Nahrain University, College of Engineering Journal (NUCEJ) Vol.16 No.2, 2014 pp.168-179

Fabrication of Germanium Detectors by Using Nd-YAG Laser

Ziad Tarik Al-Dahan Layth Mokhles Abduljabbar
Alnahrain University, College of Engineering, Laser and Optoelectronic Dept.

Abstract:

Germanium detectors were fabricated by doping n-type germanium samples with boron. Boron powder was spread over germanium and bombard with Nd: YAG laser of wavelength 1064nm at different energies of (200,500)mJ to diffused the boron atoms inside the germanium wafer. Different measurements were carried out to characterize the detector made.

Keywords: Detector, Laser, Germanium

Introduction

Nowadays, germanium and some derived chemicals (GeO_2 and $GeCl_4$) are key materials for a wide variety of applications. The main application of bulk single crystalline germanium is a photo detector [1]. Most of the modern photo detectors are based on the internal photo effect system. In this method, the generated carrier pairs (electrons and holes) will stay inside the semiconductor and there is no need for the vacuum to excited electrons. In the building of these photo detectors, there is a material with photoconductivity properties.

Photoconductor materials will generate electron-hole pairs as a result of absorption induced light, and then the generated electron will excite from valence band to conduction band. By applying an electric field to the material, the electron-hole pairs will be transported through it and photocurrent in the external circuit of detector will produce [2-4].

The laser doping process has been used to produce superior device characteristics compared with other conventional doping [5-7]. The radiation from the Nd:YAG laser is strongly absorbed in the near-surface region of the wafer. Thus, only a shallow depth from the surface can be melted. Furthermore, laser doping can only dope the semiconductor in a selected region, but can also prevent the redistribution of the impurity profile due to its short duration of irradiation.

Experimental work

There are number of procedures used for detectors fabrication, include etching, spread boron powder over the wafer, diffusion by laser, removing of excess dopant materials from the surface of the sample, and assembly process (5-7).

A wet chemical etching technique is used. The wafers of germanium are immersed in the H_2O/H_2O_2 (9:1) as etching solution for several minutes. In addition to etching the surface of the samples, also the solution polishes the germanium wafers instantaneously. After etching process boron powder is spread over n-type single crystal germanium wafers as a dopant material, then Nd: YAG laser (λ=1064 nm) with different energies (200 mJ and 500 mJ) is used to bombard the boron inside the surface of the germanium wafers with 10 shots. After the successful procedure of diffusion, it is important to remove the excess dopant material from the surface of germanium. Two methods can be used for removing process, mechanical method and chemical method. A mechanical method has many disadvantages, it is difficult to control the depth of the removed material, and i.e. it may remove the germanium itself after removing the dopant material. Also, it produces new defects which have undesired effects on the performance of Ge detectors. Water has the ability to dissolve the boron so it is easy to remove the excess boron from the germanium surface. Thermal evaporation system was used to deposit the aluminum wire which has a high purity (99%) as an electrodes as shown in figure (1). To assemble germanium detectors wafer was cuts to small pieces, each piece was fixed on a slide of glass and connected with copper wires.

Results and discussion

X-ray Diffract meter (Shimadzu) was used to ensure that the do pant material (Boron) was diffused in germanium wafers and to measure the grain size and the lattice constant of the germanium samples before and after doping.

Figure (2) show the XRD analysis of a germanium sample before the doping process with boron. Lattice constant can be calculated from equation [8]:

$$a=d_{hkl}(h^2+k^2+l^2)^{½} \quad \ldots\ldots\ldots\ldots(1)$$

Where d_{hkl} is a spacing between the lattice planes, and h,k,l are a miller indices. From figure (2)shows that the germanium sample is a single crystal and has millar indices (220), the lattice constant can be calculated from equation (1) and has a value of 5.6455Å and this value is close to the ASTM card which has a value of 5.6576 Å.

According to Scherrer equation, the crystallite size (grain size) can be expressed as[3] :

$$g_s=\frac{\kappa\lambda}{B\cos\theta}\ldots\ldots\ldots\ldots (2)$$

where B is the broadening solely due to small crystallite size , κ is a constant whose value depends on particle shape and usually taken as 1; θ the Bragg's angle, λ is a wavelength of incident X-ray beam[9].The grain size can be calculated by using equation (2) and has a value of 14.15Å.Figure (3) shows the XRD for germanium sample that is doped using laser energy 200 mJ. At angle (43.12) the millar indices has a value (220) and from equation (1), the lattice constant can be calculated and has a value of (5.9283) Å. The grain size can be calculated by using equation (2) and has a value of 26.38Å. While for laser energy 500 mJ as shown in figure (4), it is observed that at angle (43.07) the millar indices has a value (220) and from equation (1) the lattice constant can be calculated and has a value of (5.9340)Å. The grain size can be calculated by using equation (2) and has a value of (30.12) Å

FTIR Spectrophotometer was used to measure the absorption and transmission of germanium crystal in the range (4000-400) cm^{-1}, and then from these measurements the absorption coefficient and extinction coefficient can be calculated. Figure (5) shows the transmittance of germanium samples doped with boron with different laser energy (200, 500)mJ. The germanium sample that doped with laser energy 200 mJ has a transmittance greater than the sample which are doped with laser energy 500 mJ , this is due to number of atoms that is diffused inside the germanium sample with laser energy 500 mJ is greater than the atoms diffused with laser energy 200mJ. Figure (6) show the absorptivity of germanium sample that is doped with boron for different laser energy. It is noticed that the germanium sample that was doped with laser energy 500mJ has a greater absorptivity from the germanium sample which were doped with laser energy 200 mJ this is due to a greater atoms of boron will be diffused inside the germanium sample than the laser energy 500 mJ . Absorption coefficient can be calculated using the following equation [10]:

$$\alpha = 2.303A/t\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where: A is an absorptivity, and t is a sample thickness (cm).Figure (9) shows the absorption coefficient (α) as a function of energy for germanium samples that is doped with boron by using different laser energy. For the sample that is doped by using laser energy 500mJ, the absorption coefficient has the average value of (39.8)cm^{-1}, while for the sample that is doped by using laser energy 200mJ, the absorption coefficient has the average value of (26.96)cm^{-1} .It is noticed from figure (7), that the absorption coefficient of the samples that is doped using high laser energy has greater values than the sample that is doped using low laser energy this is due to the high absorption in the sample that is doping using high laser energy. Extinction coefficient (K_e) of the germanium samples that is doped with boron using different laser energy is calculated by using equation[10]:

$$K_e = \frac{\alpha\lambda}{4\pi} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

From figure (8), it is noticed that the behavior of the extinction coefficient is similar to the behavior of the absorption coefficient, this similarity is due to the calculation of extinction coefficient depend on the absorption coefficient . Figure (8) shows the extinction coefficient of the germanium samples that is doped with boron using different laser energy,the average value of extinction coefficient of the sample that is doped using 500 mJ laser energy is ($7.04*10^{-3}$) while in the second sample the value ($4.49*10^{-3}$).

From electrical measurements current-voltage characteristic and built-in potential can be measured and calculated. CO_2 laser with (wavelength 10.6μm and power 1W) is used in the measurements of the rise time and the responsivity of the fabricated detectors. Figures (9) and (10) show the results of current-voltage characteristic for germanium detectors that are doped with boron in dark and under illumination.

From these figures it is noticed that the current will increase with applied voltage in reverse bias because the depletion region is wider with applied bias voltage and the current in the detectors that are doped using laser energy 500 mJ has the values greater than the current that is results from the detectors that are doped using laser energy 200 mJ. The increasing in the values of the current is due to the increasing of the doping materials in the germanium wafer so that the number of electrons and holes are generated with high quantity and move toward the n-side and p-side. Under illumination and reverse bias, the photocurrent will increase this is because the germanium detectors absorbed more photons from the illumination source and generated an electron-hole pairs that are passed through the external circuit. A figure (11) illustrates the relation between the capacitance and the applied voltages for germanium doped with boron detectors. It is clear from this figure that the capacitance decreases with increasing the reverse bias voltages because of increasing of depletion layer with reverse bias voltages and the capacitance decreases with laser energy increases this is because the amount boron atoms which are diffusing inside germanium increases so the built-in potential will increases according to the following equation [3].

$$V_b = \frac{KT}{q} \ln \frac{NaNd}{n_i^2} \ldots\ldots\ldots\ldots\ldots (5)$$

Where N_d is doner atom concentration (cm^{-3}), n_i is intrinsic carrier concentration (cm^{-3})
Figures (12) show $1/C^2$ versus applied voltage for germanium detectors. It is clear from these figures that the detectors have the same doping profile and from the intercept (at $1/C^2 = 0$) , the built- in potential is calculated. the built-in potential has a values (0.25 and 0.58)V for germanium detectors that is doped with (200 and 500)mJ respectivity.Figures (13) show the rise time of germanium detectors that are fabricated using different laser energy. The rise time values are (83 and 75) ns for germanium detectors that is doped with (200 and 500)mJ respectivity. It is clear from these results that the increasing of laser energies which are used to diffuse the boron atoms inside the germanium samples produces detectors with short rise time. For a photodetector, the responsivity is a very important parameter. Responsivity is defined as the ratio of the output (usually in amperes or volts) to the radiant input (in watts). The responsivity can be expressed as[11]:

$$R(\lambda) = \frac{\text{photo induced current}}{\text{incident optical power}} = \frac{Ip}{P_0} \ldots\ldots (6)$$

The values of responsivity are ($35.98*10^{-6}$ and $38.98*10^{-6}$) A/W for germanium detectors that is doped with (200 and 500)mJ respectivity.
A graph plotted between ΔT and ΔV, Seebeck coefficient for germanium sample was calculated using the following equation [12]:

$$S = -\frac{\Delta V}{\Delta T} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Where: ΔV Temperature difference in a semiconductor, and ΔT Voltage difference in a semiconductor.

Figure (14) shows the relationship between the voltage and the temperature for germanium sample and and from equation (7), Seebeck coefficient is calculated and has a value of (-0.133 mV/K).The negative value of the Seebeck coefficient will give an indication that the germanium sample is n-type semiconductor.

Conclusion

Nd:YAG laser (λ = 1064 µm) with different laser energies were used to diffuse the dopant materials (B) inside the n-type Ge wafer to fabricated a PN junction photodetectors. From the results fabricated detectors works in the range (5-25) µm and it can be detect the wavelength for CO_2 laser. The rise time for Ge detector was measured and it has different values depends on the laser energy bombard the wafer (83 to 75) ns.

References

[1] R. Claeys and E. Simoen," Germanium-BaseTechnologies"1st edition, (2007).

[2]B.Saleh, "Fundamentals of photonics", malvin carl teich, JohnWiley and Sons, (1991).

[3]S.M.Sze," Semiconductor Devices Physics and Technology",2nd edition, John Wiley and Sons, (2002).

[4]A.Yariv and P. Yeh, "Photonics: Optical Electronics In Modern Communications", 6th edition ,Oxford University Press, (2007).

[5 E. Al-Nuaimy, and J.Marshall, "Excimer laser crystallization and doping of source and drain regions in high quality amorphous silicon thin film transistor", Appl. Phys. Lett., No. 69, p.3857, (1996).

[6] Y.Hatanaka, "Excimer laser doping techniques for II-VI semiconductors", Appl. Surface. Science, 175-176, p. 462,(2001).

[7] Z.Tian, N. Quick and A.Kar, "Characteristics of 6H-Silicon Carbide PIN Diodes Prototyping by Laser Doping", Journal of Electronic Materials, No.34, p. 430, (2005).

[8]B.Yacobi," Semiconductor Materials: An Introduction to Basic Principles", Kluwer Academic Publishers,(2004).

[9]B.Rehani, P.Joshi, K.Lad and A.Pratap, "Crystallite size estimation of elemental and composite silver nano-powdersusing XRD principles", Indian Journal of Pure &Applied Physics,Vol.44, 157-161, (2005).

[10] G. F. Bohren, R. Huffman, "Absorption and scattering of light by small particals", John Wiley and Son Inc., USA(1983).

[11]G.Y. ONODA JR, L.L. HENCH, Physical characterization termonolgy, A Wiley Interscience Puplication, John Wiley &Sons Inc., New York,(1978)

[12] J. Gersten and F. Smith," The Physics and Chemistry of Materials", The City College of the City University of New York, John Wiley & Sons (2001).

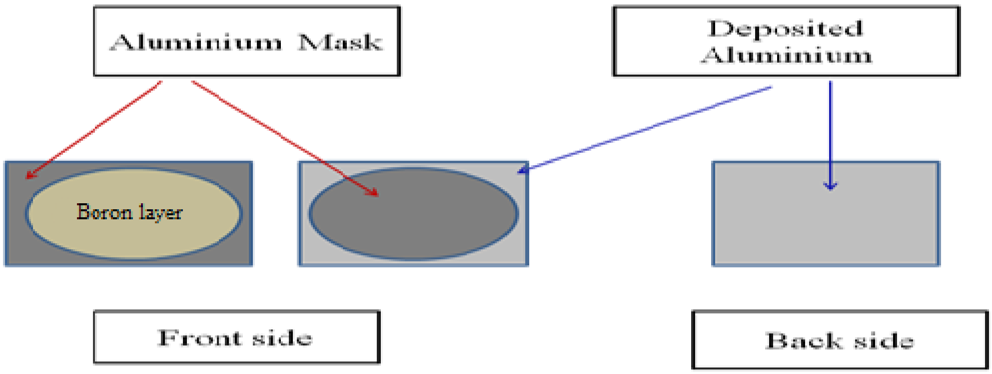


Figure (1): Aluminium masks Fabrication.

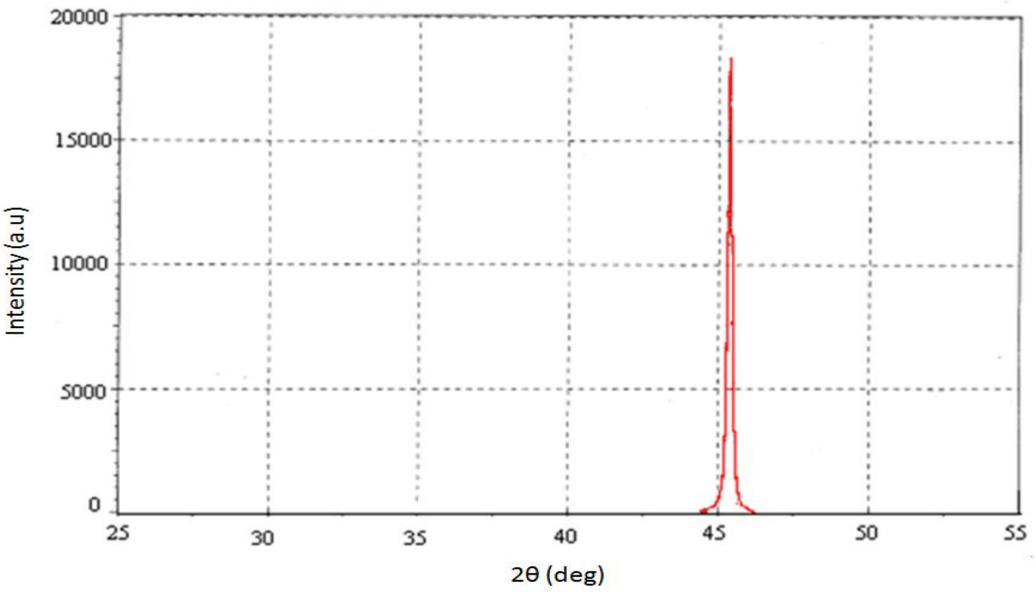


Figure (2): XRD analysis for germanium single crystal before doping process.

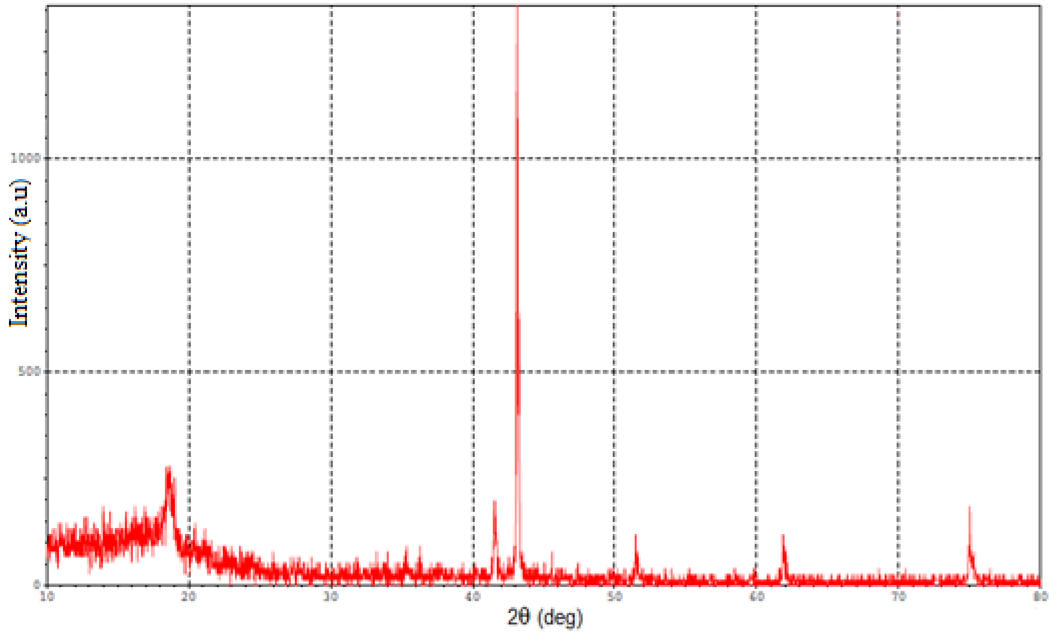


Figure (3): XRD for Ge doped with boron using laser energy 200mJ.

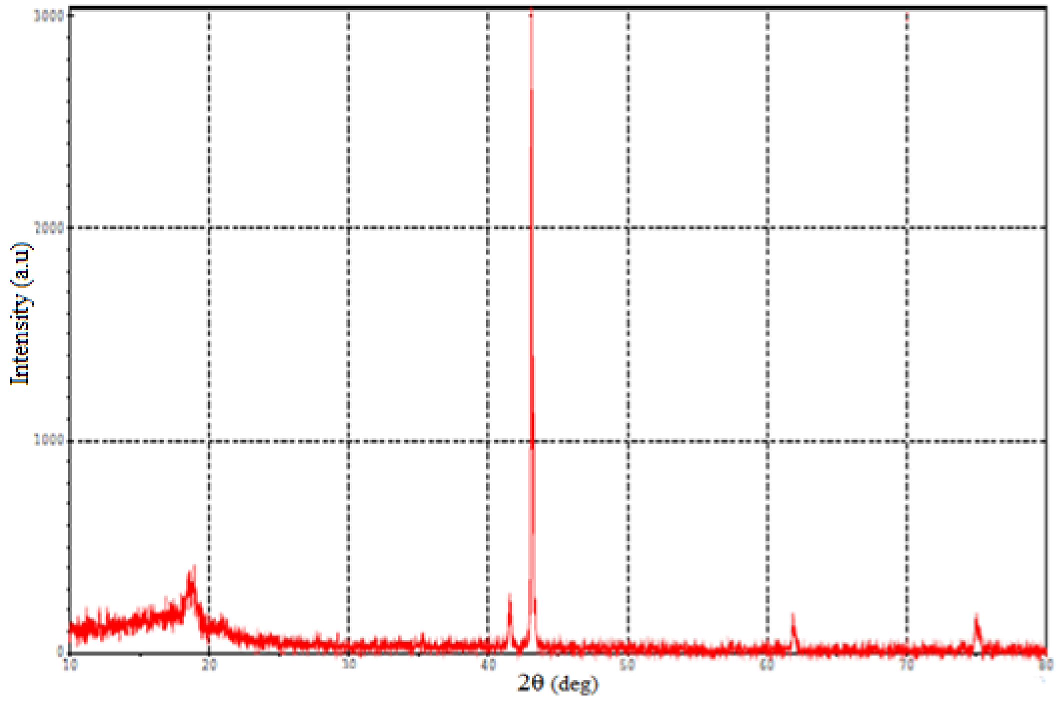


Figure (4): XRD for Ge doped with boron using laser energy 500mJ.

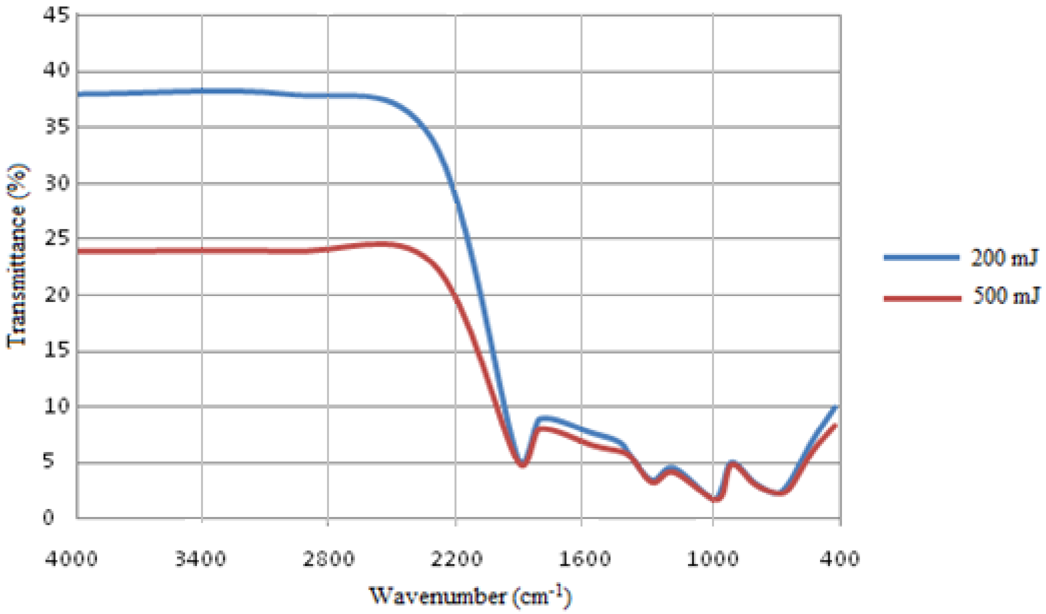


Figure (5): Transmittance of germanium samples doped with boron using different laser energy.

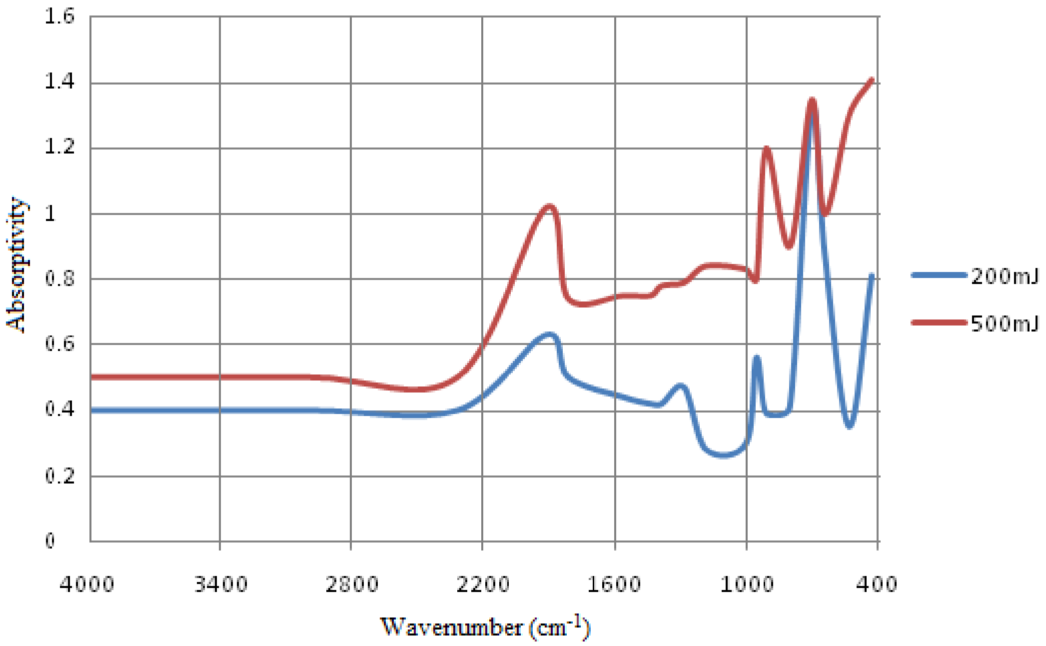


Figure (6): Absorptivity of germanium samples doped with boron using different laser energy.

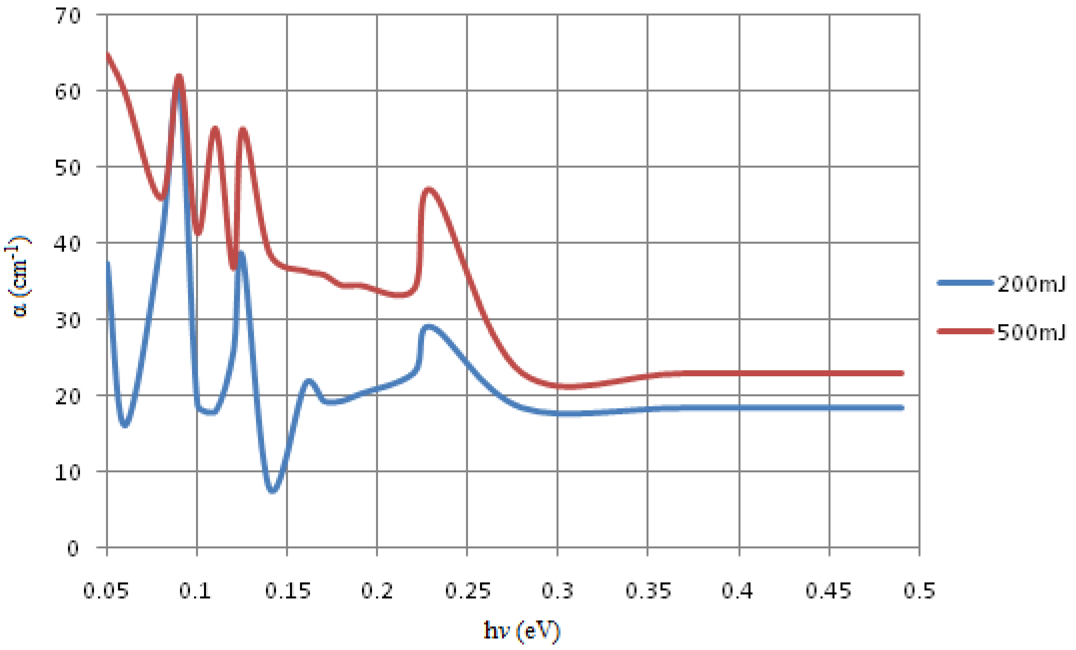


Figure (7): Absorption coefficient of germanium samples doped with boron using different laser energy.

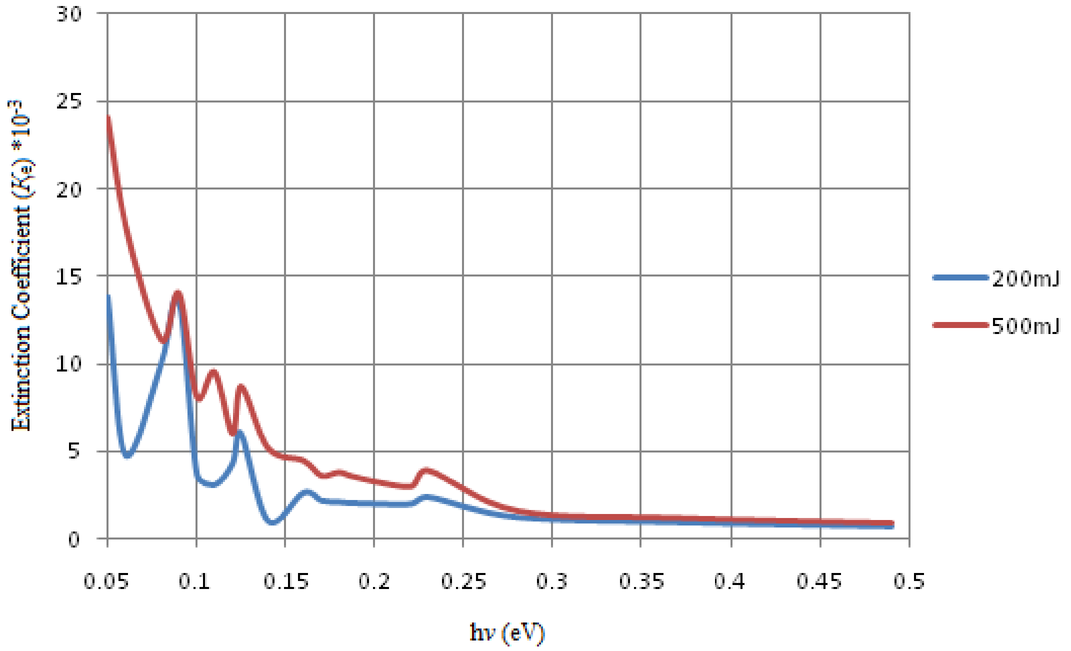


Figure (8): Extinction coefficient of germanium samples doped with boron using different laser energy.

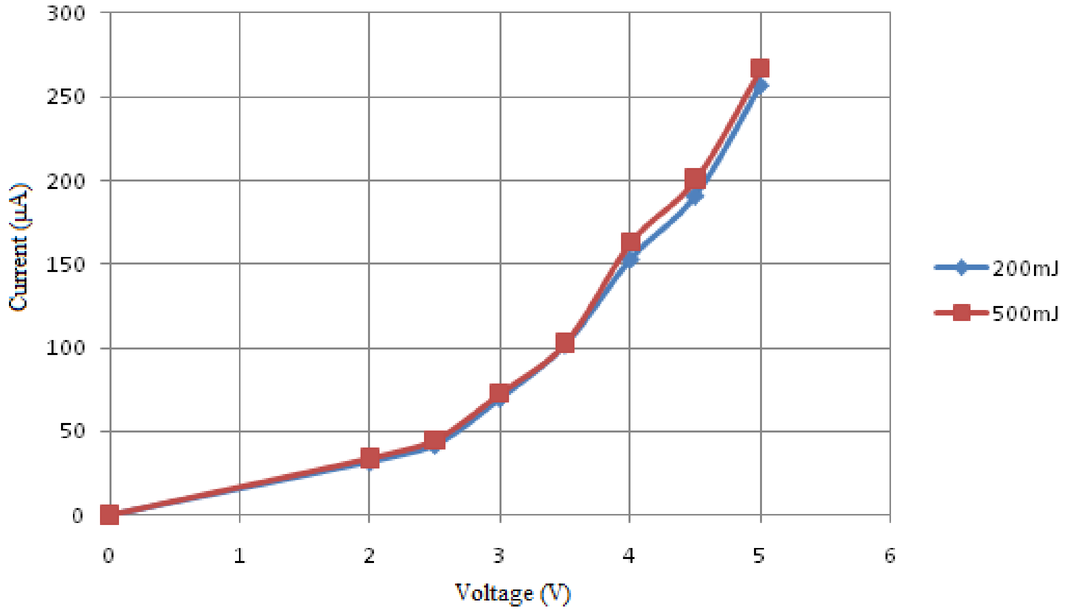


Figure (9): Current-voltage characteristic for germanium detectors that are doped with boron in dark.

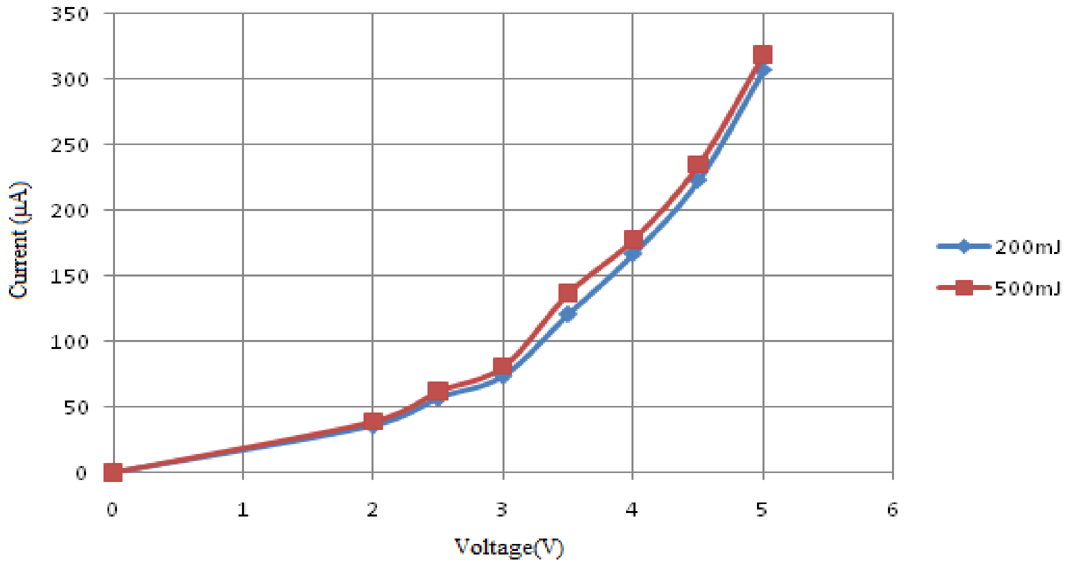


Figure (10): Current-voltage characteristic for germanium detectors that are doped with boron under illumination.

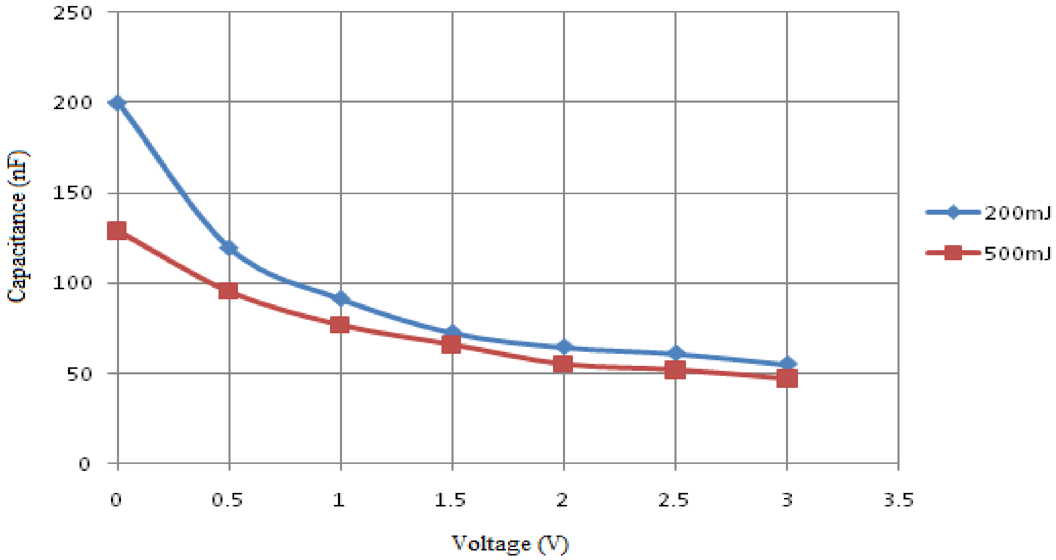
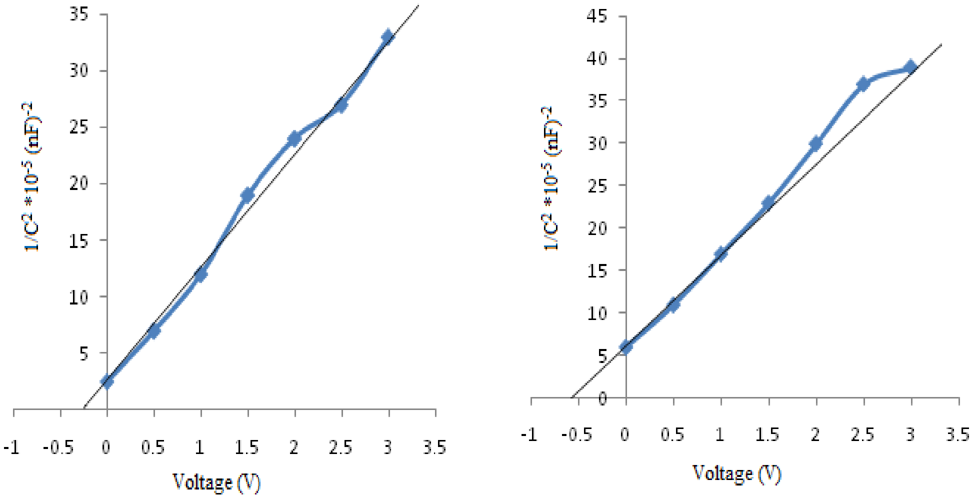
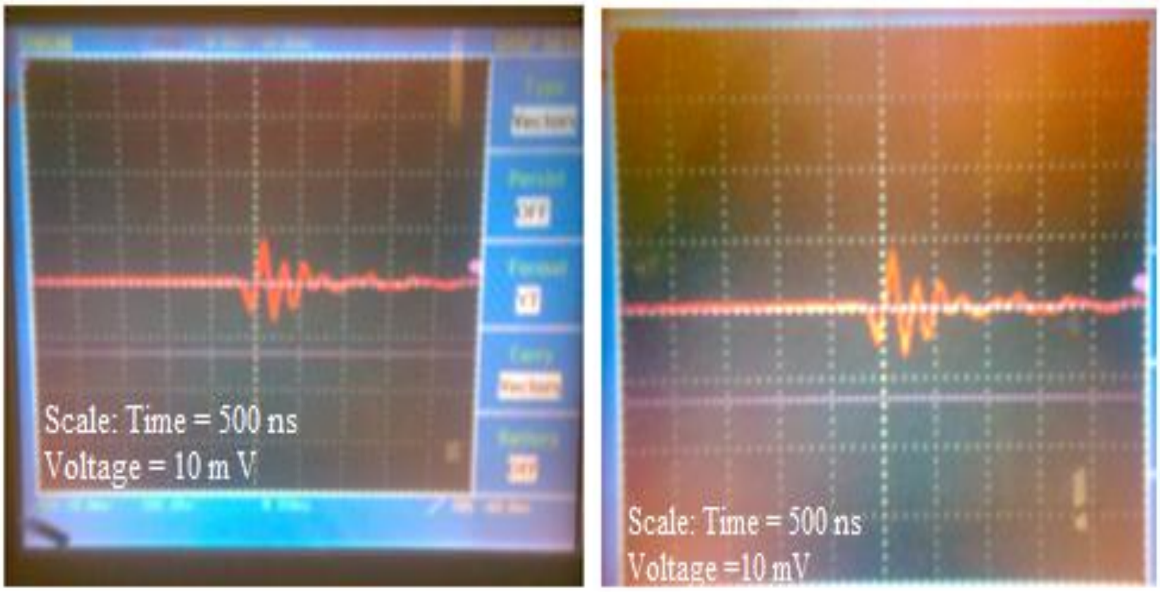


Figure (11): Capacitance as a function of applied voltage for germanium detectors that are doped with boron.



(a) (b)

Figure (12): $1/C^2$ versus applied voltage for germanium detectors that are doped with boron using laser energy :(a) 200 mJ (b) 500 mJ .



(a) (b)

Figure (13): Rise time for germanium detectors that are doped with indium using laser energy : (a) 200 mJ (b) 500 mJ .

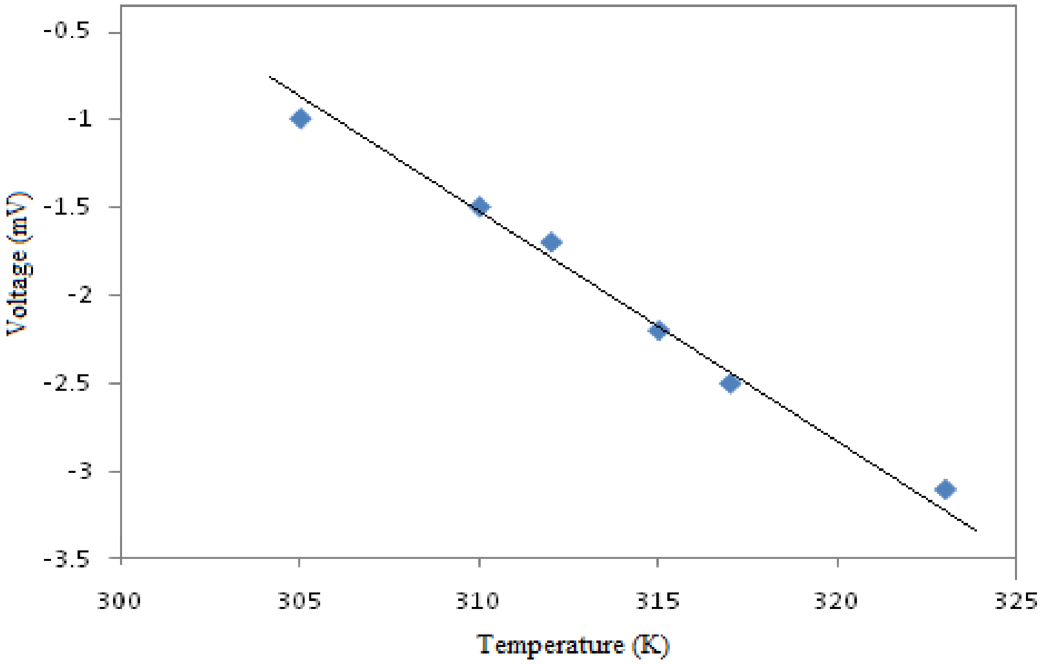


Figure (14): Voltage as a function of temperature for germanium sample.

تصنيع كواشف الجرمانيومب استخدام ليزرNd-Yag

ليث مخلص عبد الجبار   زياد طارق الدهان

جامعة النهرين, كلية الهندسة, قسم هندسة الليزر والاكترونيات البصرية.

الخلاصة:

تم تصنيع كواشف الجرمانيوم بتطعيم عينات الجرمانيوم من نوع (n-type) بمادة البورون حيث رش مسحوق البورون فوق عينة الجرمانيوم ثم تسليط ليزرالانديياك ذات طول موجي 1064 نانومتر بطاقات مختلفة (200و500) ملي جول لغرض` ادخال ذرات البورون داخل شرائح الجرمانيوم . طرق مختلفة استخدمت لغرض تعير الكاشف المصنع.