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Characterization of Radiation Damage by Deposition of GaN on GaAs

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Abstract: Radiation damage by reactive magnetron sputtering deposition at low energies is connected with marked changes of optical constants of semiconductors. It will be shown, that using ellipsometry and a special model can provide informations about relevant parameter of the amorphization process of GaN/GaAS layer System. The procedure allows the quantification of the radiation damage in the nanometer range and the refractive index of the formed amorphous GaAs.

Key words: Physical radiation effects, ions, argon ions, ellipsometry, semiconductors, gallium arsenide, gallium nitride, amorphization

INTRODUCTION

Gallium nitride on arsenide alloys is promising for optoelectronic devices working in the visible wavelength zone (Nakamura *et al*., 1994, 1996).

It is well known that the amorphization of Semiconductors crystal by ion implantation (Fried *et al*., 1992; Burns *et al*., 1991; Hu *et al*., 1991) or by deposition (Teng *et al*., 2006) is connected with marked changes of the dielectric function wich can be detected with a high sensitivity by ellipsometry.

If spectroscopic ellipsometry is used, it is possible to obtain the dielectric function for an extend wavelength range and to fit a layer model to the experimental data. In this way complex layer consisting of amorphous and crystalline material including voids can be treated (Vedam *et al*., 1985).

For a more detailed analysis of ion target-interactions, it is necessary to develop suitable multi-layer model that can be fitted to the experimental data (Hu *et al*., 1992).

It will be shown in the presented paper, that using special developed model (Bouafia *et al*., 2006) and ellipsometric measurements these changes can provide informations about relevant parameters of the amorphization process as the amorphization state and the critical concentration.

MATERIALS AND METHODS

During ion implantation the concentration of the point defects increases as a result of atomic displacements by nuclear collisions and above an accumulated critical energy density, these defects will relax into an amorphous state. The amorphization dose Da can then be defined as the ion dose required to deposit the critical energy density C. This will be equivalent to the first appearance of an amorphous layer with the thickness d. The expression of the energy density as function of dosis D is given by:

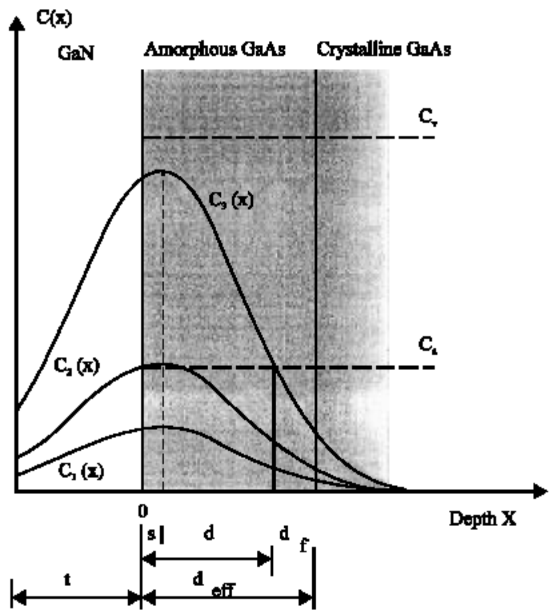

Fig. 1: Energy density distribution in the system layers GaN|a-GaAS|c-GaAs

$$\int_t^{\infty} c(x)dx = ED \qquad (1)$$

Where, t is the GaN thickness and E is the ion Energy.

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It will be assumed that the maximum of the damage depth distribution is located not far from the interface GaN/GaAs and the distribution can be approximated by a Gaussian (Fig. 1). This leads to the mathematical description of the maximum energy density distribution Cmax given by:

$$c_{max} = \sqrt{\frac{2}{\pi}} \frac{ED}{d\left[1 + \mathrm{erf}\left(\frac{s+t}{\sqrt{2}\delta}\right)\right]} \qquad (2)$$

Here, E is the ion impact energy, x is the depth in the substrate, s is the shift of the distribution related to the interface and δ is the straggling of the damage distribution.

A less damaged transition layer is formed between the amorphous GaAs and the crystalline GaAs. In the following, the later will be treated as an additional amorphous layer with a thickness d_f, which will be defined by the equivalence of the areas (Fig. 1):

$$d_f = \sqrt{2d^2 \ln \frac{D}{D_a}} + s \qquad (3)$$

The energy densities c1-c3(x) corresponds to different ion dosis. If c(x)>ca the semiconductor substrate is otherwise more or less strongly damaged.

Experiment: The GaN films were fabricated by reactive magnetron sputtering in Ar 99.99%-$N_2$99.99% gas mixture. A 99.99% purity Ga was used as target. The start pressure was 10^{-3} Pa. The substrate was located at 50 mm downstream from the target. The films were deposited at 0.6Pa. The partial pressure N2/Ar was 1.75. The substrates used in these experimental work were quartz for transmission measurements and GaAs with (100) orientation (n = 2.10^{17}cm^{-3}) for ellipsometric investigations.

GaN/GaAs samples with GaN thicknesses of about 600-900 nm were implanted with argon ions from a Kaufman-type source with energies from 500-3000eV. GaN layer thickness and ion energy have been adjusted that the maximum of the range distribution was located in the interface GaN/GaAs. The actual value of the ion dose determines the kind of the buried damaged layer (below or above the amorphous threshold, voids) and its extent in the depth.

The ellipsometic measurements were accomplished using rotating analyzer ellipsometer (Sentech Instruments, Germany) with the fixed laser wavelength 632.8 nm (1.96eV).

The angle of incidence has been chosen to 70° at this angle the laser spot is elliptical with an area of about 6 mm^2. Some measurements at other angles were only performed to verify the model.

RESULTS AND DISCUSSION

Experimental results of optical transmission as function of wavelength of GaN/quartz film with quartz substrate as reference is shown in Fig. 2. The interferences maxima in spectra. curves are located very closely. This indicates that GaN has very high transmission and possess low absorption in the visible a part of the spectrum (λ>400 nm). As indicated in Fig. 2 the average transmittance of GaN film is about 85%.

The measuring results of ellipsometry are available in the form of the ellipsometric angles ø and Ä that are correlated with the amplitude and the phase of the complex reflectance ratio

$$\rho = \frac{r_p}{r_s} = \tan \psi e^{i\Delta}$$

where, r_p and r_s are the reflection coefficients of the p- and s-polarized components. The results are shown in Fig. 3 in dependence of the GaN layer thickness.

From ψ and Δ values both the thickness and the complex refractive index ñ = n-ik of the respective amorphous zone can be derived by fitting model calculations to the measure values. Concerning the amorphization behaviour, the thickness of amorphous

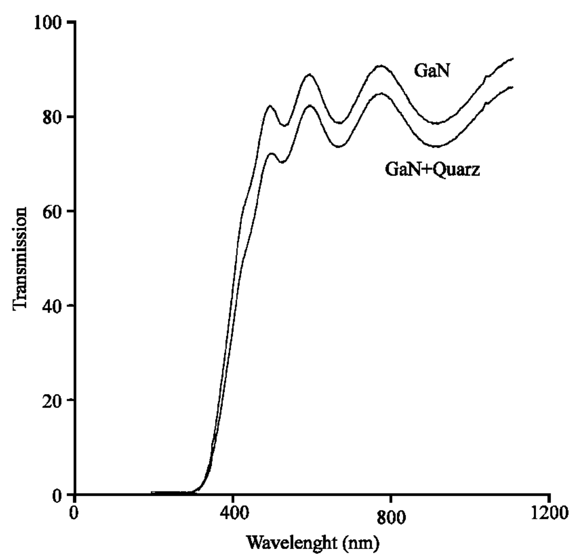

Fig. 2: Optical transmission of gallium arsenide in dependence on the wavelength

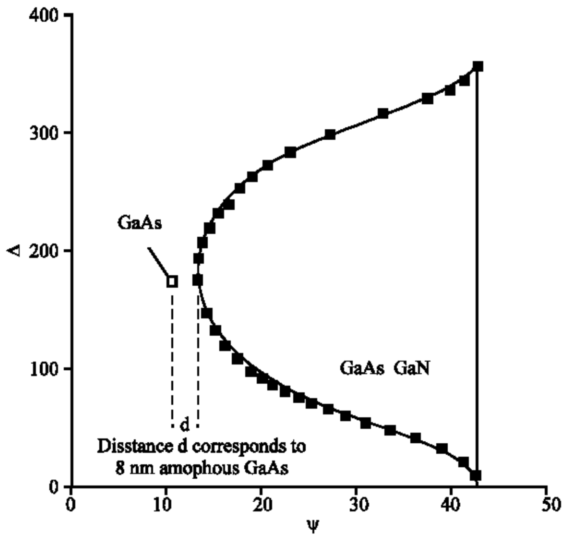

Fig. 3: Experimental ellipsometric ψ and Δ curve

GaAs has been found 8 nm. For amorphous GaAs the refractive index value ñ = 4.30-i0.70 was an acceptable fit for all values investigated here.

This complex refractive index is characterized by comparatively high n and k values compared with crystalline GaAs (ñ = 3.85-i0.19), which are typical of amorphous GaAs created by ion damaged (Jellison, 1992) or deposition (Teng *et al*., 2006). The here found refractive index agrees within some percent with the reported values.

CONCLUSION

In conclusion, it was the intention of this study to demonstrate the applicability of the here presented simple procedure to characterize the amorphization of gallium arsenide by low energy, which require otherwise more complex methods.

The method consisting of ellipsometric measurements combined with a model should be applied to determine the depth of the ion implantation damage and the resulting optical properties.

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