MÖSSBAUER STUDY OF THE DX–CENTER IN Te–IMPLANTED AlxGa1–xAs

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ABSTRACT. In Mössbauer measurements on AlxGa1–xAs implanted with 129mTe–isotopes, a defect configuration is observed which is characterized by a large electric field gradient. This defect configuration shows persistent photoionisation and it is associated with the so–called "DX–center". The time constant of the relaxation from the substitutional donor–site to the DX–center defect site is measured.

1. Introduction

The term "DX–center" was introduced by Lang et al. [1,2] with D standing for donor and X relating to an unknown associated defect. It was first found in Te–doped AlxGa1–xAs [2]. For x > 0.2, the conductivity in n–type AlxGa1–xAs was found to be controlled by a deep donor level, giving rise to persistent photoconductivity. This DX–center was also found to be present in n–type GaAs, upon applying external pressure exceeding 2 GPa, or for doping levels exceeding 10^19 atoms/cm^3. In n–GaAs with high donor concentrations and in AlxGa1–xAs for x > 0.2, this DX–center causes lack of electrical activation.

Several microscopic models have been put forward for the DX–center [3]. One of the models proposed a "displaced donor"–configuration, with large or small lattice–relaxation. They involve donor atoms that are driven away from the substitutional lattice site, by a driving force that finds its origin in the electronic level structure of the impurity–host system. Chadi and Chang proposed a negative U–center model [4], where a threefold–coordinated interstitial site is suggested for either the donor or one of its nearest neighbours.

Earlier Mössbauer measurements were performed on AlxGa1–xAs, implanted with a dose of 10^13 129mTe–atoms/cm^2 and on GaAs, implanted with doses from 10^13 to 10^16 129mTe–atoms/cm^2 [5,6,7]. In those spectra, a single line, which represents substitutional implanted Te–atoms dominates for x–values lower than 0.2. For x between 0.2 and 0.7, a component with a large electric field gradient dominates. This electric field gradient is an indication of a defect site with a strong deviation of cubic symmetry. In GaAs, for low implantation doses the single line dominates, while for high implantation doses the defect site with the large electric field gradient dominates. These two components can therefore be interpreted as follows. The

substitutional site corresponds to the shallow Te donor level, while the defect site corresponds to the deep Te defect level, the so-called "DX-center". This correspondence is supported by the dose-dependence of the presence of the quadrupole multiplet in GaAs and the x-dependence of the fraction of Te-atoms involved in this quadrupole multiplet in Al_{1-x}Ga_{x}As which agree well with the presence of the DX-center.

The vibrational properties of \(^{129}\)I in this defect configuration were studied by measuring the Debye-temperature [6]. From a comparison with \(^{119}\)Sn Debye-temperatures it is concluded that, under assumption of similar force constants for I and Sn in GaAs, a nearest neighbour vacancy configuration for the implanted Te-atom is not very likely. Also a second neighbour defect-association model is not consistent with the measurements, as a much smaller electric field gradient is then expected. A "displaced donor" configuration can be a possible explanation for the presence of the quadrupole interaction.

In this study, we want to show that the assignment of the quadrupole site, characterized by the large electric field gradient, to the DX-center, is also supported by measuring the persistent photoionisation of the DX-centers.

2. Materials and Methods

For Mössbauer measurements MBE-grown Al_{0.6}Ga_{0.4}As was implanted with 80 keV \(^{129m}\)Te-isotopes with an implantation dose of \(10^{13}\) atoms/cm\(^2\) and \(<100>-cut LEC-GaAs was implanted with a dose of \(10^{15}\) atoms/cm\(^2\). For electrical measurements stable isotopes \(^{128}\)Te and \(^{127}\)I were implanted. Rapid thermal annealing (R.T.A.) to 900°C, with the surface of the sample protected by another unimplanted GaAs sample, was used to remove the implantation damage.

3. Results

Persistent photoconductivity at low temperatures is a well known feature of the DX-center. It is accepted that photoexcitation of electrons from the deep-level traps, DX-centers, which undergo a large lattice relaxation, is the origin of this persistent photoconductivity. Persistent photoconductivity results because recapture of electrons by DX-centers is prevented by a potential barrier at low temperatures. With the aim to check this persistent photoconductivity, electrical and Mössbauer measurements were performed in darkness and during and after illuminating the samples with a red LED (\(\lambda = 655\) nm).

The sheet carrier concentration of \(^{128}\)Te and \(^{127}\)I implanted in GaAs was measured at liquid nitrogen temperature as a function of implantation dose. In both cases, the charge carrier concentration increases when the sample is illuminated with a LED from an implantation dose of \(2 \times 10^{14}\) atoms/cm\(^2\) on. This photoconductivity remains for several minutes after the light is turned off. It should be remarked that, even when the light is on, for Te and for I only a part of the implanted donor atoms behaves as a good donor. At the highest implantation dose, around 5% of the donor atoms are electrically active.

Figure 1 shows the Mössbauer spectra, measured at liquid helium temperature, of GaAs implanted with \(10^{15}\) \(^{129m}\)Te-atoms/cm\(^2\) after rapid thermal annealing at 900°C. Spectrum a is measured in darkness. It shows a quadrupole multiplet (with an absorber isomer shift \(\delta = 0.85(1)\) mm/s with respect to CuI, an electric field