MODULATED DIFFERENTIAL REFLECTANCE AS A PRECISE TOOL FOR PROBING LOW ION FLUENCES IN IMPLANTED GaAs

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Differential reflectance spectroscopy (DR), a sensitive optical modulation technique has been applied to study ion implanted GaAs. The DR spectrum corresponds to the difference of optical reflectivity signals from implanted and unimplanted (masked) halves of a sample. In the experimental setup of the present study the sample rotates synchronously with the frequency of the lock-in amplifier. The measured signal is proportional to the difference in reflectance coefficient *R*.

In this work the differential reflectance results for 5 keV Ar^+ ion implanted (100) GaAs wafers at fluencies ranging from $3 \cdot 10^{11}$ to $1 \cdot 10^{14}$ ions/cm^2 are presented. DR spectra were collected for the photon energies varying from 1.65 to 3.35 eV. Owing to the experimental conditions it was possible to obtain information about the E_1, $E_1+\Delta_1$ critical points of a GaAs band structure. The DR spectra show broadening in the vicinity of the critical points. Analysis of the DR spectral region near the critical points gives information about post-implantation damage's level depending on ion fluence.

Introduction

Modulation techniques such as electroreflectance (ER) or photoreflectance (PR) have been applied for the last forty years to precise determination of inter-band transitions energy in semiconductors [1]. These methods, however, are limited to samples of high crystalline quality. If somebody needs a detailed information on changes of some parameters in the vicinity of band structure's critical points in ion-implanted material, the use of the contactless optical modulation technique based on the differential reflectance (DR) method should be recommended. The sensitivity and relative simplicity of the DR spectroscopy will be shown in the present work by probing low ion fluence implanted GaAs wafers.

Studies of low fluence ion-implanted semi- conducting samples are important from several points of view. The DR results enable investigation of beginning stages of radiation damage, monitoring order - disorder transitions as well as ion beam-induced changes of dielectric constants. The most important advantage of the DR technique is its ability to detect very low level damage. Using this method it is possible to measure relative changes of reflection coefficient $\Delta R/R$ at the level of 10^{-3}-10^{-4}.

Experimental

The rotating sample version of differential reflectivity set-up (Fig. 1) has been adapted for post-implantation investigations.

The light source is UV halogen lamp. The diameter of the light spot incident on the sample is approximately 0.5 mm. The sample is placed exactly at the center of a chopper target. In order to obtain a good quality DR spectrum it is necessary to mount sample perpendicularly to the plane of incidence. A small tilting of the sample may cause a large periodic drift of the light spot on the detection window of photomultiplier. For direct checking the quality of the sample set up an oscilloscope was connected with the lock-in amplifier. Two channels lock-in makes possible to measure simultaneously signals proportional to difference of reflectance ΔR and average reflectance R. Collected data are calculated by a computer and a final result spectrum consists of relative changes of reflection coefficient $\Delta R/R$ as a function of photon energy.

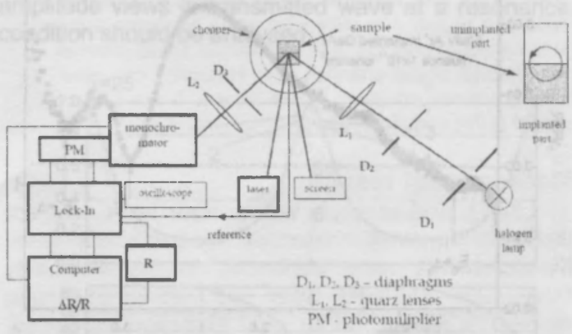

Fig. 1. Experimental set-up for modulated differential reflectance measurements.

Examined layers were formed by means of 5 keV Ar^+ ions implanted into (100) GaAs wafers at fluencies ranging from $3 \cdot 10^{11}$ to $1 \cdot 10^{14}$ ions/cm^2. In order to get a reference signal, a half of GaAs wafer was masked by a piece of GaAs during implantation process. Fig. 2 shows the depth distribution of vacancies induced by the 5 keV Ar^+ ions, as obtained from the SRIM code simulations.

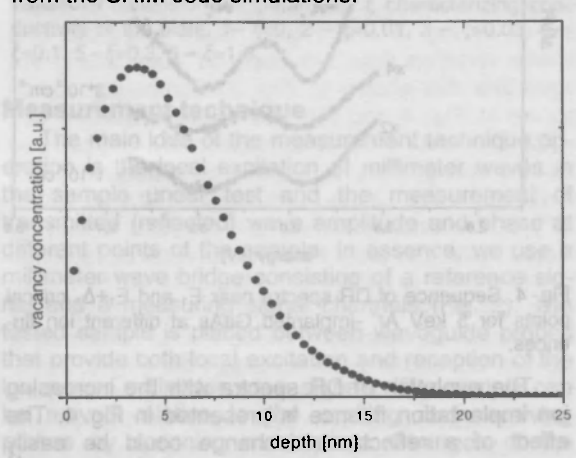

Fig. 2. Vacancy concentration depth profile for 5 keV Ar^+ implanted GaAs calculated by means of the SRIM simulation code.

Full depth of defected layer (Fig. 2) is estimated as 15 nm, and is equal to the light penetration distance in the vicinity of E_1 and $E_1+\Delta_1$ critical points, calculated as a reciprocal of absorption coefficient value of GaAs [2]. We are therefore sure that information about reflection coefficient and energies of critical points comes only from the Ar^+ implanted sublayer.

Results

Fig. 3 shows the differential reflectance spectrum of 5 keV Ar^+ implanted GaAs at a fluence of $1*10^{13}$ ion/cm^2. Except of a broadened line corresponding to the $E_0+\Delta_0$ critical point, there are two spectral features assigned to direct E_1 and $E_1+\Delta_1$ transitions in GaAs. Values of spin-orbit coupling Δ_1 obtained in our experiment are in the range: 0.26-0.28 eV, in agreement with literature data [3]. The character of the observed features in the modulated DR spectra reveals a first derivative-like structure.

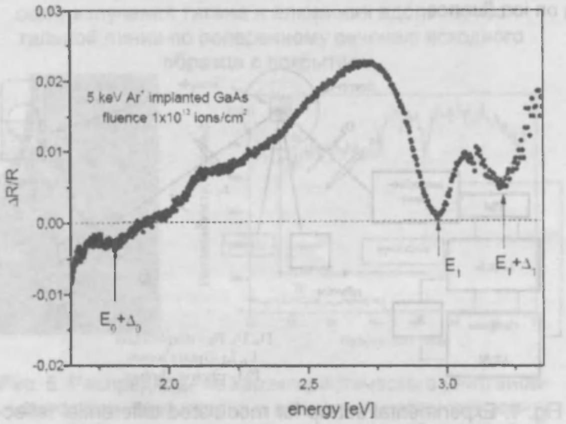

Fig. 3. DR spectrum of 5 keV Ar^+ implanted GaAs at a fluence of $1*10^{13}$ ion/cm^2.

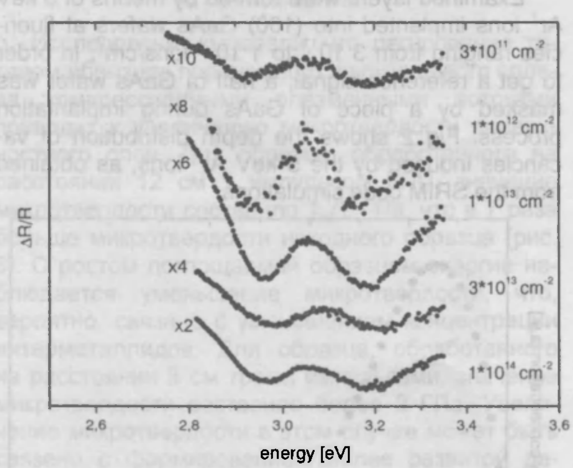

Fig. 4. Sequence of DR spectra near E_1 and $E_1+\Delta_1$ critical points for 5 keV Ar^+ -implanted GaAs at different ion fluences.

The evolution of DR spectra with the increasing ion implantation fluence is presented in Fig. 4. The effect of a reflectance's change could be easily recognized even at a fluence as small as $3*10^{11}$ ion/cm^2. The magnitude of $\Delta R/R$ increases several times in the studied fluence range. The measured spectra were fitted by a sum of two Lorentz functions with a help of the Levenberg-Marquardt routine. As an example, DR experimental and calculated spectra were shown in Fig. 5.

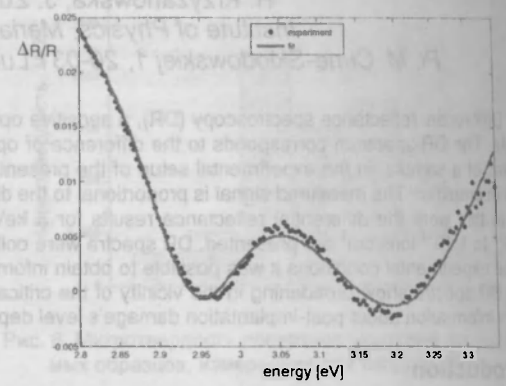

Fig. 5. DR experimental (black dots) and calculated (red line) spectrum of 5 keV Ar^+ implanted GaAs at fluence $1*10^{13}$ ion/cm^2.

It appears that there are not observed significant differences in the values of E_1 and $E_1+\Delta_1$ transitions energies for the studied ion fluences. Damage produced by ion implantation affects mostly broadening of these two lines. The broadening parameter Γ as a function of the ion fluence is shown in Fig. 6. This effect will be further investigated.

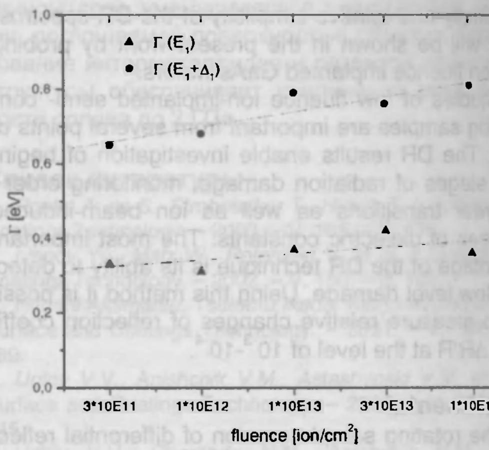

Fig. 6. Broadening parameter value as a function of fluence of 5 keV Ar^+ implanted into GaAs.

References

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