Vol. 82 (1992) *ACTA PHYSICA POLONICA A* No 4

Proceedings of the XXI International School of Semiconducting Compounds, Jaszowiec 1992

SUPERCONDUCTIVITY IN INDIUM DIFFUSED GaAs

J.M. BARANOWSKI, P. WÓJCIK

Institute of Experimental Physics, University of Warsaw
Hoża 69, 00-681 Warszawa, Poland

M. PALCZEWSKA, R. JABŁOŃSKI

Institute of Electronic Materials Technology, Wólczyńska 133, 01-919 Warszawa, Poland

E.R. WEBER, W.F. YAU, H. SOHN AND P. WERNER

Department of Materials Science, University of California, Berkeley, CA 94720, USA
and
Materials Science Division, Lawrence Berkeley Laboratory, Berkeley, CA 94720, USA

Superconductivity of indium diffused GaAs was investigated. The superconductivity in these samples was identified by the magnetic susceptibility and the characteristic field modulated microwave absorption. The static magnetic susceptibility was measured from 40 K down to 2.5 K. The result shows two distinctive diamagnetic contributions within 7 K–2.5 K range. These diamagnetic contributions were correlated with the excess of In and Ga metal in GaAs.

PACS numbers: 74.70.Mq, 76.20.+q

The discovery of superconductivity connected with indium clusters in GaAs has been reported recently [1, 2]. This finding has been independently confirmed in In diffused GaAs [3].

In this work we report investigations of indium diffused samples of GaAs. These investigations were done using field modulated microwave absorption (FMMA) and static magnetic susceptibility measurements. Samples of In and Ga diffused GaAs were investigated by FMMA in an electron paramagnetic resonance experiment. A Bruker ESP 300 spectrometer was used working near 9.4 GHz and employing 100-kHz field modulation amplitudes from 1 Gs to 10 Gs. A pair of externally fed coils allowed negative magnetic field offset for sweeps around zero field. The FMMA signal was directly connected with the field derivative of the microwave absorption. Temperature variation from 4.2 K was obtained with a He flow cryostat. A thermocouple mounted in the vicinity of the sample allowed to monitor the temperature. More accurate temperature measurement at the sample site was done with a help of the susceptibility measurements of $CuSO_4 \cdot 5H_2O$

salt which fulfils well Curie–Weiss law. Static magnetic susceptibility measurements were made using a SQUID S 600C magnetometer. The susceptibility was measured from 40 K to 2.5 K.

Crystals of GaAs which were used in the investigations had been grown in the Crystal Growth Laboratory of University of Warsaw. Diffusion of indium into GaAs was done in a quartz ampule using diffusion temperatures ranging from 490°C to 700°C for a few hours. After the diffusion process the excess of metal was removed by chemical etching. In the case of gallium, the diffusion was done at the temperature of 650°C.

Most of the In diffused GaAs samples showed at low temperatures a characteristic FMMA signal near zero field. In addition to this signal, a local maximum in FMMA amplitude was observed close to 300 Gs. This is in agreement with our earlier observation [1]. Due to more precise temperature measurements we were able to determine that the phase transition takes place close to 7 K. Above 7 K the signal disappeared completely. This temperature is lower than reported by us previously [1] and is in agreement with the value given by Li et al. [3].

Our study of numerous samples showed that the amplitude of the zero field FMMA signal is roughly independent on diffusion temperature of indium. However, we found that there are samples which show only the zero field FMMA signal without presence of a local maximum near 300 Gs. For these samples the FMMA signal connected with a minimum in absorption at $H = 0$ was observed for temperatures ranging between 4.2 K and 5 K. Above 5 K the signal disappeared completely. Representative spectra for such a sample are shown in Fig. 1a. These results indicate that the zero field FMMA signal and the local maximum near 300 Gs are independent and are not directly related to each other. On the other hand, a local maximum close to 300 Gs was found in Ga diffused samples. This indicates that this signal is directly related to gallium metal. The spectra found in Ga diffused samples are shown in Fig. 1b. The phase transition for this sample is close to 7 K.

The presence of two superconductive phases was confirmed in a Meissner effect experiment. The static magnetic susceptibility of the sample with the strongest FMMA signal (which was used in the measurements in our previous work [1]) was measured with 200 Gs of applied magnetic field. Results of these measurements are shown in Fig. 2. At 5 K there is a sharp appearance of the negative diamagnetic contribution. This effect is a clear evidence of the existence of superconductivity with the transition temperature close to 5 K. This temperature corresponds well to the transition temperature found in the microwave absorption experiment where the zero field FMMA signal disappeared close to 5 K. However, there is another diamagnetic contribution to the magnetic susceptibility present at higher temperatures close to 7 K. This is shown in the inset in Fig. 2. The onset of a weak but distinctive negative diamagnetic contribution was found by simultaneous measurement of a few samples which increased the volume of the superconductive phase. The 7 K transition temperature found in the static magnetic susceptibility measurements corresponds well to the temperature in which a local maximum FMMA signal disappears.

The transition temperature close to 5 K seems to be connected with presence

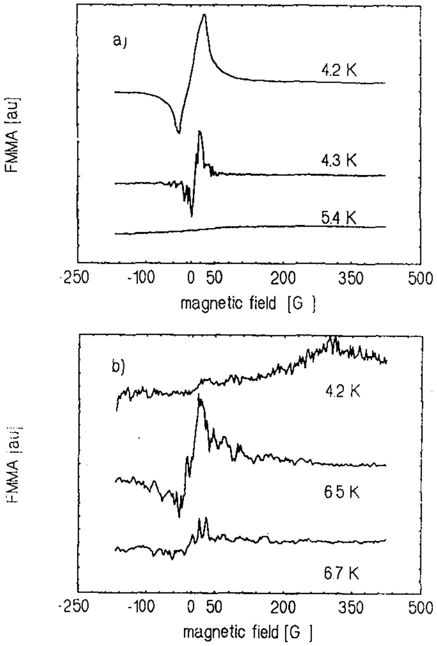

Fig. 1. Temperature dependence of FMMA signal in GaAs diffused with (a) In, (b) Ga. The base line for each temperature is offset to show the temperature effect. The incident microwave power is 2 mW, field modulation is 1 Gs.

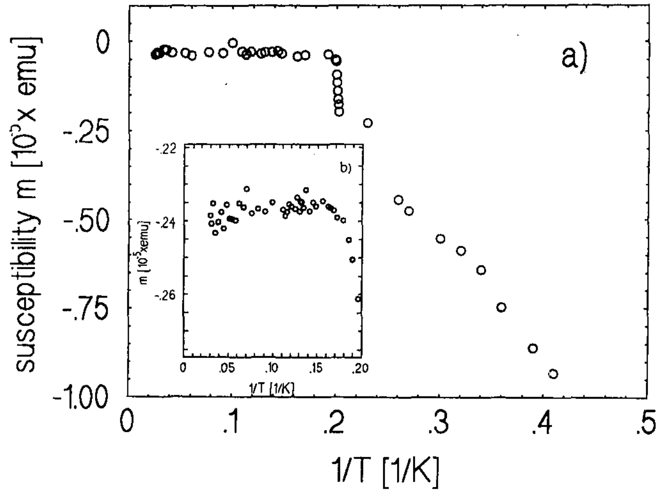

Fig. 2. Static magnetic susceptibility of GaAs:In sample as a function of reciprocal temperature. The applied magnetic field is 200 Gs. The inset shows the static susceptibility of the same type sample with a bigger volume within the reciprocal temperature 0–0.2 range.

of indium in GaAs. This transition temperature is higher than the temperature of indium metal superconductive phase transition, which is 3.5 K [4]. However, it was reported that In films evaporated at low temperature have T_c between 4 K and 5 K [4]. Therefore, it seems that 5 K superconductive phase may be related to indium which decorates dislocations or it is in a form of disorded clusters.

The other phase transition taking place at higher temperature seems to be directly related to the excess of gallium in GaAs. Superconductive transition temperature of Ga is close to 1 K [4]. However, the observed 7 K temperature corresponds well to superconductive transition temperature of gallium films evaporated at low temperature which are believed to be related to amorphous phase of gallium [4]. The weak susceptibility signal connected with this phase indicates a small volume of superconductive gallium phase. It seems that indium diffusing into GaAs goes substitutionally as well, forcing gallium atoms into interstitial sites. These interstitial gallium might form disordered clusters and may be responsible for the observed 7 K superconductive phase. Indium metal may diffuse to GaAs interstitially as well, and may be present in higher concentration in the bulk. That could explain why the susceptibility signal originating from indium is much stronger.

Concluding, we showed that the excess of In or Ga leads to formation of superconductive phases in GaAs. The most likely the superconductivity is connected with decoration of extended defects in GaAs by interstitial metal atoms.

This work was supported by the Committee for Scientific Research grant 204249101.

References

[1] J.M. Baranowski, Z. Liliental-Weber, W.-F. Yau, E.R. Weber, *Phys. Rev. Lett.* **66**, 3079 (1991).

[2] J.M. Baranowski, Z. Liliental-Weber, W.-F. Yau, E.R. Weber, *Phys. Rev. Lett.* **68**, 551 (1992).

[3] Y.K. Li, Y. Huang, Z. Fan, C. Jiang, X.B. Mei, B. Yin, J.M. Zhou, J.C. Mao, J.S. Fu, E. Wu, *J. Appl. Phys.* **71**, 2018 (1992).

[4] *Landolt-Bernstein, Numerical Data and Functional Relationship in Science and Technology, New Series,* Vol. III21a, Springer-Verlag, Berlin 1989.