P-n JUNCTION FORMATION IN i-Ge CRYSTAL BY LASER RADIATION

A.Medvid'[1,2], R.Rimsa[1], P.Onufrievs[1], E.Dauksta[1], G.Mozolevskis[1], T.Puritis[1]

[1]Faculty of Material Science and Applied Chemistry, Riga Technical University, Riga, LV-1048, Latvia

[2]Institute of Semiconductor Physics of NAS, Kyiv, 03028, Ukraine

Abstract

Rrectification effect of I-V characteristic in intrinsic Ge crystal after irradiation by Nd:YAG laser was observed. The effect is characterised by threshold intensity of the laser radiation. Increase of rectification ratio of I-V characteristics and barrier height with intensity of the laser radiation, energy of laser radiation quanta and number of pulses was observed in this experiment. The mechanism of this phenomenon is explained by generation and redistribution of intrinsic point defects in temperature gradient field. The redistribution of defects takes place because interstitial atoms drift towards the irradiated surface, but vacancies drift in the opposite direction – in the bulk of semiconductor according to Thermogradient effect. Since interstitials in Ge crystal are of n-type and vacancies are known to be of p-type, a p-n junction is formed.

Keywords: *p-n junction, i-Ge, laser, I-V characteristic.*

A possibility of p-n junction formation by laser radiation (LR) was shown in several p- and n-type semiconductors: p-Si [1, 2], p-CdTe [3], p-InSb [4, 5], p-InAs [6], p-PbSe [7], p-Ge [8] and n-HgCdTe [9] due to inversion of conductivity type. Different mechanisms have been proposed to explain the nature of inversion of conductivity type, for example, impurities segregation, defects generation [7], amorphization [10] and oxygen related donor generation [1]. However, n-type impurities in Si irradiated by laser cannot be oxygen atoms, according to paper [2]. Several authors have tried to explain p-n junction formation in n-type HgCdTe by defects generation, based on a model of defects formation related to interstitial mercury diffusion [9]. On the other hand, the authors of those papers did not take into account the effect of temperature gradient on the diffusion of atoms in solid solution. Moreover, it is theoretically shown, that the p-n junction can be formed by redistribution of impurities in co-doped Si in gradient temperature field [11].

Unfortunately, the mechanism of p-n junction formation by LR is not clear until now. In this paper a new mechanism of p-n junction formation in semiconductor by LR is proposed. For this purpose i-Ge crystal was irradiated by Nd:YAG laser with different energy of quantum. I-type Ge crystal was used in the experiments as a model material because concentration of impurities in this material is lower than concentration of intrinsic carrier at room temperature.

In experiments i-Ge single crystals with $N_a = 7.4 \times 10^{11}$ cm^{-3}, $N_d = 6.8 \times 10^{11}$ cm^{-3}, where N_a and N_d are acceptors' and donors' concentration, and slab dimensions of 16×3×2 mm^3 were used. Samples were mechanically polished with diamond grease and treated with H_2O_2 and CP-4 ($HF:HNO_3:CH_3COOH$ in volume ratio 3:5:3). Different intensities and energies of LR quanta: $h\nu_1$=1.16 eV, $h\nu_2$=2.32 eV and $h\nu_4$=4.64 eV, where ν_1- fundamental frequency, ν_2- second harmonics, ν_4- fourth harmonics of nanosecond Nd:YAG laser were used to irradiate the samples. Current-voltage (I-V) characteristics were measured for the non-irradiated and irradiated samples. Measurements of I-V characteristics were done by soldering tin electrical contacts directly on the irradiated surface of i-Ge and the opposite side. Also, I-V characteristics were measured at different number of laser pulses in order to determine mechanism of the effect. Measurements of I-V characteristics were done at room temperature and atmospheric pressure. Rectification ratio (RR) was calculated at constant 30 V voltages.

I-V characteristics of i-Ge samples before and after irradiation by Nd:YAG laser with energy of LR quantum - 4.64 eV and different intensities, are shown in Fig. 1a. The I-V characteristic of the non-irradiated sample is linear. After irradiation by the laser I-V characteristics becomes diode like. This process takes place on threshold manner - resistance of the sample increases by 10 times and rectification effect appears at certain intensity of the laser radiation. Threshold intensity (I_{th}) decreases with increase of energy of LR quantum as seen in Fig.1.b. I_{th} are observed at the fundamental frequency I_{th1}= 76.0 MW/cm^2, the second harmonic I_{th2}= 18.0 MW/cm^2 and the fourth harmonic I_{th4}= 16.0 MW/cm^2.

The rectification ratio of 9.3 at 350 laser pulses was observed after irradiation with the highest quantum energy - 4.64 eV, but the highest RR of 400 and potential barrier height 0.472 eV were observed at 650 laser pulses for second harmonics (2.32 eV) as can be seen in Fig. 2a. I-V characteristics of samples irradiated with energies of LR quanta 1.16 eV and 2.32 eV are not shown here because they are similar to I-V characteristics in Fig. 1a. Decrease of the I_{th} with increase of energy of LR quantum and appearance of I-V characteristics rectification effect we explain in the following way: irradiation of the sample by strongly absorbed LR leads to transformation of the light energy to the thermal one. Heating up the sample by LR increases additional generation of intrinsic defects in crystal - interstitials and vacancies which are quenched in crystal lattice after the end of the laser pulse. The formation of a potential barrier takes place due to separation of vacancies and interstitials in temperature gradient field [12].

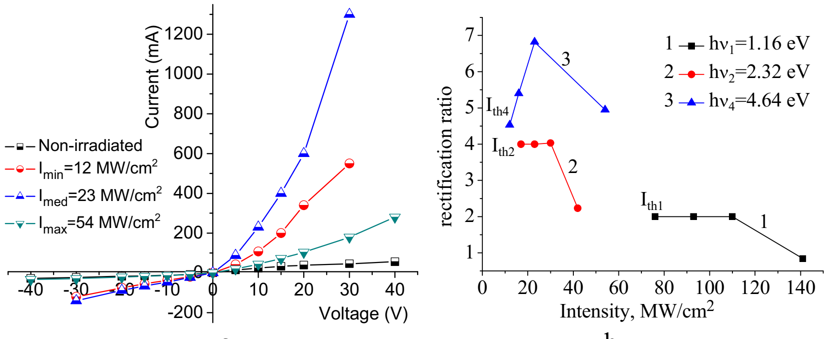
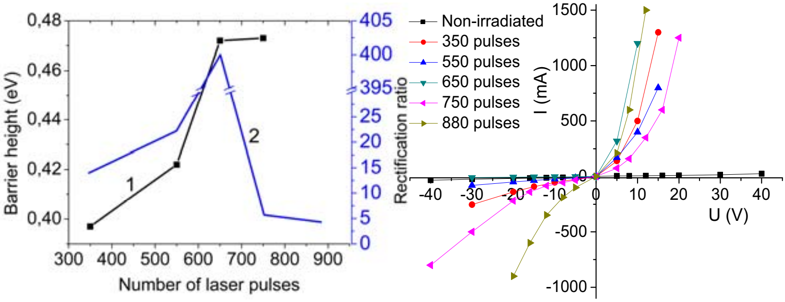


Fig. 1. a- I-V characteristics of a non-irradiated and an irradiated i-Ge samples by Nd:YAG laser with different intensities of quantum energy - 4.64 eV. b - rectification ratio as a function of irradiation intensity of Nd:YAG laser for different energies of the laser radiation quantum.

Calculations of T_{max1} on the surface of the sample for the fundamental frequency at I_{th} of LR using the heat balance equation in approach of adiabatic process show, that T_{max} in the case of fundamental frequency is lower than T_{max2} for the second and T_{max4} for the fourth harmonics. It means that gradient of temperature has the main role in formation of the potential barrier, because gradient of T is proportional to the light absorption coefficient in i-Ge crystal which increases with energy of LR quantum. Decrease of the I_{th} of LR with increase of LR quantum, as can be seen in Fig.1b, is an evidence of this suggestion. Concentration of interstitials at the irradiated surface and vacancies in the buried layer of the sample leads to formation of n-p junction because interstitials are donors and vacancies are acceptors in Ge [13]. Nonmonotonous dependence of RR as function of the LR intensity and decrease of RR at irradiation of the samples by the second and fourth harmonics are explained by formation of nanocones on the irradiated surfaces of the samples [14] and therefore a partial destruction n-type layer on the irradiated surface of the samples. The I-V characteristics measured at a different number of the laser pulses (N) from 350 to 880 at irradiation of the samples by the second laser harmonic and laser intensity 30.0 MW/cm^2 are shown in Fig.2b. We can see that RR of the I-V characteristics is a non-monotonous function of N. At the initial stage of the function RR increases with N, but at 650 it sharply decreases. Increase of RR with N (Fig.2a) we explain by accumulation effect: after every laser pulse concentration of interstitials at the irradiated surface and concentration of vacancies in the bulk of the sample increases and, of course, n-p junction barrier height increases, too, as shown in Fig. 2b, curve 1.



a b

Fig. 2. a- barrier height and rectification ratio as a function of number of laser pulses with energy of LR quantum - 2.32 eV. b - I-V characteristics of i-Ge samples before and after Nd:YAG laser irradiation at intensity 30 MW/cm^2 and quantum energy - 2.32 for different number of laser pulses.

A sharp decrease of RR at N more than 650 pulses is explained by nanostructure formation on the irradiated surface of the sample due to relaxation of mechanic compressive stress. It arises in the structure due to a high concentration of interstitials in the top layer and vacancies in the buried layer. For the first time we have proved that the mechanism of p-n junction formation in semiconductor is caused by generation and redistribution of intrinsic point defects in temperature gradient field. Increase of RR and the potential barrier of p-n junction with the increase of LR intensity and number of the laser pulses are typical for Thermogradient effect.

References

1. Y. Mada and N. Ione, Appl. Phys. Lett., 48, 1986, 1205 p.
2. J. Blums and A.Medvid', Physics Status Solidi (a), K91, 1995.
3. A. Medvid' and V.G. Litovchenko et al., Radiat. Meas., 33, (2001) 725 p.
4. I. Fujisawa, Jap., J. Appl. Phys, 19, 1980, 2137 p.
5. A. Medvid', L. Fedorenko and V. Frishfelds, Vacuum, 51, 1998, 245 p.
6. L. Kurbatov and I. Stojanova: Reports of Acad. Sc.USSR, 268, 1983, 594 p.
7. K.D. Tovstyuk, G.V. Placko, V.D. Orletskiy, S.G. Kiyak and J.V. Babytskiy, Ukrainian Journal of Physics, 21, 1984, 1918 p.
8. S.G. Kiyak and G.V. Savitsky, Phys. and techn. of semiconductors, 18, 1984, 1958p.
9. L.Dumanski, M. Bester, I.S. Virt, M. Kuzma, Appl. Surf. Sci., 252, 2006. 4481 p.
10. I.J. Ljamichev, I.I. Litvak and N.A. Osvhepkov, Devices on amorphous semiconductors and their application. Moskva, Sov. Radio, 1976.
11. A. Medvid', J. Kaupuzs, Proc. Intern. Autumn. School Sol. St.Phys.: Fundam. Appl., K104, 1994.
12. Arthur Medvid, Defect and Diffus. Forum, 210-212, 2002, 89.
13. D. Shaw, Atomic Diffusion in Semiconductors, Ed.; Plenum Press London and New York, 1973, pp. 260 – 261.
14. A.Medvid', P.Onufrijevs and A.Mychko, Nanoscale Res. Lett., 6, 2011, 582 p.