Optical Properties of Platinum*

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The optical functions ϵ_1, ϵ_2, α, and $-\text{Im}(1/\epsilon)$ have been deduced from reflectance data on electron-gun-evaporated Pt samples. They were obtained by two different methods: (1) the Kramers-Kronig analysis of the normal-incidence reflectance data, and (2) the analysis of reflectance at two different incident angles. The absorption coefficient α shows small peaks at $h\nu=0.4$, 7.7, and 10.5 eV, and a broad peak centered about 4 eV. The imaginary part of the dielectric function, ϵ_2, has structure at $h\nu=6.5$ and about 11 eV.

I. INTRODUCTION

To complete the experimental studies of the electronic structure of transition metals at the end of the 3*d* (Ni), 4*d* (Pd), and 5*d* (Pt) series,[1,2] we have undertaken the optical and photoemission studies of platinum. These metals are particularly interesting because Ni is ferromagnetic while Pd and Pt are not, although they all have the same number of outer electrons. In this paper, optical functions deduced from reflectance data will be presented and discussed. These data will be used along with photoemission results in a subsequent paper[3] to deduce the electronic structure of Pt over an energy range about 10 eV above and below the Fermi level.

II. DETERMINATION OF THE OPTICAL FUNCTIONS OF PLATINUM

Recently, normal incidence reflectivity data of electron-gun evaporated Pt films have been reported[4] over the spectral range 0.06 eV$\leq h\nu \leq$5.63 eV. In Table I, data taken at several different angles for $6.88\leq h\nu \leq 21.23$ eV are presented. The films were prepared in the same manner as reported previously.[4] In Fig. 1 the normal-incidence reflectance curve is shown. This curve was obtained using the data of Ref. 4 and the 10° data from Table I and extrapolating from 5.63 to 6.88 eV. The reflectance has slope changes at 0.6 and 6.7 eV and a small peak is present at 10.1 eV.

Two approaches were used in calculating the optical functions. They were first calculated from the reflectance data at two different incident angles (10°, 60°, 60°, 80°, and 10°, 80°) at the available 14 data points in the region 6.88 eV$\leq h\nu \leq$21.23 eV by solving the two equations relating the optical functions with reflectivity exactly.[5] Second, the optical functions over the complete range were calculated by the Kramers-Kronig (KK) analysis[6] using the "normal-incidence" (10°) data. The high photon energy reflectance extrapolation was adjusted so that the optical functions obtained from the KK analysis agree with those from reflectance at two angles of incidence. In Fig. 2 ϵ_1 and ϵ_2 from KK analysis are shown along with results from the two-angle incidence data. This is the best match obtained for the two results. The agreement of the two ϵ_2's is within 15% but it is worse (within about 50% at $h\nu=16$ eV) for the ϵ_1's. The extrapolation has been adjusted so that the ϵ_2 values by the two methods agree most closely over the range 7 eV$\leq h\nu \leq$11 eV, which is the region of the most interest. The curves by the two methods have different over-all slopes which could not be made equal by adjusting the high photon energy extrapolation. This discrepancy is probably due to the following reasons: (1) The light used for reflectivity measurements probably was not completely unpolarized; (2) the data points for $h\nu>12$ eV were far apart (~3 eV). The reflectance be-

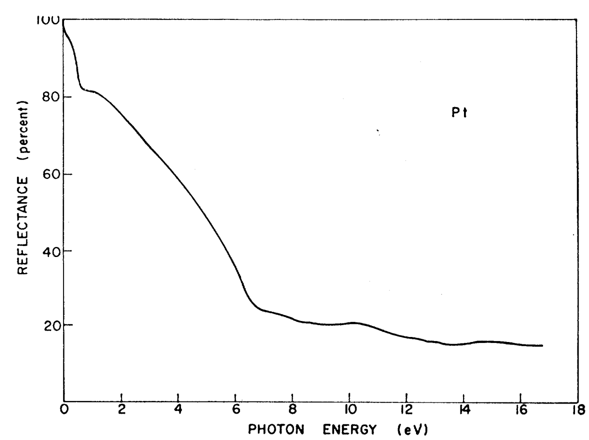

FIG. 1. Reflectance of Pt.

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[1] A. J. Blodgett, Jr., and W. E. Spicer, Phys. Rev. 146, 390 (1966).

[2] A. Y-C. Yu and W. E. Spicer, Phys. Rev. (to be published).

[3] A. Y-C. Yu and W. E. Spicer, Phys. Rev. (to be published).

[4] L. F. Durmmeter and G. Hass, *Physics of Thin Films* (Academic Press Inc., New York, 1964), Vol. 2, p. 337.

[5] R. Tousey, J. Opt. Soc. Am. 29, 235 (1939); A. Y-C. Yu, Ph.D. thesis, Stanford University, 1967 (unpublished).

[6] J. L. Shay (private communication).

tween data points was extrapolated by exponentials. The error introduced by this will be appreciable since data points are relatively far apart. However, since for 7 eV$\leq h\nu \leq$11 eV the data points were quite close together ($\sim$0.5 eV) and since the agreement between results of the two different methods is good, the optical functions in this region should be very reliable. Note that location of the major pieces of structure in ϵ_2 is the same for the two ϵ_2 curves.

TABLE I. Reflectance data of Pt (G. Hass).

$h\nu$ (eV)	Angle of Incidence (deg)	Reflectance (%)
21.23	80	61.17655
	60	31.13701
	10	21.72616
16.84	80	55.77633
	60	24.39885
	10	14.69829
14.86	80	57.02338
	60	26.25589
	10	15.66564
13.68	80	54.39103
	60	24.30080
	10	14.94917
12.08	80	55.85290
	60	25.81948
	10	16.48173
10.92	80	56.58180
	60	27.93711
	10	19.20076
10.19	80	55.60826
	60	28.26232
	10	20.66767
9.71	80	54.63517
	60	27.69484
	10	19.90159
9.23	80	54.70237
	60	27.37519
	10	19.87917
8.83	80	54.32747
	60	27.63155
	10	20.25131
8.33	80	54.79938
	60	28.18447
	10	20.81851
7.7	80	55.84696
	60	29.76346
	10	22.51346
7.29	80	55.66986
	60	29.88077
	10	23.33367
6.88	80	56.53064
	60	30.76324
	10	23.85045

In Fig. 3 the absorption coefficient α and the loss function $-\text{Im}(1/\epsilon)$ obtained from KK analysis are shown. The agreement between the absorption coefficients obtained from the two different methods is very good. α shows a small piece of structure at 0.4 eV, a very broad maximum centered around 4 eV, and a shoulder at 10.5 eV. The origin of this structure will be discussed in a subsequent paper.[3] The loss function has

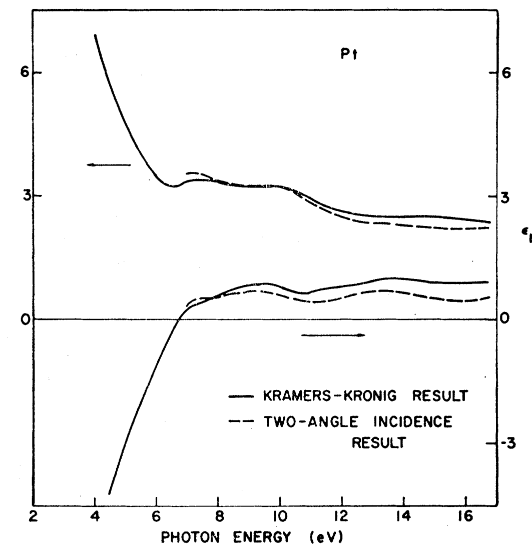

FIG. 2. Plots of ϵ_1 and ϵ_2 of Pt.

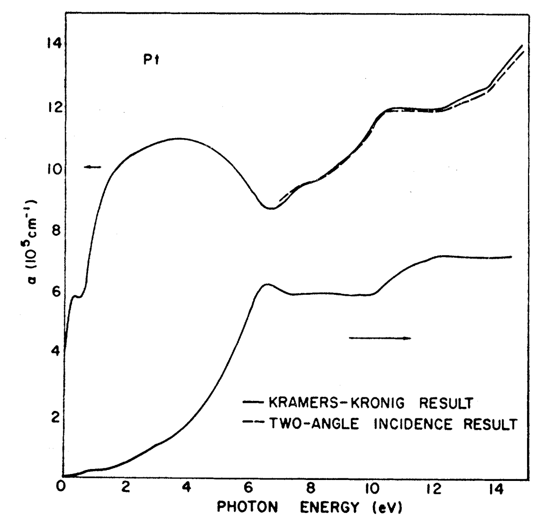

FIG. 3. Plots of α and $-\text{Im}(1/\epsilon)$ of Pt.

a small peak at 6.5 eV. Note that the electron energy loss spectra[7] show a small peak at 6.2 eV, in reasonable agreement with the optical results. However, this peak is probably not due to an "ideal" plasma resonance because ϵ_2 is quite large ($\sim$3) there and damping will be severe.

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[7] C. J. Powell, Proc. Phys. Soc. (London) **76**, 583 (1960).