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The principal purpose of our research is to show that low-temperature treatment of materials can be successfully used instead of annealing. Laser shock waves (LSW) were chosen as an alternative to form p-n junctions in HgCdTe after arsenic ions were implanted. Electrical characteristics of As implanted HgCdTe bulk crystals were studied to determine the effect of LSW generated by nanosecond laser irradiation pulses. The samples were of *n*-type conductivity immediately after the implantation. Then LSW processing was performed under increasingly growing laser beam power density and shock wave pressure. The experiment demonstrated that a threshold shock wave pressure should be reached to ensure the *p*-to-*n* conductivity conversion in the surface layer of samples. On the whole the results provide evidence that LSW combined with ion implantation can be used to form *p*-*n* junctions in HgCdTe.

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1 Introduction

Study of the effect of shock waves (SW) on semiconductors has both fundamental and applied value. Laser-induced shock waves (LSW) provide more convenience during experiments in comparison with other SW (burst SW, accelerated electron and ion bombardment SW), because laser processing allows a better control of SW parameters through varying the laser irradiation parameters.

It is known that SW propagation through a crystal volume can result in generating different point defects with a concentration reaching 10^{-4} at. % [1], that causes significant changes in the characteristics of semiconductors as well as of semiconductor devices [2].

$Hg_{1-x}Cd_xTe$ is the material system of choice for high-performance sensing in the long-wave infrared [3, 4]. The p-on-n heterojunction device is currently the preferred device design, in which a wider gap p-type cap layer is grown on a n-type base layer with $x = 0.22$. Although doping of the base layer with $\sim 10^{15}$ cm^{-3} indium is well in hand, the cap layer doping is more complicated. Both group I and group V elements are candidate acceptors in II-VI compounds and alloys. The group V elements are to be preferred over those from group I for smaller diffusivities that provides device structures having greater thermal stability [5, 6]. Recently As has attracted much attention because it has been found that 100 % activation of the acceptor state can be achieved under certain conditions [7].

Previously we studied the general features of defects behaviour in narrow gap $Hg_{1-x}Cd_xTe$ and $Pb_{1-x}Sn_xTe$ materials under the LSW impact [8, 9]. It was found that the strongest influence is in crystals with high density of initial point defects and especially in the samples with macroscopic inhomogeneities. It was shown that laser shock wave treatment is an effective way to reduce the relative volume of precipitates in semiconductors [10]. Besides, the possibility of the group I elements diffusion stimulated by LSW from a layer on the semiconductor surface into the bulk of the sample has been demonstrated

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[11]. The LSW technique was considered to be very promising for developing a low-temperature tool for modification of device parameters.

The principal purpose of our research is to show that low-temperature treatment of materials can be successfully used instead of annealing. Laser shock waves were chosen as an alternative to form *p*-*n* junctions in $Hg_{1-x}Cd_xTe$ after arsenic ions were implanted.

2 Experimental

Electrical characteristics of As implanted $Hg_{1-x}Cd_xTe$ bulk crystals were studied to determine the effect of LSW generated by nanosecond laser irradiation pulses at room temperature. Starting *n*-$Hg_{1-x}Cd_xTe$ single crystal samples had the initial electron concentration of about 4.2×10^{14} cm^{-3} for $x = 0.18$ and 1.1×10^{13} cm^{-3} for $x = 0.24$. The As implantation was carried out with 100 keV energy and 1×10^{15} cm^{-2} density. The samples were of *n*-type conductivity immediately after the implantation. Then LSW processing was performed under increasingly growing laser beam power density that increseas the shock wave pressure.

To induce LSW the samples were exposed to irradiation of a neodymium laser with a LiF gate. The laser operated in the Q-switched mode (1.06 μm wavelength, 30 ns pulse duration). To prevent the direct laser effect, the semiconductor was covered with a copper foil of 100 μm thickness and placed on a heavy metal substrate to remove the unloading wave. An epoxy was used as a transparent condensed medium to enhance the laser energy flux control. Additionally, good acoustic contacts were provided in the foil-sample and sample-absorber junctions to match the shock impedances and avoid damaging the sample when a SW goes out. The sample dimensions (5 x 6 x 1 mm^3) were chosen so that to ensure that the shock compression is uniform and uniaxial.

To evaluate the change of semiconductor parameters, field dependences of the Hall effect and transverse magnetoresistance were measured in 0.02–1.6 T magnetic fields at 77 K and processed accordingly to the two-band model. This processing allows determining the contribution of two types of carriers and their parameters (densities and mobilities) separately. As the depth of the layer formed by ion implantation and LSW processing remain unknown, the values of carrier densities shown in the Table 1 correspond to the values averaged over all the sample volume.

3 Results and discussion

The experiment demonstrated that a threshold shock wave pressure should be reached to ensure the *p*-to-*n* conductivity conversion in the surface layer of samples. The results of under threshold LSW treatment are summarized in Fig. 1.

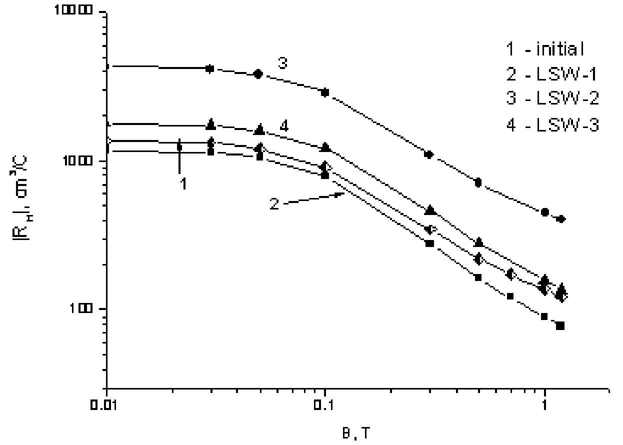

Fig. 1 Hall coefficient vs. magnetic field for different treatment modes.

Figure 1 shows the magnetic field dependencies of Hall coefficient. Labels LSW-1, LSW-2, LSW-3 denotes three shock wave processing modes with increasing energy density of laser irradiation (2.0, 2.42 and 2.7 J/cm^2). The corresponding values of LSW pressure for these samples are: 0.91, 1.00 and 1.06 GPa. In contrast to over-the-threshold processing, the electron concentration is slightly decreased only (Fig. 1) when the LSW treatment is carried out below the threshold.

It is worth noticing that these results are reported as an early brief communication. Nevertheless, taking into account our previous results which have demonstrated the possibility of impurity diffusion stimulated by LSW [11], we suppose that such behaviour of Hall coefficient and magnetoresistance follows from complicated diffusion and incorporation processes occur in the crystal. These processes involve increasing inhomogeneity of the samples that might result in negative magnetoresistance observed. The maximum change of parameters takes place in LSW-2 sample, not in LSW-3. To explain this, we may suggest that LSW pressure which is beyond a certain value but below the threshold of *p*-to-*n* conversion decreases the arsenic distribution inhomogeneity mentioned.

Table 1 shows the electrical parameters of the sample treated under over-threshold LSW pressure (the value of energy density of laser irradiation for this sample was 8 J/cm^2 which corresponds to LSW pressure of 1.82 GPa). One can notice the conductivity type conversion in LSW treated sample in contrast to the implanted one. The decrease of electron mobility can be ascribed to the total increase of carrier concentration as well as ionised impurity density that results in increased scattering of centers within the crystal. Hole mobility is in the frames of typical mobility for the material but is about twice lower than normal value of about 600 cm^2/(V·s).

Table 1 The electrical parameters of the sample treated under over-threshold LSW pressure.

Sample	σ, cm$^{-1}\cdot\Omega^{-1}$	n, cm^{-3}	μ_n, cm^2/(V·s)	p, cm^{-3}	μ_p, cm^2/(V·s)
Initial	28.9	4.21×10^{14}	426 000	-9.61×10^{13}	-14 600
Implanted	33.2	4.36×10^{14}	467 000	-6.49×10^{13}	-59 900
LSW	5.63	1.29×10^{14}	148 000	5.17×10^{16}	310

The behavior of Hall coefficient vs. magnetic field for this sample is plotted in Fig. 2. One can easily see a clear *p*-type dependence of the Hall coefficient for LSW sample.

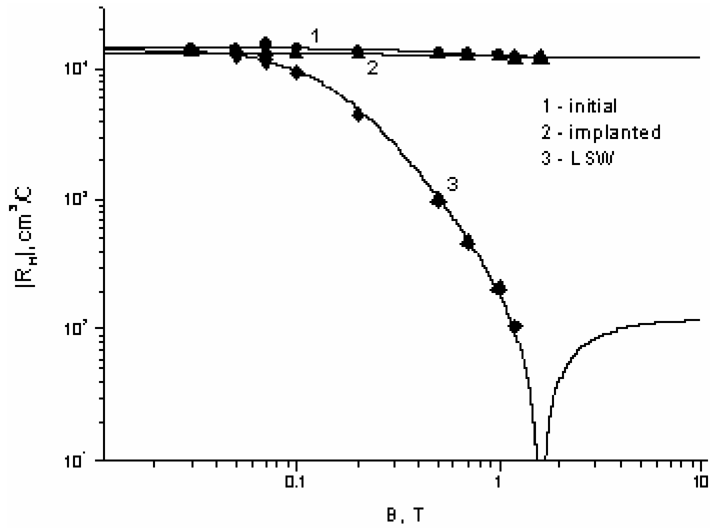

Fig. 2 Hall coefficient vs. magnetic field for the sample treated under over-threshold LSW pressure.

Thus our experimental results for different samples with different composition show the tendency to diffusion, redistribution and incorporation of As impurity under LSW impact that results in formation of *p-n* junction in $Hg_{1-x}Cd_xTe$. We suppose that the over-threshold LSW treatment involves the near-complete As in-diffusion and incorporation thus creating a *p*-type layer on the *n*-type substrate. Our experiments do not allow determining the exact value of the threshold, but it may be estimated as 4–5 J/cm^2, which corresponds to LSW pressure of 1.29–1.44 GPa (that value is about 10% of $Hg_{1-x}Cd_xTe$ shear modulus).

On the whole the results provide evidence that LSW combined with ion implantation can be used to form *p-n* junctions in $Hg_{1-x}Cd_xTe$.

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