5-1974

Electrical Characteristics of Al-Implanted ZnSe

B. K. Shin

Y. S. Park

David C. Look

Wright State University - Main Campus, david.look@wright.edu

Follow this and additional works at: http://corescholar.libraries.wright.edu/physics

Part of the Physics Commons

Repository Citation


http://corescholar.libraries.wright.edu/physics/615

This Article is brought to you for free and open access by the Physics at CORE Scholar. It has been accepted for inclusion in Physics Faculty Publications by an authorized administrator of CORE Scholar. For more information, please contact corescholar@wwwlibraries.wright.edu.
Electrical characteristics of Al implanted ZnSe

B. K. Shin, Y. S. Park, and D. C. Look

Citation: Appl. Phys. Lett. 24, 435 (1974); doi: 10.1063/1.1655250
View online: http://dx.doi.org/10.1063/1.1655250
View Table of Contents: http://apl.aip.org/resource/1/APPLAB/v24/i9
Published by the American Institute of Physics.

Additional information on Appl. Phys. Lett.
Journal Homepage: http://apl.aip.org/
Journal Information: http://apl.aip.org/about/about_the_journal
Top downloads: http://apl.aip.org/features/most_downloaded
Information for Authors: http://apl.aip.org/authors

ADVERTISEMENT

EXPLORE WHAT’S NEW IN APL
SUBMIT YOUR PAPER NOW!
Electrical characteristics of Al-implanted ZnSe

B. K. Shin*, Y. S. Park, and D. C. Look†

Aerospace Research Laboratories, Wright-Patterson Air Force Base, Ohio 45433

(Received 3 December 1973; in final form 22 February 1974)

Aluminum was implanted in ZnSe at 90 keV to a dose of $10^{14}$ ions/cm$^2$ at room temperature. Hall-effect and sheet-resistivity measurements were made on the samples for various annealing conditions. The implanted layer is found to be degenerate $n$-type having a sheet resistivity of $-10^3$ Ohm/sq after annealing at 900°C for 4 h.

The production of low-resistivity layers is an important goal of ion implantation efforts in semiconductors. Factors which affect the conductivity, such as radiation damage and compensation, can often be conveniently studied by Hall-effect measurements. Most of the early work in the II–VI compounds, including ZnSe, has been concerned with the formation of $p-n$ junctions, and consequently the implanted layers have in general been of high resistivity (due to self-compensation), making Hall measurements difficult. Thus, it is of interest to create a low-resistivity layer in ZnSe and we have done this by implanting high-resistivity $n$-type material with a known shallow donor, Al. In this way, we have produced degenerate electrical behavior (for the first time, we believe, in an ion-implanted II–VI compound) and have been able to show that the Al is almost uncompensated.

The substrate used was a melt-grown cubic single crystal of undoped high-resistivity ($\sim 10^9$ Ohm cm) $n$-type ZnSe. The use of a high-resistivity substrate makes it possible to confine the resulting electrical characteristics to the lower-resistivity implanted-layer region. The crystal was mechanically polished and chemically etched at 90°C for 1 min in a mixture of 2 parts $H_2SO_4$ and 3 parts saturated aqueous solutions of $K_2Cr_2O_7$ followed by a 20-sec rinse in a boiling 25% solution of NaOH. Aluminum was then implanted at 90 keV to a dose of $10^{15}$ ions/cm$^2$ at room temperature. A projected ion range of 920 Å was calculated from the theory of Lindhard, Scharff, and Schiött with an assumed Gaussian profile. Implanted samples were annealed up to 1050°C in evacuated quartz ampoules of $\sim 10^4$ Torr for times up to 4 h. Each sample was removed from its ampoule following a water quench to room temperature. Samples were cut into small rectangular parallelepipeds having typical dimensions of 1.0 x 0.5 x 0.1 cm and

Ohmic contacts were attached using an ultrasonic soldering gun and pure In solder. The dc Hall-effect and sheet-resistivity measurements were made over the temperature range 5–300°C, in a magnetic field of 18 kG. A conventional five-lead configuration was used to minimize the problem of contact resistance.

Samples were annealed for 30 min at 600, 750, 900, and 1050°C and additionally for times of 1 and 4 h at 900°C. Precise Hall measurements were possible only for the 900°C annealed samples and indicated $n$-type conductivity. The results of room-temperature electrical measurements are given in Table 1. The sample annealed for 4 h at 900°C was further investigated over the temperature range 7–300°C, and these data are presented in Fig. 1. The quantities $p'$ and $n'$ are the so-called sheet-resistivity and effective sheet carrier concentration, respectively. For a uniform implantation, $n'=nz$ and $p'=\rho z$, where $n$ and $\rho$ are the normally defined carrier concentration and resistivity, respectively, and $z$ is the layer thickness. Because of the narrow degeneracy of the data at 900°C, as demonstrated in Fig. 1, $n'$ and $\mu$, the effective mobility, are calculated assum-

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Time</th>
<th>Sheet resistivity $\rho'$ (Ohm/cm$^2$)</th>
<th>Concentration $n'$ (cm$^{-2}$/V sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>days</td>
<td>$\sim 10^6$</td>
<td></td>
</tr>
<tr>
<td>600</td>
<td>30 min</td>
<td>1.0 x $10^6$</td>
<td></td>
</tr>
<tr>
<td>750</td>
<td>30 min</td>
<td>4.0 x $10^6$</td>
<td></td>
</tr>
<tr>
<td>900</td>
<td>30 min</td>
<td>2.0 x $10^6$</td>
<td>1.5 x $10^{15}$</td>
</tr>
<tr>
<td></td>
<td>1 h</td>
<td>7.5 x $10^5$</td>
<td>1.0 x $10^{15}$</td>
</tr>
<tr>
<td></td>
<td>4 h</td>
<td>2.0 x $10^5$</td>
<td>0.85 x $10^{15}$</td>
</tr>
<tr>
<td>1050</td>
<td>30 min</td>
<td>$\sim 10^5$</td>
<td></td>
</tr>
</tbody>
</table>


Copyright © 1974 American Institute of Physics
ing a Hall factor of unity. In Table I it is seen that the resistivity decreases with increasing annealing time and temperature except that at 1050°C it increases again to near the substrate value. This latter fact is probably due to thermal etching of the implanted layer during annealing, as evidenced by a yellowish deposit on the wall of the evacuated ampoule. Also, it should be mentioned that the samples annealed for 1 and 4 h at 900°C were implanted in the dark, while the other samples were illuminated with high-intensity light in an attempt to reduce space-charge effects. This fact could account for the 50% difference observed in \( n' \) at 900°C.

From Fig. 1 and Table I several observations can be made. (i) The quantities \( p' \), \( \mu \), and \( n' \) are almost independent of temperature, implying nearly degenerate carriers (the Mott criterion for ZnSe is \( n \gg N_c \approx 7 \times 10^{17} \text{ cm}^{-3} \)). This lack of temperature dependence also suggests that profile effects are not too important. \(^{10}\) (ii) For the 900°C data, \( n' \approx 10^{15} \text{ cm}^{-3} \), almost the same as the implanted Al dose. This implies that most of the Al are uncompensated donors. Since the magnitude of \( n' \) changes little with annealing time, the Al must become electrically active in less than 30 min. (iii) The mobilities are very low compared to pure ZnSe. An explanation of this fact is difficult because we do not as yet know the densities of either the Al ions or the damage centers. Often a mobility as low as 0.2 cm\(^2\)/V·sec is indicative of high disorder in the solid. \(^{11}\)

It is useful to compare Al implantation with conventional Al doping. A melt-grown ZnSe sample doped with about 100 ppm Al exhibits high resistivity (~10\(^7\) Ω·cm), evidently due to compensating centers formed by Zn vacancies and Al. \(^{12}\) Heat treating the sample in molten Zn for 24 h at 900°C reduces the resistivity to 0.01 Ω·cm. In Al-implanted ZnSe, low resistivity is achieved by annealing in vacuum at 900°C for a short period of time, suggesting that such compensating centers are not present.

In conclusion, it has been demonstrated here that implantation of high-resistivity \( n \)-type ZnSe by Al ions can create a degenerate \( n \)-type layer with a relatively low sheet resistivity and that the Al donors are nearly uncompensated. However, much work remains to be done, for example, on the investigation of profiles and annealing processes, but it is clear that Al may be an important implant species in II-VI compounds.

The authors wish to thank Dr. J. A. Hutchby of NASA Langley Research Center who generously performed the implantation of the samples.

\(^{*}\)Permanent address: Systems Research Laboratories, Inc., Dayton, Ohio 45440. Work performed under Contract No. F33615-72-C-1099 supported by the Aerospace Research Laboratories.

\(^{1}\)Permanent address: Department of Physics, University of Dayton, Ohio 45469. Work performed under Contract No. F33615-71-C-1877 supported by the Aerospace Research Laboratories.


\(^{8}\)The ion implantation was done at NASA Langley Research Center.


\(^{10}\)See, for example, C. MacDonald and Galster, in Ion Implantation, edited by F. Eisen and L. Chadderton (Gordon and Breach, New York, 1971), p. 172.

\(^{11}\)See, for example, J. C. Male, Brit. J. Appl. Phys. 18, 1543 (1967).