Temperature and Thickness Dependence of Transition Radiation From Thin Silver Foils

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The transition radiation from vacuum evaporated silver foils bombarded by 25-, 40-, and 60-keV electrons was investigated as a function of foil thickness and temperature. The intensity at the wavelength of maximum emission was found to oscillate with foil thickness as predicted theoretically. The peak in the spectrum was observed to increase in intensity and also to be shifted to shorter wavelengths when the foil temperature was decreased. The observed shift in wavelength was much greater than the value predicted on the basis of a change in the electronic density alone as would be the case for a pure plasma oscillation. The additional shift may be due to the change in the Fermi distribution of electrons which participate in the interband transition. The emission from silver thus appears to arise from a hybrid type of resonance with the pure plasma resonance being shifted in energy by the interband transition.

THE radiation emitted by thin silver foils bombarded by 25-, 40-, and 60-keV electrons was investigated as a function of foil thickness and temperature. The vacuum evaporated foils varied in thickness from 300 to 2300 Å and the temperature was varied from 90 to 390°K. The spectral distribution of photons was determined with a Seya-Namioka vacuum uv spectrometer equipped with a Glan prism analyzer in the exit arm. Details of the experiment have been described previously.[1,2]

The theoretical and experimental spectra for a foil 660 Å in thickness are shown in Fig. 1. The theoretical spectra are calculated from the equation of Ritchie and Eldridge[3] using both the dielectric constants of Ehrenreich and Philipp[4] for bulk silver and also the constants of vacuum evaporated silver determined at this laboratory.[5] The discrepancy of about 30% noted previously[2] between the theoretical and experimental intensities at the peak wavelength ($\lambda=3300$ Å) is removed when the experimental spectrum is compared with the theory using the dielectric constants of evaporated silver.

An oscillatory behavior of the intensity at the peak wavelength as a function of foil thickness is predicted by the theory. The experimental results for electron energies of 25, 40, and 60 keV shown in Fig. 2 agree well

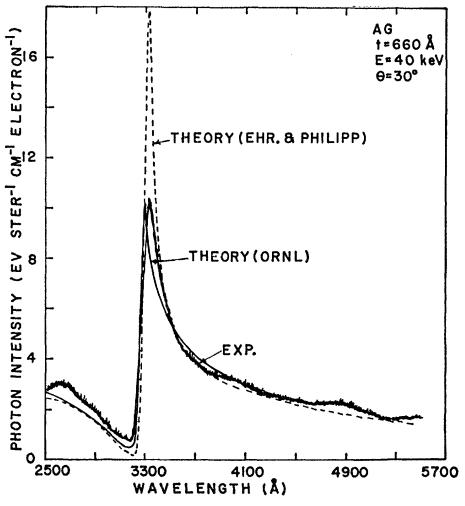

FIG. 1. Spectral distribution of transition radiation from electron-bombarded silver foil.

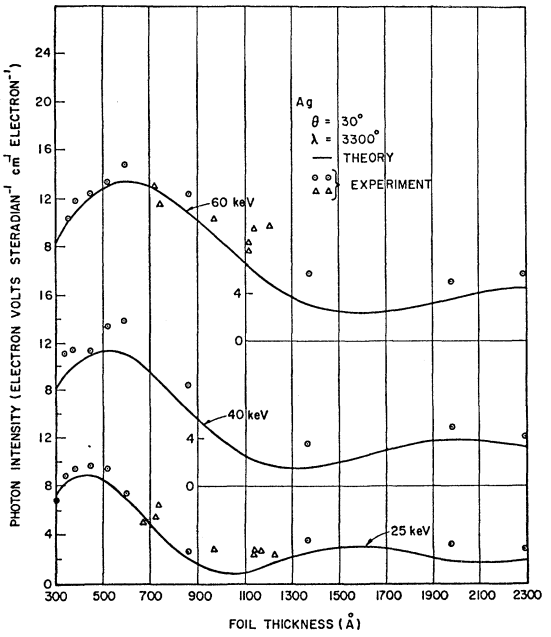

FIG. 2. Photon intensity at peak wavelength as a function of foil thickness.

* Operated by Union Carbide Corporation for the U. S. Atomic Energy Commission.

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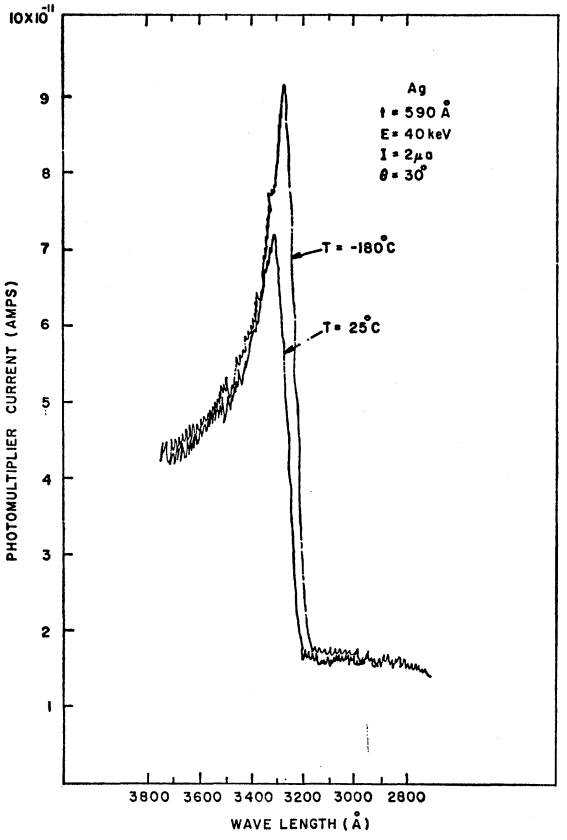

FIG. 3. Recorder traces of the photon emission from Ag foil at room temperature and liquid nitrogen temperature.

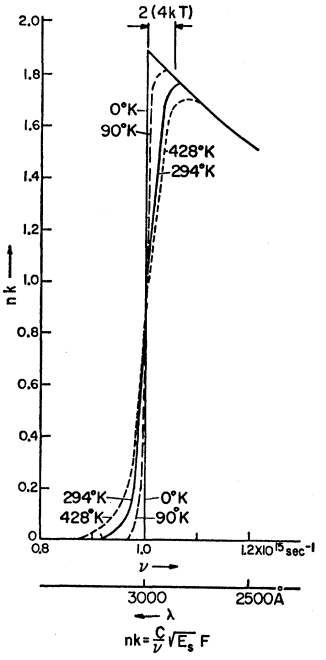

FIG. 5. Change in the absorption nk as a function of temperature.

with the theoretical predictions. This behavior is due to the constructive and destructive interference of the photons produced at the front and back surfaces of the foil. The second maximum is weaker than the first because of the absorption in the foil of the photons produced at the front surface. The first maximum is predicted to appear at $\beta\lambda_p/2$ where β is the electron velocity relative to that of light and λ_p is the wavelength of the peak. The maxima should thus vary with energy as is clearly seen in the figure with the first maximum occurring at a foil thickness of around 400 Å for 25-keV electrons, 500 Å for 40-keV electrons, and 600 Å for 60-keV electrons. This oscillatory dependence is an excellent demonstration of the transition radiation

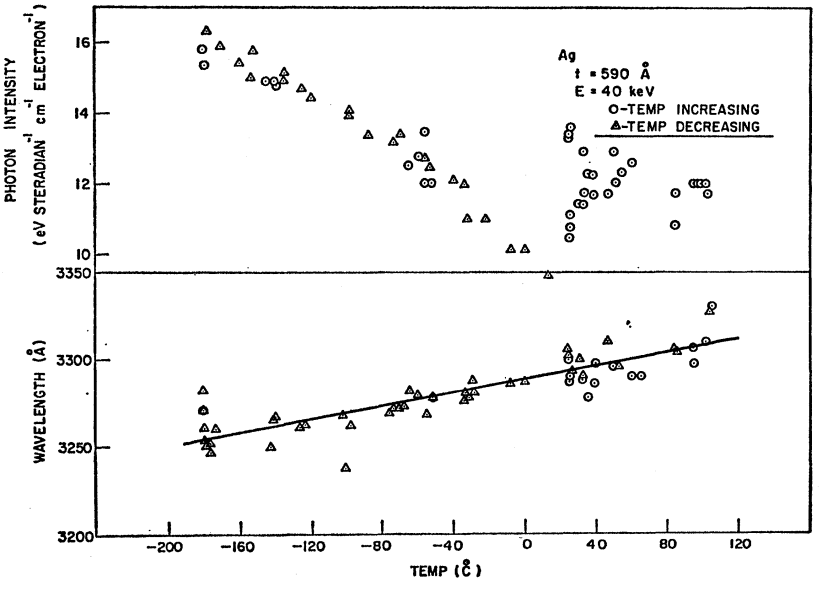

FIG. 4. Variation of photon intensity and peak wavelength as a function of foil temperature.

description of photon production, i.e., that photons are produced by a uniformly moving electron whenever it crosses any interface.

Recorder traces of the peak in the silver emission for two foil temperatures are shown in Fig. 3. The peak is seen to increase in intensity and also to be shifted to shorter wavelengths when the foil is cooled from room temperature to liquid nitrogen temperature. This region of the spectrum was repeatedly scanned as the temperature of the foil was decreased from 300 to 90°K and then increased to 380°K. The variations in intensity and wavelength are shown as a function of temperature in Fig. 4. The peak wavelength shows a linear dependence with temperature with a slope of 0.21 Å/deg or -2.5×10^{-4} eV/deg.

Earlier studies[6,7] on Ag films of the variation in wavelength of the minimum in reflection and maximum in transmission as a function of temperature have revealed similar results. Joos[7] found a value -4.1×10^{-4} eV/°K and described the change in the absorption in terms of the change in the Fermi distribution of electrons in the 5s band. His figure for the absorption

$$nk=C(1/\nu)F(E_s)^{1/2},$$

where C=dimensional constant, E_s=energy in the 5s band, F=the Fermi function and ν=frequency, calculated under the assumption of free electrons, is reproduced in Fig. 5.

The absorption at 3200 Å has been described as a transition from the top of the 4d band to the conduction band at the Fermi energy,[4] and the emission at 3300 Å in the present experiment appears to arise from these same two levels. Both the intensity and wavelength variation of emission with temperature agree well with the change in the Fermi distribution of electrons.

It is of interest to see whether the emission found in silver is from the decay of the plasma oscillation as described originally by Ferrell.[8] If the plasma frequency is given by

$$\omega_p=(4\pi ne^2/m)^{1/2},$$

where e, m, and n are the electronic charge, mass, and number density, respectively, the change in this frequency as a function of temperature may be calculated readily from the known volume-expansion coefficient (dV/V) of silver. Since

$$d\omega/\omega=\tfrac{1}{2}(dn/n) \text{ and } dn/n=-dV/V,$$
$$d\omega/\omega=-\tfrac{1}{2}(dV/V).$$

Taking dV/V for silver to be 0.51×10^{-4}/°K, we find

$$d\omega/\omega=-0.25\times10^{-4}/°\text{K}$$

or

$$dE=-0.95\times10^{-4} \text{ eV}/°\text{K},$$

as compared with the value -2.5×10^{-4} eV/°K found in the present experiment. It is thus obvious that the shift in frequency with temperature is not accounted for adequately by the change in the electronic density alone. The additional shift may be due to the change in the Fermi distribution of electrons which participate in the interband transition. The present results are in good agreement with the description given by Ehrenreich and Philipp[4] that this phenomenon in silver is a hybrid type of resonance with the pure plasma resonance being shifted in energy by the interband transition.

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