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AN ULTRAVIOLET SPECTROMETER FOR SURFACE OPTICAL ANISOTROPY MEASUREMENTS

L. F. Lastras-Martínez, R. E. Balderas-Navarro and A. Lastras-Martínez

Instituto de Investigación en Comunicación Optica
Universidad Autónoma de San Luis Potosí
Alvaro Obregón 64
San Luis Potosí, S.L.P., México.

We describe a reflectance spectrometer (1.2-5.3 eV photon energy range) for the measurement of surface optical anisotropies in cubic semiconductors . The spectrometer employs a photo elastic modulator to modulate the polarization of the light incident on the sample. A procedure to correct the measured spectra for parasitic components is discussed. To evaluate the spectrometer response we report measurements of optical anisotropies in the reflectance spectra of, both, (001) and (110) oriented GaAs bulk crystals.

INTRODUCTION

Reflectance-Difference Spectroscopy (RDS) is a promising tool for the study of surface processes in cubic semiconductors [1-11]. RDS has been shown to be valuable in impurity-adsorption studies [3], as well in the *in situ* characterization of epitaxial growth by Molecular Beam Epitaxy (MBE) [10] and Vapor Phase Epitaxy (VPE) [10]. For MBE, RDS provides complementary information to that offered by the electronic characterization techniques available in Ultra High Vacuum systems [10]. As such techniques are not available for chemical vapor deposition reactors, due to their high working pressure, RDS becomes particularly important for the study of VPE growth processes [11]. It is noted that RDS, as an optical technique is not necessarily ruled out in high pressure environments.

The working principle of RDS is based on the fact that, as the bulk optical properties of cubic semiconductors are nominally isotropic, any observed anysotropy in the reflectance spectrum should be due to the breakdown of the cubic symmetry associated to the semiconductor surface [2-4]. Then, by measuring the difference in reflectance for two mutually perpendicular light polarizations, the bulk contribution to the sample reflectivity should be filtered out remaining only the surface contribution.

In probably the simplest RDS set up, linearly polarized monochromatic light incides on the sample which is kept rotating at a fixed frequency [2,3,7,8]. The modulated component of the sample reflectivity is isolated by using synchronous detection techniques. A rotating-sample set up, although have some advantages, is not convenient to carry out studies of epitaxial growth processes. For such purposes, an experimental set-up in which the sample is kept static is preferred.

In this paper we describe a RDS spectrometer in which the sample does not move during measurements. It uses a photelastic modulator to modulate the polarization of the light incident on the sample and operates in the 1.2-5.3 eV energy range. Although with the spectrometer described here it is only possible to measure absolute values of the RD signal (in contrast to that of reference 12 which allows for the measurement of both the real and imaginary parts of such signal) its implementation and operation is relatively simple. Furthermore, it allows for a simple procedure to eliminate parasitic components of the anisotropy spectra, which plague RDS measurements.

SPECTROMETER DESCRIPTION

The spectrometer is schematically shown in figure 1. In this set up, light coming out from a 75 watt arc Xenon lamp is focused at the entrance slit of a 0.25 m monochromator (SPECTRAL ENERGY, model GM252) which has a choice of two diffraction gratings, one optimized at 240 nm (1180 lines/mm) and the other at 500 nm (600 lines/mm). An arrangement of two 50 cm focal length mirrors (MgF coated for enhanced UV reflectivity) directs the light beam at the output of the monochromator through a polarizer prism (quartz Rochon) and a photoelastic modulator (HINDS INSTRUMENTS, model PEM 80) in

tandem (figure 2) and focuses it on the sample surface with an angle of incidence of about 3 degrees. Upon reflection, the light beam is depolarized and focused with a quartz lens of 5 cm focal length on a UV enhanced, 5.1 mm^2 active area, silicon photodetector (United Detector Technology, model UV 005), which has been matched to a TL071 operational amplifier [13]. The photodetector/amplifier combination has a flat response up to 100 kHz [13]. The electric signal at the output of the photodetector is processed by a lock-in amplifier (PAR 124A) tuned to twice the operating frequency of the photoelastic modulator (100 kHz). The spectrometer is controlled by a host computer.

The heart of the photo elastic modulator is a fused silica element, mechanically coupled to a piezoelectric transducer which is driven by 50 KHz electrical pulses. Because of the directional stress applied by the piezoelectric transducer, the fused silica element becomes birrefringent, allowing for a periodic retardation between the two components of the polarization vector directed along the two modulator optical axis. In the polarizer/modulator arrangement used in the spectrometer described here (figure 2) we have a half-wave peak retardation, so that the polarization vector of the light emerging from the modulator, oscillates at a frequency of 100 kHz between two orthogonal linearly polarized states [13].

ELIMINATION OF PARASITIC COMPONENTS IN THE RD SIGNAL

The main source of parasitic signals in the spectrometer described in this paper comes from the fact that the polarization of the light is oscillating periodically between s and p states. Thus, as for angles of incidence different from zero the Fresnel coefficients for s and p polarizations are not the same, the measured RD signal necessarily includes components not associated to the sample surface anisotropies.

In our particular case, with a known angle of incidence, we may easily calculate and substract the parasitic signal coming from the air-sample interface. It is noted, however, that parasitic signals due to the difference in s an p reflectivities could come as well from any optical surface the light may cross after reflection at the sample surface, including the air-phtodetector interface. In these conditions, it is not practical to try to calculate and substract numerically parasitic signals.

Instead, the parasitic components of the RD spectrum, are more conveniently eliminated by a two step process in which we take two spectra, one with the sample optical axis aligned with the two extreme polarization states of the incident light, and the other after rotating the sample for 45 degrees. This second spectrum should correspond entirely to the parasitic component, so that subtracting it from the first spectrum, the free- parasitic component spectrum is obtained.

To allow for the parasitic component elimination procedure the sample is attached to a kinematic mount, which consists of two aluminum plates joined by three screws and a spring. With the help of a laser beam reflected at the sample surface , the arrangement allows for the alignment of this surface with respect to the optical axis of the spectrometer. The kinematic mount is directly coupled to the rotating shaft of a stepping motor (0.9 degree per step) which is controlled by the host computer.

During the elimination procedure we adjust first the three screws of the kinematic mount so that the surface of the sample is aligned perpendicular to the rotation axis of the sample holder. Next, the computer rotates the mounting plate step by step, measuring DR/R at 0.9 degree intervals in order to determine rotation angles for DR/R maxima and minima, which should be 90 degrees apart. In figure 3 we show a typical plot of DR (for 3.3 eV photon energy) as a function of rotation angle. We note that adjacent DR maxima an minima are indeed 90 degrees apart. As a final step, to obtain a parasitic-free RD spectrum, we should make two runs, one at a rotation angle corresponding to a maximum (DR/R_{max}) and another ($DR/R_{(0)}$) after rotating the sample for 45 degrees. The difference ($DR/R_{max}-DR/R_{(0)}$) gives the parasitic-free RD spectrum.

We note that an additional source of parasitic RD signals is the polarization dependence of the Silicon photodetector response, which is highest around 3.4 eV. Although this component is in principle also eliminated by the procedure described above, we included in the design of our spectrometer an optional depolarizer between the sample and photodetector focusing lens (figure 1), in order to reduce to a minimum any parasitic signal contribution.

MEASURED SPECTRA

To evaluate the spectrometer performance we present in this section RD spectra for, both, (001) and (110) oriented GaAs bulk crystals. In figure 4 we show the spectrum for a Cr-doped semi insulating (110) GaAs sample. Figures 4a and 4b correspond, respectively, to DR/R_{max} and $DR/R_{(0)}$. As expected, due to its parasitic origin, the spectrum of figure 4b is relatively featureless. In figure 4c we show the ($DR/R_{max}-DR/R_{min}$) difference spectrum, which, as discussed above, correspond to the parasitic-free RD spectrum.

Figure 5 shows RD spectrum for a Si-doped ($N=10^{18}/cm^3$) (001) GaAs sample. As in figure 4, figures 5a, 5b and 5c correspond respectively to DR/R_{max}, $DR/R_{(0)}$ and ($DR/R_{max}-DR/R_{(0)}$). The same comments we offered for the spectra of figure 4 apply to those of figure 5.

To evaluate the effect of the depolarizer on the spectrometer performance, in figure 6a and 6b we present spectra for the (001) sample, taken without it. As before, figures 6a and 6b correspond respectively to $(DR/R_{max})$and $(DR/R_{(o)})$. As it can be seen, a strong parasitic signal is evident. Further, around 3.4 eV we note an structure which coincides in energy with one of the critical points of silicon, suggesting that it is due to the polarization dependence of the photodetector. However, as it can be seen from figure 6c $(DR/R_{max}-DR/R_{min})$, our parasitic components elimination procedure takes care for the lack of depolarizer.

CONCLUSIONS

We present in this paper a spectrometer for the measurement of RD spectra of cubic semiconductors. The instrument is based on a photoelasic modulator to modulate the polarization of the light incident on the sample.The experimental set-up allows for a simple procedure to subtract parasitic components from the measured RD spectra. The spectrometer is suitable to carry out studies of epitaxial growth processes as well as impurity-adsorption and chemical-etching characterization.

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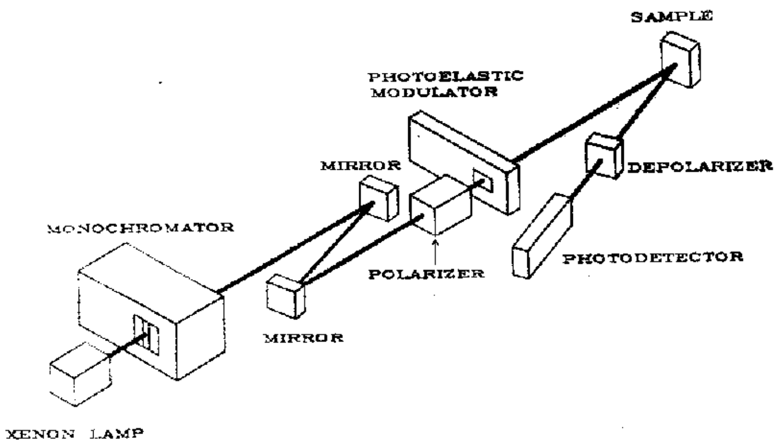

Figure 1. Schematics of the photoelastic modulator espectrometer.

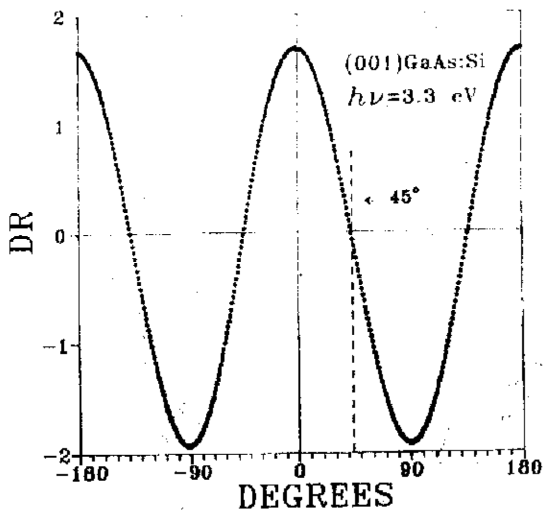

Figure 2. The Photoelastic modulator is an optical device that retards the x component of the light polarization vector with respect to the y component by a mechanical stress applied along x. The light emerging from the modulator is in general elliptically polarized.

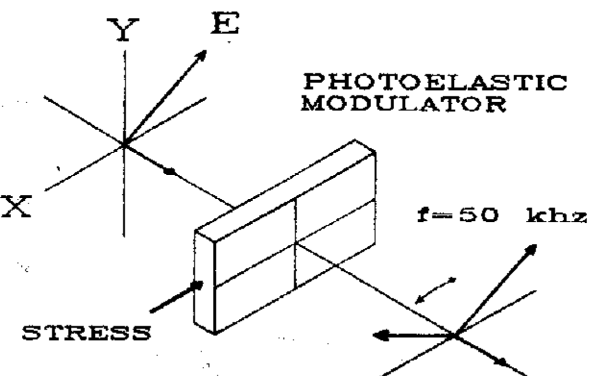

Figure 3. Anisotropy signal as a function of angle between sample crystal axis and extrema light polarization states, for a 3.3 eV photon energy.

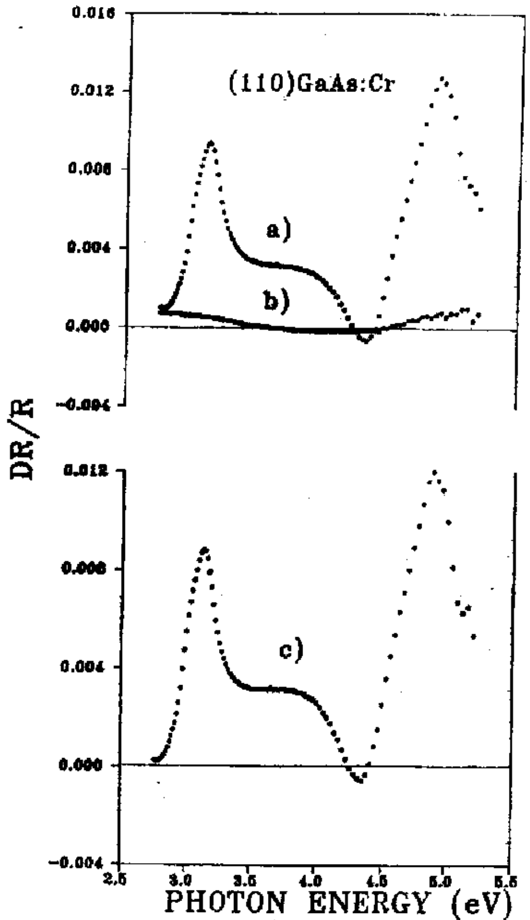

Figure 4. DR spectra for a (110) GaAs:Cr crystal; a) crystal axis aligned with the two sample extreme polarization states; b) sample crystal axis rotated 45; difference between a) and b) spectra.

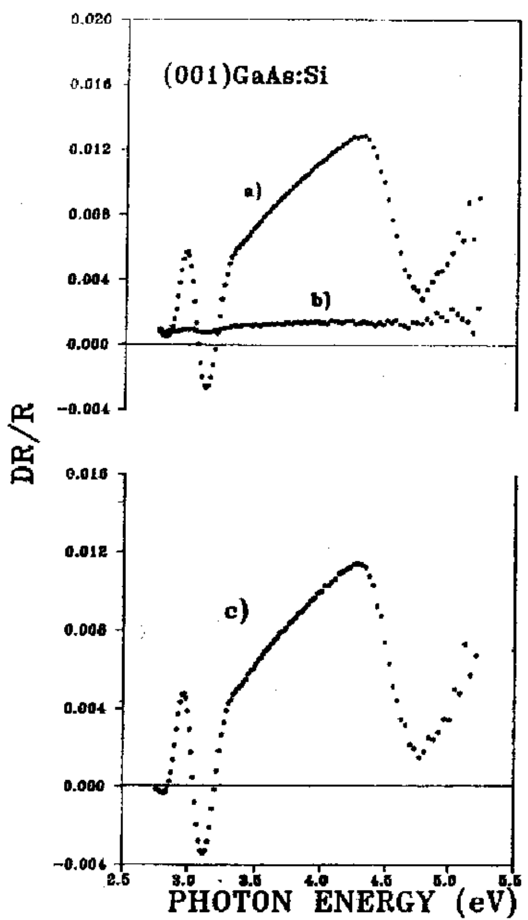

Figure 5. DR spectra for a (001) GaAs:Si crystal; a), b) and c) as in figure 4).

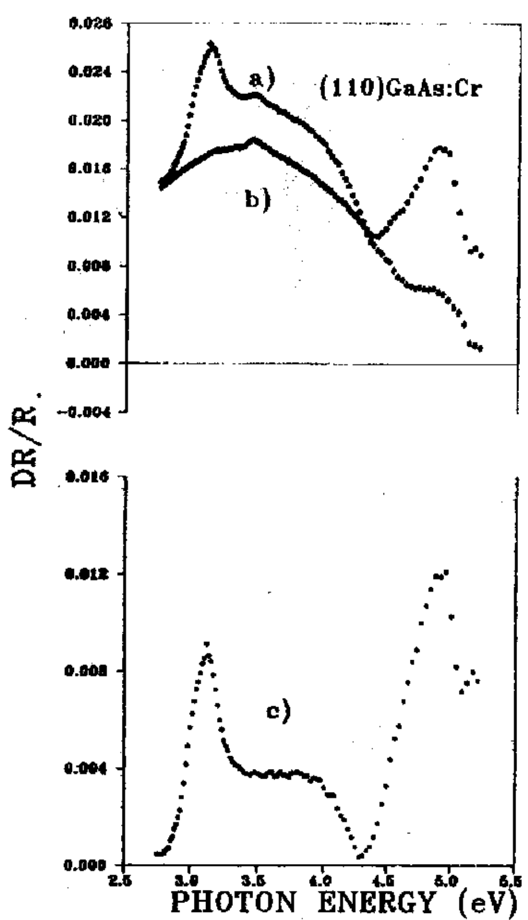

Figure 6. DR spectra for a (001) GaAs:Si crystal taken without depolarizer; a), b) and c) as in figure 4.