# Effect of thermal annealing on the depth distributions of the atoms and optical constants of near surface layers the implanted GaAs with In<sup>+</sup> ions

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## **This presentation**

Introduction and Motivation Preparation of samples Measurement methods Measurements Summary and Conclusions Semiconductor materials such as GaAs and InAs. are widely used in the production of various types of equipment in electronics and optoelectronics.

Ion implantation is one of the ways to change the electrical and optical properties of the semiconductor materials.

In the mentioned process, ions introduced into the doped material cause various types of defects. In order to remove the defects and rebuild the starting material, thermal annealing is used.

This presentation shows the results of research on the influence of the ion implantation process and thermal annealing on the optical properties and atomic composition of the subsurface layer of SI GaAs monoterystalline samples (100). What was the motivation to study In<sup>+</sup> and ion implanted samples by Rutherford Backscattering and Spectroscopic Ellipsometry?

*Ito determine composition of ion implanted GaAs,* 

*Ito estimate optical constants obtained from ellipsometric measurements,* 

 $\square$  to make precise measurements of light absorption in thin transparent layers with a help of reflectance polarization spectrometry (SE).

**RBS monoenergetic particles** in the incident beam collide with target atoms and are scattered backwards into the detector-analysis

system, which measures the energies of the particles.



The kinematics of the collision and the scattering cross section are independent of chemical bonding, and hence backscattering measurements are insensitive to electronic configuration or chemical bonding with the target.

The energy transfers or kinematics in elastic <u>collisions between</u> <u>two isolated particles</u> can be solved fully by applying the principles of <u>conservation of energy and</u> momentum. Nuclear particle detector with respect to scattering angle courtesy of MeV He<sup>+</sup> electron beam.

He<sup>+</sup> undergo close-impact scattering collisions that are governed by the well-known Coulomb repulsion between the positively charged nuclei of the projectile and target atom.



$$\begin{aligned} \frac{1}{2}M_1v^2 &= \frac{1}{2}M_1v_1^2 + \frac{1}{2}M_2v_2^2, \\ M_1v &= M_1v_1\cos\theta + M_2v_2\cos\phi, \\ 0 &= M_1v_1\sin\theta - M_2v_2\sin\phi. \end{aligned}$$

## **Result solutions of equations**

$$\frac{V_1}{V_0} = \frac{\left[\pm \left(M_2^2 - M_1^2 \sin^2(\theta)\right)^{\frac{1}{2}} + M_1 \cos(\theta)\right]}{M_1 + M_2}$$
$$M_1 < M_2$$
 attention
$$K = \left[\frac{M_1 \cos(\theta) + \left(M_2^2 - M_1^2 \sin^2(\theta)\right)^{\frac{1}{2}}}{M_1 + M_2}\right]^2$$

 $E_o K = E_1 \longleftarrow$  Energy particles after impact

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## **Rutherford backscattering – experimental conditions**

*RBS investigations were carried out using He<sup>+</sup> particles with 2.035 MeV energy.* 

 $\Theta$  - the scattering angle of 170 degs.

The <sup>4</sup>He<sup>+</sup> ion beam was produced by an EG-5 accelerator of a Van de Graaff type.

The beam intensity did not exceed 100 nA to avoid heating of the sample above the room temperature.

The detector resolution was at the level of 15 keV in this experiment.

Pressure of about 10<sup>-6</sup> Tor was into vacuum chamber.

 $\alpha = 60^{\circ}$  angle, that the target surface was tilted with respect to the analyzed beam.

## JINR DUBNA NP RBS EG5

**EG5**;









#### The source of ions



### Energy He<sup>+</sup> 0.9-3.5 MeV 2 keV

### Ion beam intensity 10µA -30µA



#### **Robert Jemison Van de Graaff**<sub>6</sub>









**RBS** exp





## **RBS** - the diffusion process of In atoms



RBS spectra of GaAs implanted with indium after thermal annealing. • - measurement results, solid line is calculated by the DVBS [x] computer code. a)  $T_{ann} = 600$  oC and  $t_{ann} = 0.5$  h, b)  $T_{ann} = 600$  oC and  $t_{ann} = 2.0$  h, c)  $T_{ann} = 800$  oC and  $t_{ann} = 0.5$  h, and d)  $T_{ann} = 800$  oC and  $t_{ann} = 2.0$  h

**Results of calculation of diffusion coefficient D and defects of D<sub>V</sub> for Indu impl. for GaAs and thermal annealed** 

Temperature of annealing [°C]	D [cm²/s]	<i>D<sub>V</sub></i> [cm <sup>2</sup> /s]
600	2.0x10 <sup>-12</sup>	3.5x10 <sup>-16</sup>
800	9.7x10 <sup>-12</sup>	1.4x10 <sup>-14</sup>

[X] Bohac V, Shirokov DM. Nucl Instrum and Methods B 1994;84:497

[Y] Jaworska D, Kobzev AP. Electron Technology 1997;30:149

# **Physical basics of ellipsometry**

## **ELECTROMAGNETIC WAVES**

In 1849, James Clark Maxwell



found out that light waves are electromagnetic

 $E_0$ 

E Fig.2

waves that follow electromagnetic theory.

Fig. 2 shows the propagation of an electromagnetic wave derived from the well known Maxwell's equations.

The equations for conductors including metals and semiconductors are

expressed by:

div  $\boldsymbol{E} = \rho/\varepsilon_{p}$ div  $\boldsymbol{B} = 0$ rot  $\boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t}$ rot  $\boldsymbol{B} = \mu_{p} \left(\varepsilon_{p} \frac{\partial \boldsymbol{E}}{\partial t} + \boldsymbol{J}\right)$ 

In the Fig.2; *E* and *B* show the electric field and magnetic induction.  $\varepsilon_p$  and  $\mu_p$  are the permittivity and permeability of materials, respectively.  $\rho$  shows the electric charge, and *J* in indicates the current density given by  $J = \sigma E$ , where  $\sigma$  is the conductivity.

### Ellipsometric measurements



VASE of J.A. Woollam firm Co. Inc.

## Ellipsometry

In ellipsometry, p- and s-polarized light waves are irradiated onto a sample at the Brewster angle, and the optical constants and film thickness of the sample is measured from the change in the polarization state by light reflection or transmission. Figure below illustrates the measurement principle of ellipsometry.



As mentioned, the amplitude reflection coefficients for p- and s-polarizations differ significantly due to the difference in electric dipole radiation. Thus, upon light reflection on a sample, p- and s-polarizations show different changes in amplitude and phase. ellipsometry measures the two values  $(\Psi, \Delta)$  that express the amplitude ratio and phase difference between p- and s-polarizations, respectively. In ellipsometry, therefore, the variation of light reflection with p- and s-polarizations is measured as the change in polarization state.





b)

(a) Optical model consisting of an air/thin film/substrate structure
(b) Ψ and Δ spectra obtained from an a-Si:H thin film (2500 Å) formed on a c-Si substrate



### Ellipsometry – modeling and calculations



for unimplanted samples

for annealed and implanted samples

$$n(\lambda) = A + \frac{B}{\lambda^2} + \frac{C}{\lambda^4}$$
Cauchy equation

C.M.Herzinger, P.G. Snyder, B. Johans, J. A. Woollam, A. Appl. Phys. 77 (1995) 1715 J.A. Woollam, Ellipsometry Modeling Software, 2004





GaAs Vir

1	ema2 gaas-ox/0.0001% a-gaas/0.0001% gaas1.4 nm	
0	gaas 1 mm	

#### GaAs Impl In and stripped

8	ema ox_12l/0.042% a-gaas	1.1824 nm
7	impl_08l	13.8 nm
6	impl_09l	15 nm
5	impl_10l	15 nm
4	impl_11I	15 nm
3	impl_12l	15 nm
2	impl_13l	15 nm
1	impl_14lm	15 nm
0	gaas	1 mm

15 ema ox_12l/0.0902% a-gaas	1.9712 nm
14 impl_01l	13 nm
13 impl_02l	15 nm
12 impl_03l	15 nm
11 impl_04l	15 nm
10 impl_05l	15 nm
9 impl_06l	15 nm
8 impl_07l	15 nm
7 impl_08l	15 nm
6 impl_09l	15 nm
5 impl_10l	15 nm
4 impl_111	15 nm
3 impl_12l	15 nm
2 impl_131	15 nm
1 impl_14lm	15 nm
0 gaas	1 mm





λ [nm]

# Summary and Conclusions

- The Indium atoms were diffused deeper when the annealing temperatures up to 800°C.
- When the annealing temperature increases, the optical constant values of the samples were changed.
- SE measurements allow the determination of depth profiles of optical constants