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ABSORPTION SPECTRA OF CRYSTALLINE AND AMORPHOUS SILICON BY PHOTOTHERMAL DEFLECTION SPECTROSCOPY

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Warren B. Jackson, Nabil M. Amer, Danièle Fournier, and A. Claude Boccara

June 1981

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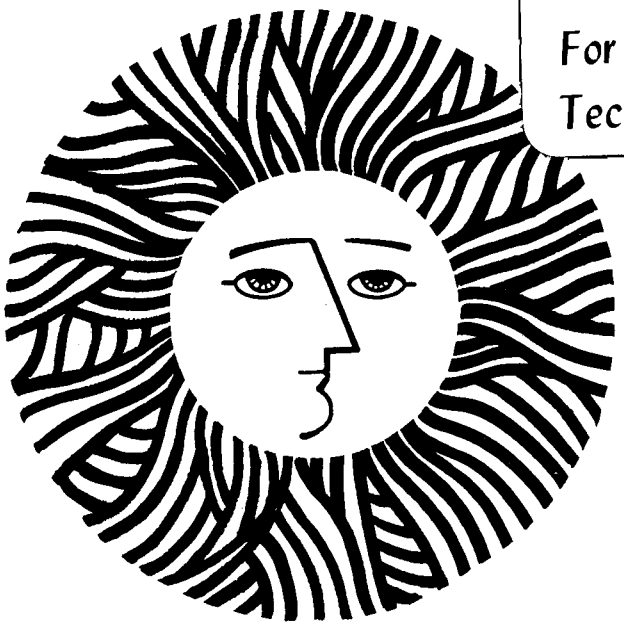

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ABSORPTION SPECTRA OF CRYSTALLINE AND AMORPHOUS SILICON BY PHOTOTHERMAL DEFLECTION SPECTROSCOPY

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Abstract

Absorption spectra of crystalline and amorphous silicon, were obtained by photothermal deflection spectroscopy. Sensitivity will be compared to that of PZT and gas photoacoustics.

This work was supported by the Assistant Secreatry for Conservation and Solar Energy, Photovoltaic Energy Systems Division of the U.S. Department of Energy under Contract W-7405-ENG-48, and by contract DS-0-8107-1 from the Solar Energy Research Institute (which is funded by DOE contract EG-77-C-01-4042).

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Introduction

The nature of the optical absorption in semiconductors at and below the absorption edge is of interest, particularly in the case of amorphous materials. The sensitivity of conventional transmission techniques are limited by the requirement of measuring the difference between two nearly equal signals. Furthermore, such techniques are highly sensitive to scattering. While adequately sensitive, the disadvantages of piezoelectric photoacoustic detection[1] are that it requires a laser as the exciting source, is highly sensitive to scattering, and requires reliable coupling between the transducer and the sample.

In this contribution, we present absorption spectra, obtained by photothermal deflection spectroscopy[2] (PDS) of hydrogenated amorphous silicon (a-Si:H) films and of crystalline silicon in the range of 2.1 to 0.6 eV. These spectra would be difficult to obtain by other methods.

Experimental Considerations

When an intensity-modulated light beam (pump beam) is absorbed by a medium, heating will ensue. This heating causes a periodic index of refraction gradient in a thin layer adjacent to the sample surface. A second beam (probe beam), propagating through this thin layer, will then experience a periodic deflection which can be quantitatively related to the optical absorption. We have shown that the magnitude of the deflection ϕ is related to optical absorption in the following manner[2]

$$\phi \propto (1-e^{-\alpha \ell})$$

where ℓ is the film thickness. The experimental arrangement is shown in Fig. (1). Our pump beam was the monochromatized output of Hg-Xe are lamp (0.01 eV bandwidth), and the deflection of the He-Ne laser probe beam was monitored with a conventional position sensor whose output was detected with a lock-in amplifier and noramlized for the intensity variations of the pump beam as the wavelength was change. Since the dN/dT of liquids is typically an order of magnitude larger than that for gases, we immersed the sample in filtered C Cl_4. The experimental set-up with the exception of the pump source, was enclosed to eliminate temperature gradient caused by air currents.

Absolute absorption coefficient (α) can be determined in one of two ways: 1) For large absorptions, the signal saturates

$$\phi = A\ (1-e^{-\alpha \ell}) \Rightarrow A\ \phi_{sat} = A$$

The value of the saturated signal can be used to determine $\alpha\ell$ from the equation

$$\alpha \ell = -\ln\left[1 - (\phi/\phi_{sat})\right]$$

or, 2) the reflection and transmission of the samples are measured at a photon energy where absorption is significant. The equations for reflection and transmission are then solved for the index of refraction and the absorption coefficient using a numerical routine.

Results and Discussion

In Fig. (2), the spectrum of n-type crystalline silicon is shown. The doping level was 10^{15} phosphorous atoms/cm^3. It can be seen this

is in excellent agreement with published results. In Fig. (3) we give the absorption edge and tail of a-Si:H films ($\sim 1\mu$ thick) deposited under various conditions. Our measurements extend the measured values of α by two orders of magnitude over those obtained by other techniques. The error bar shown on the graph is due to uncertainty in the transmission measurement (fixing the position of the entire curve) and does not represent a sensitivity limit for PDS. The noise level at 0.7 eV corresponds to an $\alpha\ell = 10^{-5}$ for a 1 mW beam and a 40 second averaging time. Hence, the limiting sensitivity is 10^{-8} W of absorbed power. This is comparable to the sensitivity of piezoelectric photoacoustic detection[1] and eliminates its disadvantages. When compared to gas photoacoustic detection (for solids) with its sensitivity of 10^{-6} W of absorbed power,[3] clearly PDS is superior.

In conclusion, it appears that PDS, with its versatility, yields spectroscopic information equal to or significantly better than those obtained by transmission or photoacoustic techniques.

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2. W. B. Jackson, N. M. Amer, A. C. Boccara and D. Fournier, to appear in Appl. Optics, April 15, 1981; A. C. Boccara, D. Fournier, W. Jackson and N. M. Amer, Optics Lett. 5, 377 (1980).
3. G. C. Wetsel and F. A. McDonald, Proc. of the OAS Topical Conference on Photoacoustic Spectroscopy, Ames, Iowa, August 1979, paper ThA5.

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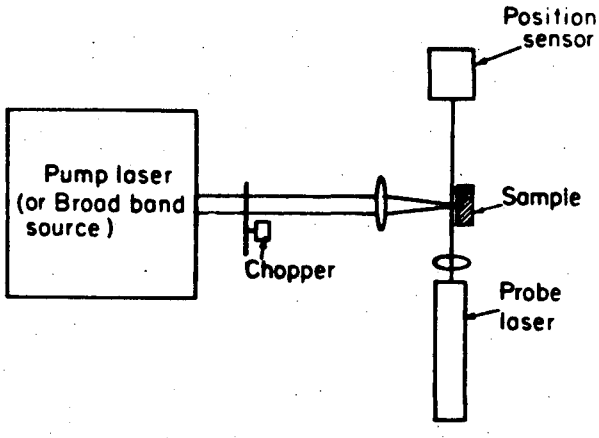

Fig. (1) Experimental Arrangement

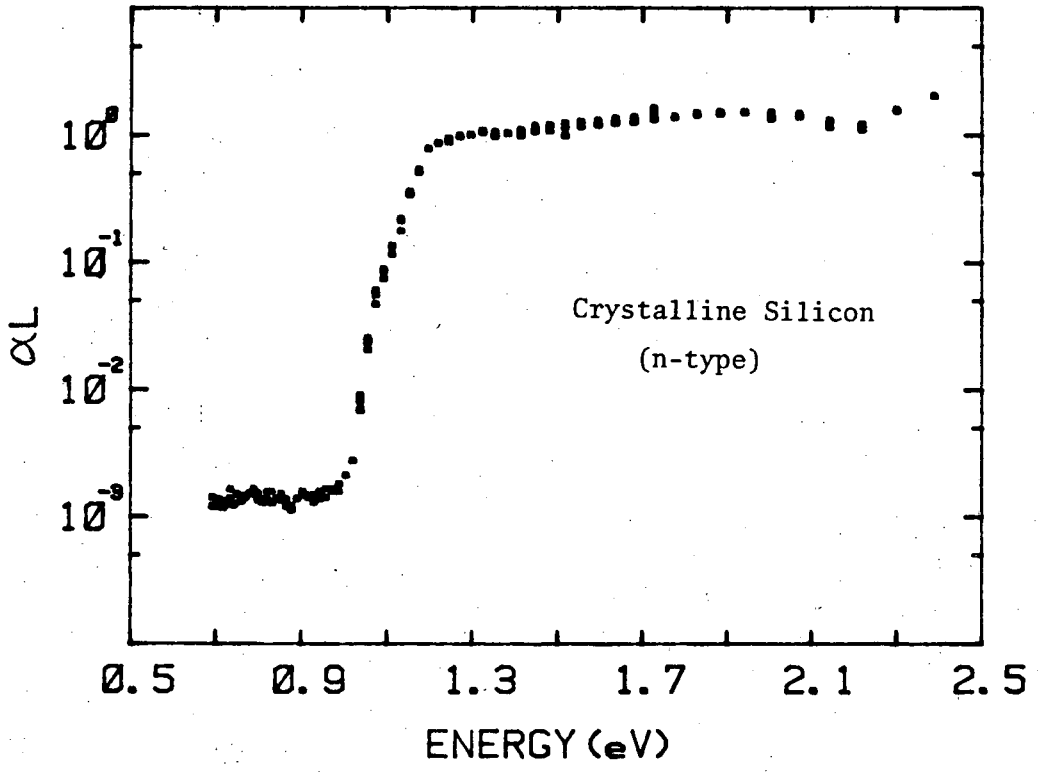
αL
10^0
10^-1
10^-2
10^-3
Crystalline Silicon
(n-type)
0.5
0.9
1.3
1.7
2.1
2.5
ENERGY (eV)

Fig. (2)

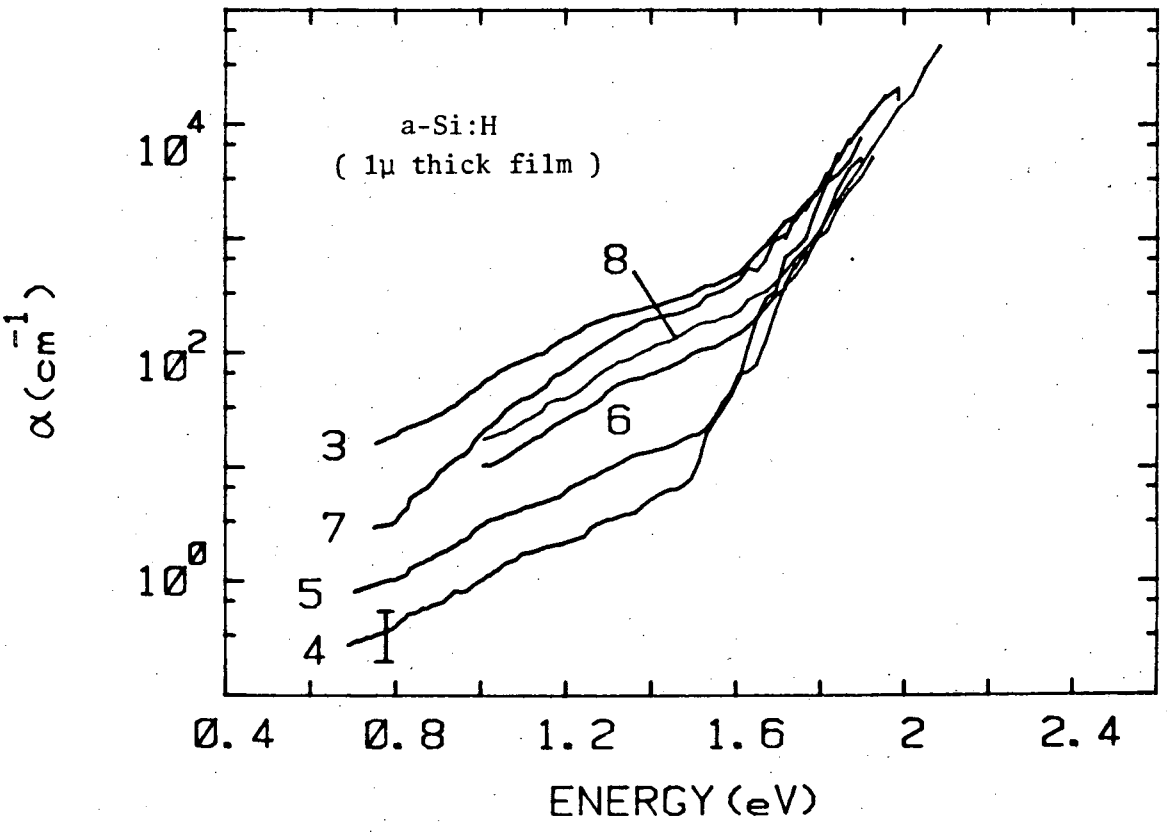
α (cm^-1)
10^4
10^2
10^0
a-Si:H
(1μ thick film)
8
6
3
7
5
4
0.4
0.8
1.2
1.6
2
2.4
ENERGY (eV)

Fig. (3)

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