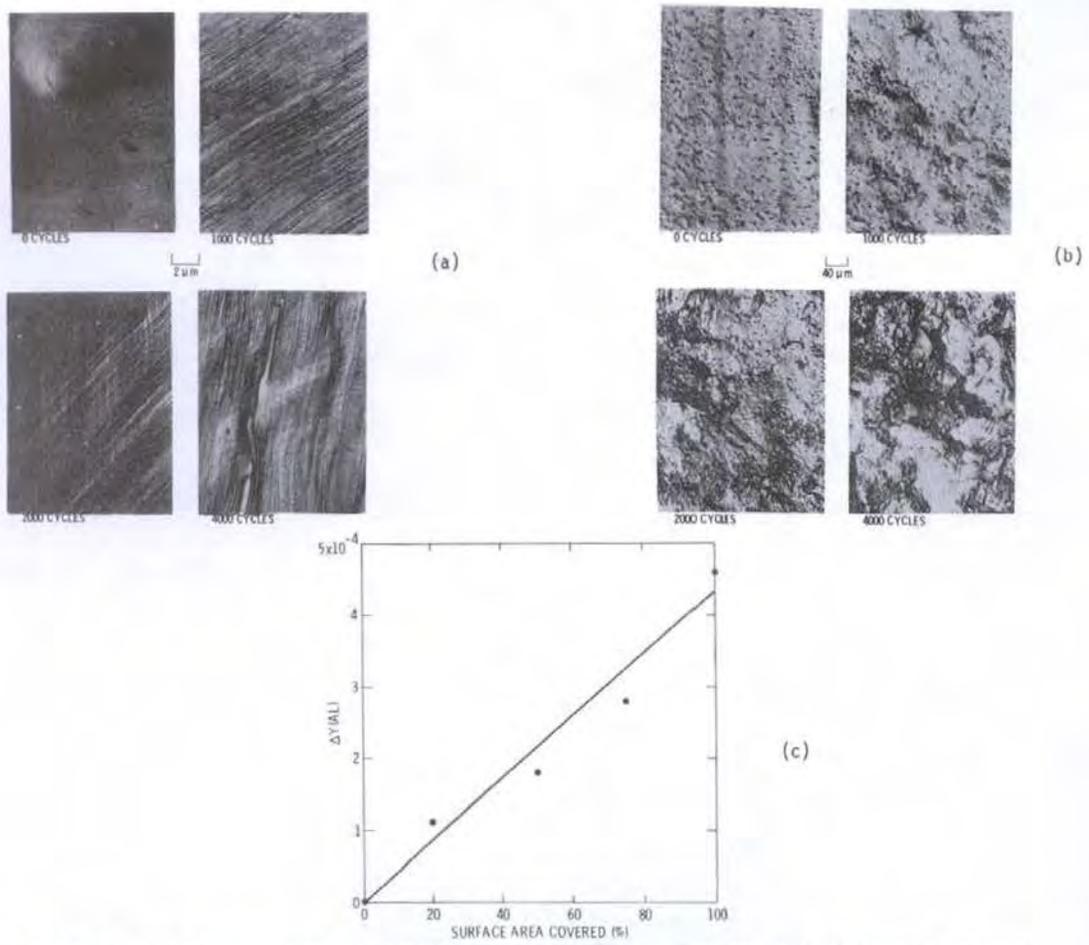


Figure 6. (a) Micrographs of well-annealed Aluminum 1100 at various stages of fatigue (2 μm scale). (b) Micrographs of well-annealed Aluminum 1100 at various stages of fatigue (40 μm scale). (c) Change in photoyield vs. area covered by slip step.