Materials Physics and Mechanics 13 (2012) 48-50 Received: March 13, 2012

ACTION OF LASER RADIATION ON CRYSTALS OF GALLIUM ARSENIDE

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Abstract. In this paper we investigated the mechanical and morphological characteristics of gallium arsenide single crystals after laser irradiation of their surface.

1. Introduction

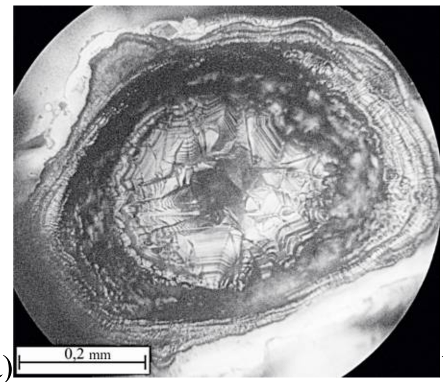
Gallium arsenide is one of the basic semiconductor materials. Due to successful combination of properties, today it is the second by value after silicon in electronic engineering. Gallium arsenide has good thermophysical properties, rather large value of the band gap, high electron mobility. The objective of this research is studying interaction between laser radiation and single crystals of GaAs.

2. Experimental technique

The research was carried out on GaAs crystal wafers 0.95 mm in thickness. The irradiation of specimens was made by a laser source with the active element based on an yttrium aluminum garnet doped by neodymium (Nd:YAG) operating on a wave length of 1.064 micrometers. The characteristic dimension of a laser action spot on the surface of a specimen did not exceed 1 mm. The study of mechanical properties of specimens was carried out on a micro-hardness-testing machine PMH-3M under a load of 1 N.

3. Experimental results

After laser irradiation, there appears a melting zone on the specimen surface in which crystallization is observed (Fig. 1). Crystal growth goes on from the center to the periphery.

a) 

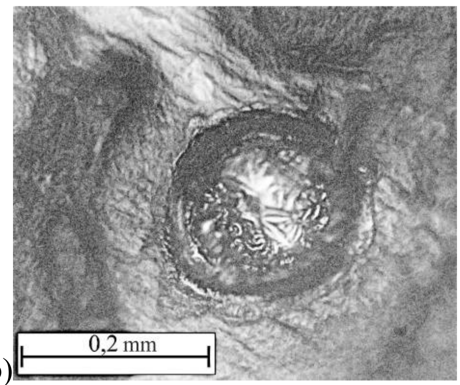
b) 

Fig. 1. Typical view of the melting zone after laser irradiation ($2.2 \cdot 10^5$ $W \cdot cm^{-2}$): a) melting zone at a front side; b) melting zone at a back side.

Here formation of the wave-like relief occurs, it being earlier observed in an iron-silicon alloy [1], as well as in tungsten [2]. The power density, necessary for melting of a gallium arsenide surface, amounts to ~ $2.2\cdot10^4$ W·cm^{-2} for a rectangular temporary pulse shape of duration 3 ms. At irradiation of specimens with the power density exceeding $2\cdot10^5$ W·cm^{-2}, there forms on the back side of the wafer a melting zone similar to that of the front side (Fig. 1). Then on the plate back side there also observed the oriented crystallization from the center to the periphery.

To investigate the structure of breakdown zone, crosscut cleavage of the specimen was done. As shown in Fig. 2, the shape of the channel formed looks like a "bowl", crystal formation being also visible. It should be noted that the crystal growth direction makes an angle 60° with the surface of laser irradiation. The crystal growth originates from the interphase boundary between a liquid material and a solid matrix and proceeds to the melting zone center.

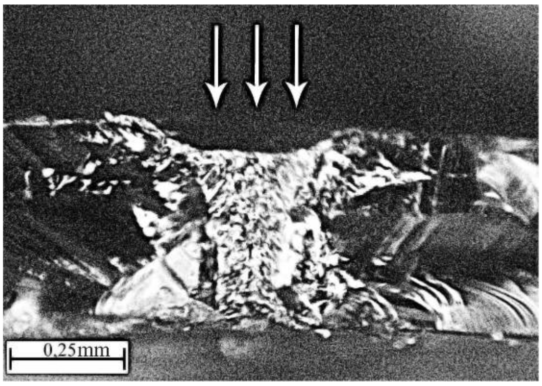


Fig. 2. Crosscut cleavage of a specimen in the melting zone ($2.2\cdot10^5$ W·cm^{-2}).

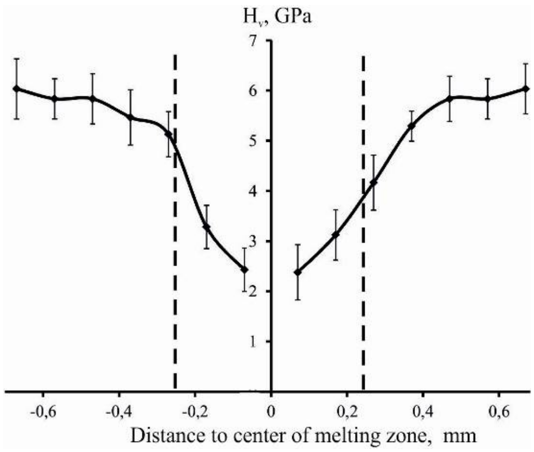


Fig. 3. Plot of the micro hardness against a distance to the melting zone center at power $2.2\cdot10^5$ W·cm^{-2}. The melting zone boundary is shown by a dashed line.

In the melting zone, the micro-hardness falls to 40-50 % of its initial value, the reduction beginning at some distance from the melting zone (Fig. 3). It can be related to formation of a heat-affected zone. For verification of this assumption a series of experiments was carried out. It consisted in heating of specimens for 5 minutes in a furnace. For each heating temperature the micro-hardness was measured. From the results shown in Fig. 4, it follows that at a temperature of 1000 °C the micro-hardness reduces up to 2 GPa, whereas at a temperature of ~700 °C the decrease is 5 GPa. This means that heating the heat-affected zone close to the melting zone is not less than 700 °C.

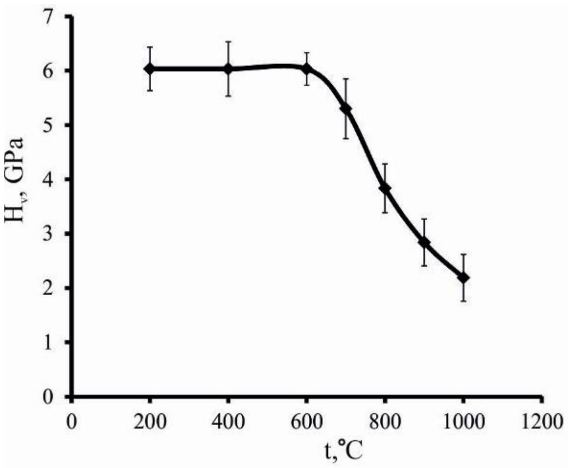


Fig. 4. Dependence of the micro-hardness on temperature annealing during 5 min.

4. Discussion of results

Oriented crystallization in the melting zone is caused by the fact that heat exchange of a melt with the solid matrix of a material is more than heat exchange of a melt with ambient air. Therefore the crystallization occurs preferably in a molten pool between its center and a solid wall. The micro-hardness changes due to crystal growth in the melting zone. The crystal growth occurs in a direction different in crystallography than it used to be for the matrix.

Formation of wave-like relief is induced by thermocapillary instability [2]. The channel shape (Fig. 2) can be explained from the viewpoint of the theory of heat conduction and mass transfer in a fluid [3]. According to this theory, in case of near-surface melt formation convective streams of melt are formed, directed from the center to the periphery [1, 3, 4]; it is testified by the wave-like relief. There occurs substance melting on the fluid-solid interphase boundary accompanied by magnification of the melting zone diameter. This explains the shape of the melting channel in the melting zone, both on the up and down sides, and the crystal growth in the affected zone from the centre to the periphery.

5. Conclusion

The laser irradiation on the GaAs surface is accompanied by formation of melting zone with wave-like relief on its surface which is connected with thermo capillary instability. The micro-hardness reduction in the area of laser radiation action is caused by the growth of new crystals oriented differently from the crystallographic orientation of a matrix.

This work was supported by the Russian Foundation for Basic Research (grant 09-01-97514_p_center_a).

References

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