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PLASMA RESONANCE IN THE PHOTOELECTRIC YIELD OF ALUMINUM*

W. Steinmann and M. Skibowski
II. Physikalisches Institut der Universität München, München, Germany
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Aluminum is known to behave like a free-electron gas in a wide range around its plasma frequency. A characteristic electron energy loss of 15 eV which is unambiguously due to the excitation of a plasmon has been reported by many authors.[1] The radiative decay of the plasmon into a photon, the so-called plasma radiation,[2] has also been measured.[3] The inverse process, the excitation of a plasmon by a photon, is known as optical plasma-resonance absorption.[4] It has been established experimentally as a dip at the plasma frequency in the transmittance curve of thin Al foils.[5] This minimum occurs only for the p component (E vector parallel to the plane of incidence) at non-normal incidence, while the s component shows no structure at the plasma frequency.

The dip in the spectral transmittance of the p component is partially due to the fact that a plasmon which has been excited by a photon does not necessarily decay into a photon again, but may alternatively be damped by electronic damping.[2] This can be accomplished either by disorganization of the collective motion, leading to an increase in the temperature of the electron gas and subsequently of the lattice, or by an interband transition of one electron. The latter process has been predicted theoretically[6] for plasmons with small wave vector. In this case, if the plasmon energy is greater than the work function, the excited electron may leave the metal. Thus, the decay of a plasmon may give rise to photoemission, which should result in a peak at the plasma frequency in the spectral photoelectric yield. As in the case of the optical plasma resonance, this peak should only appear if the sample is irradiated by p-polarized light at non-normal incidence.

An experimental test of this hypothesis requires a polarized continuum light source in the far ultraviolet. For Al, the peak is expected at 835 Å.[3] In this spectral range, the synchrotron radiation is the most effective light source with the above-mentioned features. In the experiment reported here, the synchrotron radiation of the 6-BeV electron synchrotron at Hamburg (DESY) was used. A normal-incidence monochromator[7] provided monochromatic light from the visible region down to about 400 Å. An Al film about 250 Å thick was evaporated onto a glass slide of 0.2-mm thickness and the slide was mounted as the photocathode of a Bendix Model 306 photomultiplier. The multiplier was then positioned behind the exit slit of the monochromator. The multiplier could be tilted with respect to the optical axis and could be turned so that the plane of in-

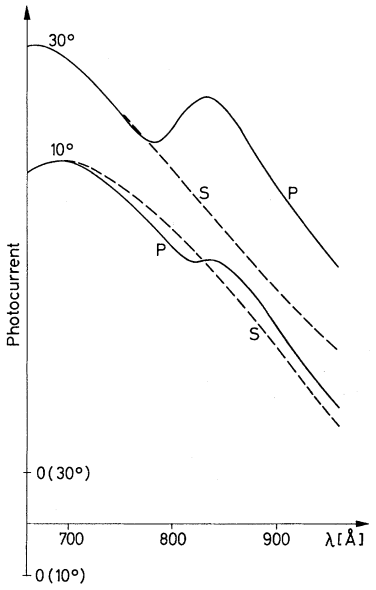

FIG. 1. Anode current (arbitrary units) of a Bendix photomultiplier, equipped with an Al cathode 250 Å thick, as a function of wavelength for two angles of incidence and two directions of polarization [E vector parallel (p) and perpendicular (s) to the plane of incidence]. All curves have been normalized at 700 Å and the 10° curves have been shifted downward.

cidence was either in or perpendicular to the synchrotron plane. Since synchrotron radiation is almost perfectly polarized in the synchrotron plane, the Al photocathode could be irradiated by either p- or s-polarized light.

Our measurements are shown in Fig. 1. The spectrum of the p component shows the expected peak at the plasma wavelength 835 Å, while there is no structure in the spectrum of the s component. The intensity of the peak increases with the angle of incidence, as one would expect for the optical plasma-resonance absorption. The half-width of the peak (about 70 Å) is somewhat greater than the half-width of the electron energy loss[8] (0.9 eV corresponding to 50 Å). This broadening is due to the additional damping of the plasmon caused by the radiative decay.[2,4]

The experimental result proves that the decay of a plasmon into a single-electron excitation actually occurs. This is amazing, since it means that the 10^7 electrons taking part in a plasmon[2] give their combined energy to one single electron. A similar result obtained by Mayer and Thomas[9] with potassium photocathodes may be interpreted in the same manner.

For a quantitative comparison between optical plasma-resonance absorption and photoelectric emission, the spectral distribution of the light source, the spectral dependence of the grating yield, and the degree of polarization have to be taken into account. Experiments to determine the latter two are under way.

The experimental advantage of this method of measuring the optical plasma resonance is that one can, in principle, evaporate the sample under ultrahigh-vacuum conditions and measure the effect in the same vacuum, while it is practically impossible to produce and investigate the clean, unsupported, thin foils needed for the absorption measurement.

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