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KEZUKA, Hiroshi

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AN ANTIREFLECTION COATING FOR A METAL-SEMICONDUCTOR (Au-CdS) SOLAR CELL**

Hiroshi KEZUKA*

ABSTRACT

As AR coating material thin films of Ta_2O_5 are deposited onto the Au-surface of the Au-CdS cells by vacuum evaporation in the presence of Oxygen at a total gas pressure of about $10^{-4}-10^{-5}$ Torr. Ta_2O_5 is evaporated from a resistance heated tungsten boat with a deposition rate of about 5Å / sec, producing Ta_2O_5 films of different thickness, mainly around 1000 Å. This was done for three values of the thickness of the Au film (100, 150 and 200 Å). The reflectance of all samples was measured as a function of the wavelength in the interesting spectral region from 330 to 600 nm in order to find out the optimum value of the thickness of the Ta_2O_5 film for each value of Au film thickness. In all cases, the value of the minimum reflectance was approximately zero. However, on both sides of the minimum value the reflectance rose relatively steeply. For fixed value of $d_{Ta_2O_5}$ there was a slight tendency of λ_{min} to move to longer wavelengths with increasing thickness of the Au-film.

INTRODUCTION

Recently cadmium sulfide solar cells [1] are discussed with deep interests as low-cost solar cell because of their superior efficiency per unit cost, comparing with Si and GaAs solar cells which are widely used. The aim of this work is the design of an antireflection (AR) coating for an MS Schottky Type (Au-CdS) solar cell. As one of the most important requirements for building solar cells, an AR coating is necessary in order to reduce the reflectance of the surface and to increase the transmission of the incident light into the cell.

As AR coating material Ta_2O_5 was chosen because of its suitable value of refractive index (n=2.2) and its wide optical bandgaps (E_g=4.6 eV)[2]. This paper reports the reflectance measurement of Au-CdS solar cells with and without AR coating in the interesing region of wavelength from 330 to 600 nm in order to find out the optimum value of the thickness of the Ta_2O_5 for three values of thickness of Au-films (100, 150 and 200 Å). In order to compare our experiment results with theory, the refractive index of Ta_2O_5-film should be known as a function of wavelength and thickness. In practice, calculations of reflectance for Au-CdS solar cells with Ta_2O_5 films as AR coating are made with the optical data available in literature by the concept of surface impedance [3][4] for Ta_2O_5[6]-, Au-[7] and CdS-films, [8] in which the exact theory is derived by Wolter[5].

The main purpose of this work is to obtain suitable thickness of Ta_2O_5 as an AR caoting for three different values of thickness of Au (100, 150 and 200Å) by the

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Institut für Grenzflächenforschung und Vakuumphsik, K.F.A Jülich (Germany)
現在，法政大学大学院工学研究科博士課程在学中（電気工学専攻）

reflectance measurement of Au-CdS solar cell with Ta_2O_5 in order to reduce the reflectance of the surface.

EXPERIMENTAL

All samples of Au-CdS solar cells with Ta_2O_5 films for the optical reflectance measurement are produced by vacuum evaporation in vacuum system which is pumped down to a pressure of 2×10^{-6} Torr by the diffusion-pump. Gold is evaporated onto CdS films by W-boat at deposition rates of 0.5 to 1.0 Å/sec. Ta_2O_5 layers of about 630, 950 and 1220 Å are deposited on the surface of Au-CdS cells by an another W-boat with a rate of about 5 Å/sec in the pesence of oxygen (total gas pressure: $10^{-4}-10^{-5}$ Torr). Glass slides prepared with evaporated CdS films of 1.5 μm thick are taken as substrates. W-boats for Au and Ta_2O_5 are located 14 cm apart from the substrate with the quarz-crystal thickness monitor. As shown in Fig. 1, each sample of 13×10 mm are fixed at right angles to the incident light. A monochromatic photon flux is obtained with a Zeiss MM 3 double monochrometer using a 150 W Xenon short arc lamp as a light source. The incident and the refleted intensities are measured by a silicon photodiode which can be rotated round the sample. In order to measure the incident intensities the sample is removed from the light beam and the photodiode is located at the position of A (see Fig. 1). With the sample lying in the incident light beam and the photodiode at the position of B, the reflected intensity is obtained. The angle of the reflected light beam is about 5^0. The electrical signal of the photodiode is measured with a PAR 126 lock-in-amplifier. The incident light beam is obtained through the light-chopper located near the entrance slit of the monochrometer. The adjustment of the optical system is achieved by taking a freshly evaporated gold film as a standard, The results are in reasonable agreement with values obtained from the literature.[7] The reflected and incident signals are measured under the same condition in the interesting region of wavelength from 330 to 600 nm.

After the reflectance of evaporated Au film onto CdS films without AR coating are measured for each thickness of Au (100, 150 and 200Å), Ta_2O_5 in pellet is evap-

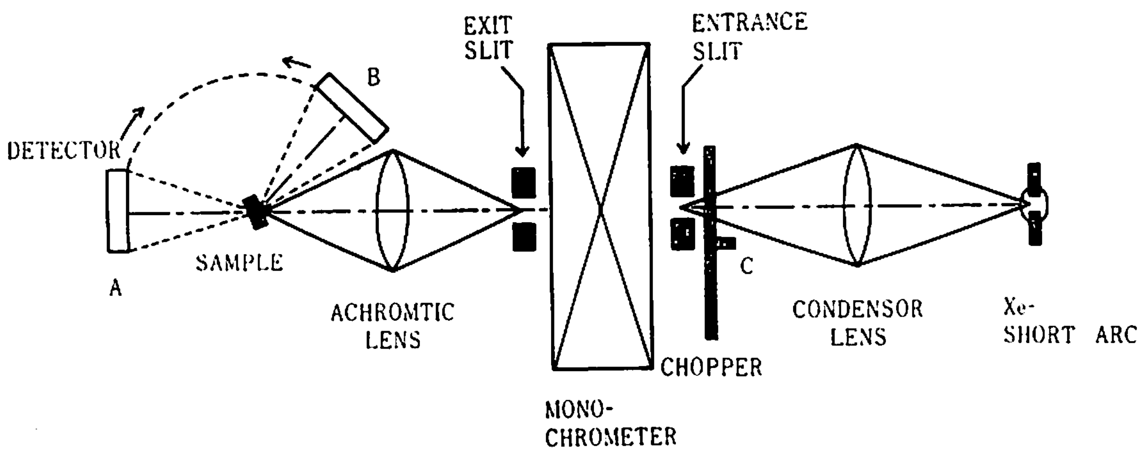

Fig. 1 Optical system for reflectance measurements.

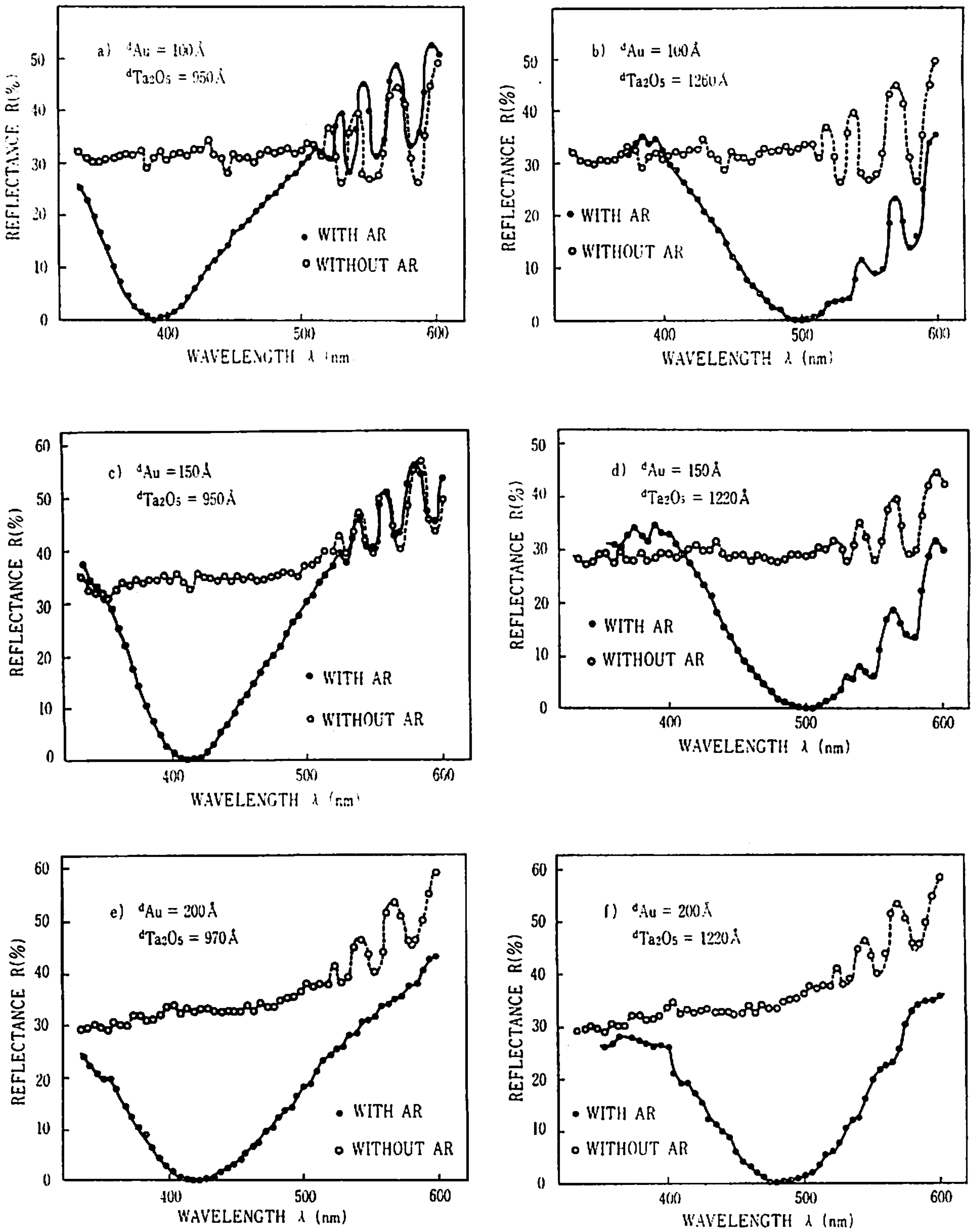

Fig. 2—4 Reflectance from an Au-CdS solar cell with and without an AR coating of Ta_2O_5.
Fig. 2. a) $d_{Au}=100$ Å, $d_{Ta_2O_5}=950$ Å, b) $d_{Au}=100$ Å, $d_{Ta_2O_5}=1260$ Å.
Fig. 3. c) $d_{Au}=150$ Å, $d_{Ta_2O_5}=950$ Å. d) $d_{Au}=150$ Å, $d_{Ta_2O_5}=1220$ Å.
Fig, 4. e) $d_{Au}=200$ Å, $d_{Ta_2O_5}=970$ Å, f) $d_{Au}=200$ Å, $d_{Ta_2O_5}=1220$ Å.

orated onto the same samples of Au-CdS films which are used for reflectance measurement in the same experimental arrangements.

RESULTS AND DISCUSSIONS

In addition to a transparent metal-film (Au), the sheet resistance of the metal-film should be low as important requirements for a metal-semiconductor Au-CdS solar cell. Therefore the sheet resistances of gold are chosen between 100 and 200 Å because these resistances of the films lie between about 12 and 3.45 ohm/square respectively in literature[1]. In the production of Au-films onto CdS-fils in three values of thickness (100, 150 and 200 Å) by vacuum evaporation, the sheet resistances are measured in vacuum, comparing with the thicknesses from a quarz crystal thickness-monitor, in order to know the relation between sheet resistances per square and thicknesses of gold- films exactly.

In practice, the reflectances for Au-CdS solar cells with Ta_2O_5 films 630 Å thick are measured in the wavelength region 330 to 600 nm in order to find out the wavelength λ_{min} for the minimum reflectance. The reduction in reflectance occurs in the wavelength less than 400 nm and λ_{min} is estimated about 300 and 310 nm for 100 and 150 Å thickness of gold films respectively as shown in Table 1.

In order to move λ_{min} up to around 450 nm, the optimum thickness of around 970 Å for Ta_2O_5 films is obtained approximately by calculations using the relation of a well known quarter-wave (QW) : $nd=\lambda/4$ which is derived from the ideal relation[5] between the thickness (d) and refractive index (n) of AR coating (Ta_2O_5)

$$d= (\lambda/2\pi n) \arctan (g_1 (U-g_2)/g_2 V) \qquad (1)$$

g_1 : Impedance for Ta_2O_5

g_2 : Impedance for Air

g_0 : Surface Impedance for Au-CdS Structure ($=U-jV$)

λ : Vacuum wavelength

if, $g_0 = U$ ($V=0$).

In experiment, the reflectance dependency on the wavelength is measured for 100, 150 and 200 Å thickness of gold with Ta_2O_5 of around 970 Å. It is clear that λ_{min} is

Table 1 : Wavelength λ_{dml} for Minimum Reflectance

d_{Au} [Å]	$d_{Ta_2O_5}$ [Å]	λ_{min} [nm]
100	630	300*
	950	390
	1260	500
150	630	310*
	950	410
	1220	500
	1260	515
200	970	420
	1220	480

*)extrapolated

390, 410 and 420 nm for respective thickness of gold as shown in Fig. 2—4. As a next step, the optimum thickness of Ta_2O_5 is calculated from λ_{min} of 970 Å of Ta_2O_5 by QW in order to obtain around 500 nm of λ_{min} for each thickness of gold. As a results, optimum thickness of Ta_2O_5 is 1244, 1182 and 1154 Å for 100, 150 and 200 Å of gold films (Fig. 5). As expected from these calculations, measured λ_{min} lies around 500 nm as shown in Fig. 2—4.

In order to compare the experimental data with the the calculated reflectance, the reflectances for 100, 150 and 200 Å are calculated as a function of thickness of Ta_2O_5 by the formula of reflectance coefficient,

$$r=((g_2-g_1)(g_1+g_0)\exp(pd)+(g_2+g_1)(g_1-g_0)\exp(-pd))/((g_2+g_1)(g_1+g_0)\exp(pd)+(g_2-g_1)(g_1-g_0)\exp(-pd)), \quad (2)$$

$$p=j\,(2\pi/\lambda)\,g_1$$

((1) is derived from (2), if $r=0$ as an ideal case.).

Consequently, calculated λ_{min} is 1360 (Au: 100 Å), 1340 (Au : 150 Å) and 1320 (Au : 200 Å) Å. In comparing the experimental results with the calculated λ_{min} by QW and (2), λ_{min} is a large different from the experimental data because of taking the scarce and incomplete data in literature[6),7),8)] and calulatetd λ_{min} is rather in good agreement with measured λ_{min} as shown in Fig. 5.

On both sides of the minimum reflectance the reflectances rise relatively steeply. In all samples, however, the value of the minimum reflectance is approximately zero.

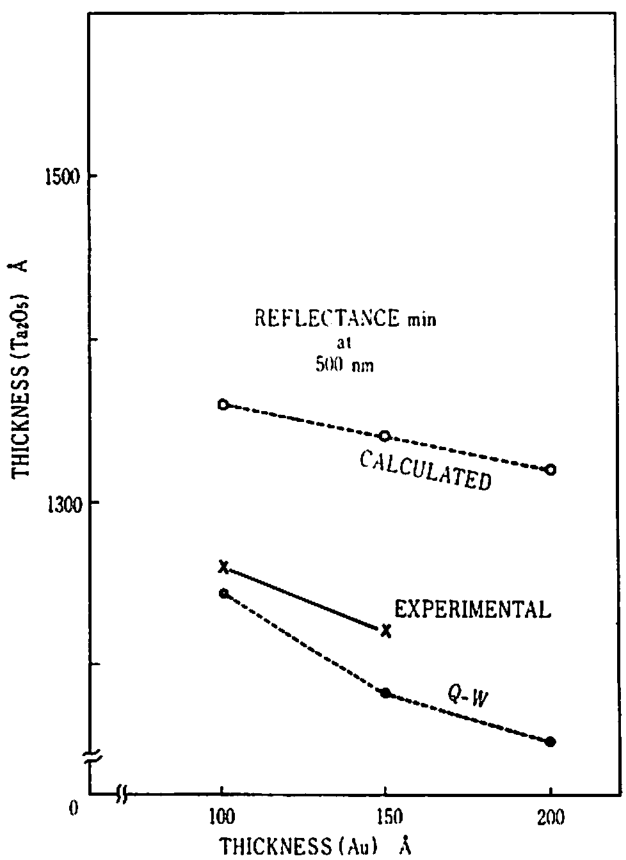

Fig. 5. R_{min} at 500 nm of experimental data and calculated by QW and formula (2).

The measured wavelength for λ_{min} is given in Table I.

CONCLUSION

From the optical measurement of reflectance of Au-CdS solar cell with Ta_2O_5 as an AR coating for around 970 and 1220 Å thick, λ_{min} is a slight dependenct on the thickness of gold. As expected by calculations, λ_{min} is about zero for every case, which shows that Ta_2O_5 is a very suitable material as an AR coating for Au-CdS cell.

In comparing experimental results with the calculated value of λ_{min}, λ_{min} calculated approximately by QW is in good agreement with the experimental results.

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