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DETERMINING PROPERTIES OF GALLIUM ARSENIDE DETECTOR BY USING PENELOPE

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Abstract

Gallium Arsenide (GaAs) is a III-V compound semiconductor with some good properties suitable for a detector operating at room temperature. Although nowadays there are many semiconductor detector as Si(Li), Ge(Li), HPGe,GaAs detector has more advantages than other detectors especially, it has a low cost and can operated at room temperature, at which many other types of semiconductor detectors operate difficultly. This paper will describe the properties of semiconductor GaAs and fabrication method of GaAs detector. At the same time, this paper also presents the simulation results GaAs detector signal when receiving photons at different energy levels and the detector absorption efficiency depends on factors such as energy, the position of the radiation source, the thickness of the GaAs layer, contact materials. The comparison between Si and GaAs detectors will show more clearly the advantages of GaAs detectors.

1. Introduction

GaAs is a material with large electron velocity suitable for high-speed electronics, detector GaAs has been studied by many different research groups for over five decades from the 1960s. Currently a GaAs semiconductor occupies few percent of the overall semiconductor market. Although there is a small market

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Key words: Gallium Arsenide detector, simulation with PENELOPE

share, but the importance of GaAs lies in its application for permission. For example, GaAs is used in electronics and photonic devices such as electronic equipment, the application of bipolar transistors, diodes and field-effect transistors, with the photonic device applications as emitting diode light (LEDs), laser diodes (LDS), photodetectors and waveguides.

PENELOPE - acomputer program using FORTRAN 77, performed Monte Carlo simulations of electron transport, photons and positrons in any material with a wide energy range, from a few hundred eV to 1 GeV [1]. The main content of this paper is to apply PENELOPE simulation program to determine the properties of GaAs detectors.

2. Physical characteristics of gallium arsenide

Gallium arsenide (GaAs) is a compound of gallium and arsenic. It is an III-V semiconductor. GaAs is often used as a substrate for epitaxial technique of III-V semiconductors include: InGaAs and GaInNAs. [2]

Crystalline GaAs networks form zincblende (sphalerite) with size unit a= 5653 A. The average atomic number is 32 GaAs (Ga 31, As 33) and a specific weight is 5.3174±0.00262 g/cm3. In crystalline of GaAs semiconductors, atoms Ga are surrounded by four As atoms, evenly spaced, with equal associated length and equal associated angles $(109^o, 50)$. [3]

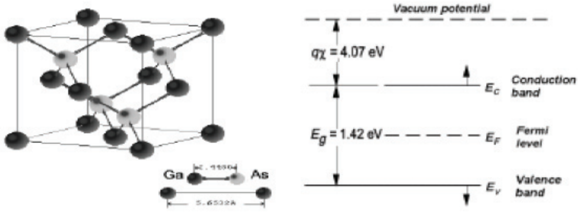


Figure 1: The crystal structure and the energy band of GaAs [4]

Band gap at room temperature (300K) for the non-doped GaAs is 1.42 eV and Si is 1.14 eV. GaAs is a direct semiconductor, it means that energy transition only changes the energy requirements, while the momentum of electrons does not change when moving from the highest energy of the valence band to the lowest energy conduction band. So GaAs is often found in photonic applications. While Si is a indirect semiconductor and requires the support of phonons (Figure 2)

If the comparison between the GaAs material and Si materials, each material has its own advantages and disadvantages. GaAs which has the advantages of high electron mobility, saturation electron velocity greater than Si, should be

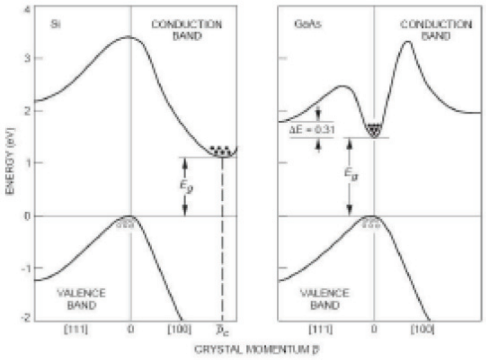
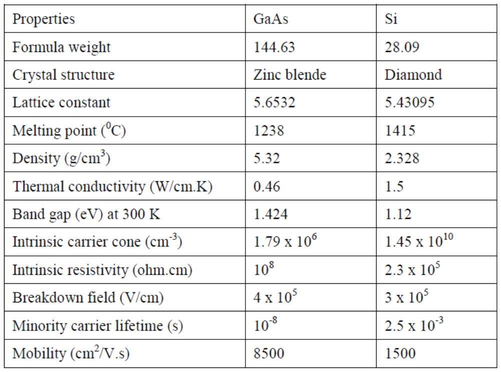


Figure 2: Structure of energy band of the Si and GaAs [4]

used in high speed integrated circuits and allows gallium arsenide transistors operating at frequencies exceed 250 GHz. GaAs is capable of emitting light should be used in LED, laser, telephone circuit ... Not the same as Si, GaAs equipment are relatively less sensitive to heat due to the band gap energy is wider than Si. In addition, the GaAs equipment tends to be less noise than Si equipment, particularly at high frequencies. GaAs is an excellent material for electronic equipments and space optical windows in high-power applications.

Table 1: Comparison of physical properties of Gas and Si semiconductors.



Properties	GaAs	Si
Formula weight	144.63	28.09
Crystal structure	Zinc blende	Diamond
Lattice constant	5.6532	5.43095
Melting point (^{0}C)	1238	1415
Density (g/cm^3)	5.32	2.328
Thermal conductivity (W/cm.K)	0.46	1.5
Band gap (eV) at 300 K	1.424	1.12
Intrinsic carrier cone (cm^{-3})	1.79 x 10^6	1.45 x 10^{10}
Intrinsic resistivity (ohm.cm)	10^8	2.3 x 10^5
Breakdown field (V/cm)	4 x 10^5	3 x 10^5
Minority carrier lifetime (s)	10^{-8}	2.5 x 10^{-3}
Mobility (cm^2/V.s)	8500	1500

3. Detector gallium arsenide

GaAs detector can be made in many different ways. For example, the structure of detector is made from insulating GaAs wafers (SI GaAs) by LEC method.

The insulator wafers doped oriented diameter of 50.8 mm. Front surface is polished, behind surface is engraved while grinding. Resistivity was measured $7,58.10^7\Omega$. cm. The size of the SI GaAs detector is $5 \times 5mm^2$ with a thickness of $350\mu m$. Before "metallized" the surface of the GaAs plate was cleaned with solvent, clean water and ionized, then it is removed the oxidized layer by a dilute acid solution. Exposed metal surface is made of a thermal evaporator in vacuum conditions. The front and back of structure is the layer Au / Ni used exposure Schottky contact with the thickness of the metal layer is 200nm Au, and Ni is 30 nm and the diameter of layer exposure is 3mm. [5]

4. Signal simulation and performance detector gallium arsenide

In this simulation, the spatial structure of detector consists of 5 layers of material (Figure 4). GaAs semiconductor material with a radius of 5 mm, a thickness of $350\mu m$, material is exposure Au / Ni with the same radius of 3 mm, a thickness of 200nm Au layer, Ni layer thickness is 30nm. Detector is located in the Oxy plane, perpendicular rays Oz. In addition, we have been supported by the program GVIEW 2D and 3D GVIEW to help shape space observation and reporting of syntax errors.

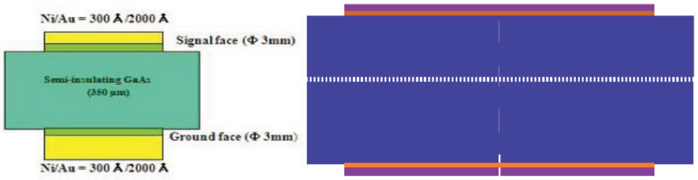


Figure 3: Cross section of the detector; after the detector is defined and displayed in 2D GVIEW

After running the program PENDOSE with 350μm thick, GaAs layer in the case corresponding to the energy is 6 keV and location of radiation sources is 0.1 cm, to obtain the results shown in Figure 4.

Survey dependence of performance Gallium Arsenide detector into photon energy:

We consider the case that the place of radiation sources is 0.1 cm, the GaAs layer thickness is 0.35mm. Energy is changed from 2 keV to 200 keV. This is the X-ray energy often used in that range in medicine.

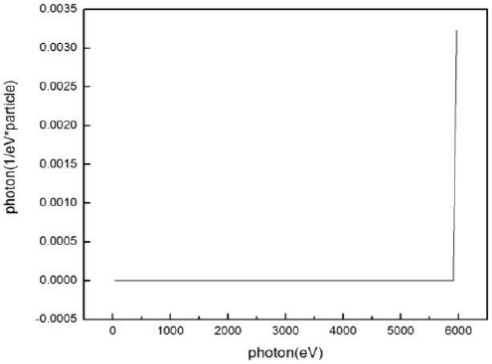


Figure 4: Signal response at 6 keV energy

With each level of energy, we will change the file PENDOSES.IN. Then, we open the Command Prompt window, run PENDOSES.IN file. With different levels of energy, we have specific simulation results in PENDOSE. Performance results calculated in each case are shown in PENDOSES.DAT. From the calculated results, we can draw the relationship between the photon energy and absorption absorption efficiency of GaAs layers (Figure 5)

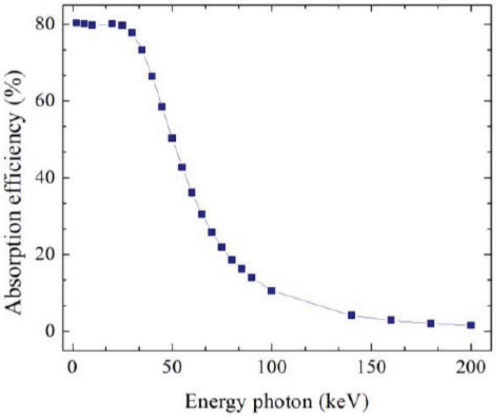


Figure 5: The dependence of absorption efficiency according to the photon energy.

GaAs layer thickness is 350μm in the energy region from 2 keV to 35 keV. Absorption efficiency is relatively high (about 70-80%) and relatively stable. In the energy region from 40 keV to 100 keV, the absorption efficiency plummeted to 10%. Energy region from 100 keV to 200 keV, the absorption efficiency falls below 10% and has mitigation. Thus we see that GaAs is a candidate for medical applications in the acquisition of X-ray photon energy, for example 3D detector applications for medical imaging. For a flat geometry detectors, the charged particles to pass through the entire thickness of the detector to be obtained by electrodes. This means that the thickness of the detector is limited, resulting in reduced sensitivity. And this is overcome if using 3D detector which will be drilled to a depth of sensor [6]

Survey of the dependence of the performance of GaAs detectors on the distance between source and detector:

In this case, we change positions between source and detector from a few millimeters to several centimeters, (1mm to 6cm). Photon energy is 50 keV. For each source location, we change parameters in pendoses10.in. Running the program, we will obtain the corresponding results in pendoses.

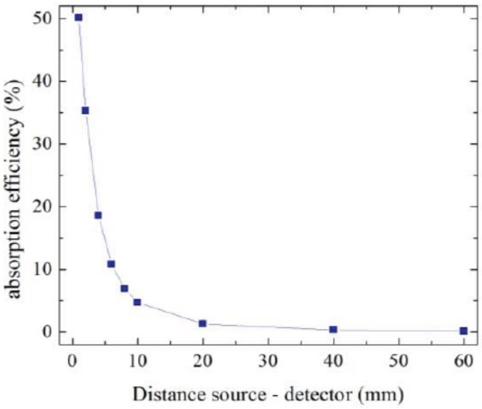


Figure 6: The dependence of absorption efficiency according on the distance between source and detector.

From the figure 6, the GaAs layer thickness 0.35 mm, we found that the farther distance between source and detector is, the more absorption efficiency decreases. From 1mm to 10mm, absorbing performance plummeted. Ranging from 1 mm to 3 mm, relative performance is high (approximately > 20%). But from 6mm onwards, the performance is less than 10%.

This suggests that the GaAs detector works well when we place source far from the detector a few mm. Although the choice of the distance between the detector and the sample depends on the objectives of the measurement, but in the general trend, the closer source and detector is, the better it is.

This optimizes counting statistics and reduces time measurement. In some cases with low-level, we can place source directly on the detector. And in fact, the photon energy measurements is below 10 keV, the attenuation of photons in the atmosphere is great. In principle, these values will be adjusted during the preparation. However, when the measurements are extended longer, temperature and pressure can change the environment so that the attenuation coefficient will be different. So if possible, the distance between source and detector as little as possible or placed in a vacuum environment. In this case, we examine the performance of the detector in the energy region from 2 keV to 200 keV when distance between the source and the detector are 1 mm, 2 mm, and 6 mm (Figure 7)

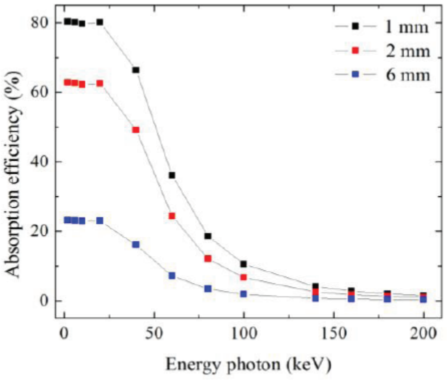


Figure 7: The dependence of absorption efficiency according to the energy and at different distances

In this case, we consider when the location of the source is 1 mm, the photon energy of 50 keV. GaAs semiconductor layer thickness will vary from 80μm to 1000μm. With each semiconductor GaAs layer thickness will change the parameters in the file test_new_14.geo. Then run the file pendoses10.in. For each thickness we will have results in pendoses. (Figure 8)

From the graph shown in Figure 8, when the thickness of GaAs semiconductor layer increases, absorption efficiency also increases. At 50keV energy, from 700μ m absorption efficiency increases slowly. So, if we want detectors to have good performance without costly and to produce, the manufacturer will consider the choice of the semiconductor layer thickness being suitable for energy area in which they measure. For example, based on Figure 8, with 650 μm thickness, the absorption efficiency is approximately 70%, while the absorption efficiency with 1000 μm thickness is also approximately 70%. Thus, the manufacturer will choose the thickness 650μm to make.

In this case, we will investigate the dependence of absorption efficiency

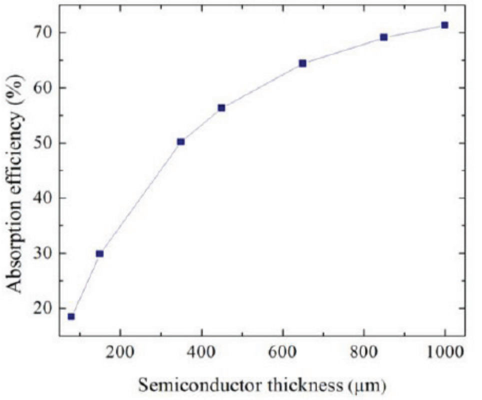


Figure 8: The dependence of absorption efficiency according to the GaAs layer thickness

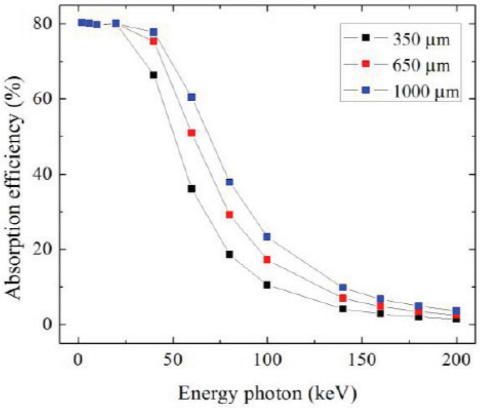


Figure 9: The dependence of absorption efficiency according to the energy and at various thickness

according to the energy and at contact material (Al-Ni or Au-Ge [7]) with distance from source to detector is 1 mm, thickness of contact layer is as same as Au-Ni

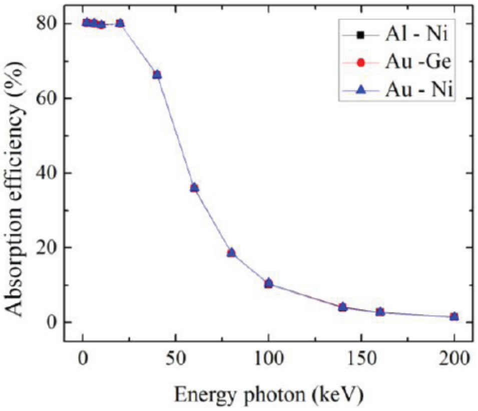


Figure 10: The dependence of absorption efficiency according to the energy and at contact material .

From the dependence of absorption efficiency according to the energy and at contact material, the absorption efficiency of the detector does not change significantly when they are changed exposed material. Therefore, in reality of production, depending on the operating conditions of temperature environment, producers select preferable contact materials.

Compare performance Si and GaAs detectors:

In this case, we compare the performance of GaAs and Si detectors in the energy 20keV, 30keV, 40keV, 50keV when we change thickness of semiconductor material 150μm, 250 micron, 350μm

Thus, we find that in the applications of tens of keV energy, the absorption efficiency of a GaAs detector is better than a Si detector at the same size. Moreover, due to the band gap of GaAs detectors fit works well in normal temperature, detectors do not need refrigeration parts. So equipment cost will be cheaper. GaAs detectors also have high radiation durability [8]. With the remarkable progress in manufacturing technology, SI GaAs detectors will be present widely in the medical devices as well as applications in industry, technology and nuclear technology, [9], [10].

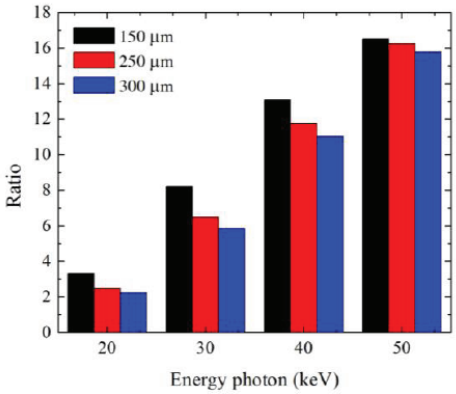


Figure 11: The ratio of the absorption efficiency GaAs and Si detector

5. Conclusion

In the signal simulation, calculations of the absorption efficiency of GaAs detectors according GaAs semiconductor layer thickness, photon energy, the location of the radiation source, electrode materials ... is a complicated problem due to the interaction of photons for the material. By using the simulation program PENELOPE by Monte Carlo method the problem has basically solved.

The results of such simulations are very helpful in the detector fabrication process as well as the ability to use forecasts, although they are usually only given for reference, to compare with the results of the other methods in measuring results and practice. Because in the method of simulation and in practice there are many different conditions and bias (eg, differences in location and radiation systems acquisition, angle, size of the system, temperature ...). It needs to build a dedicated simulation program to calculate the probe performance more accurately.

Through the simulation determines the properties of Gallium Arsenide probe by PENELOPE program,it shows that the simulation program can be used in many branches of nuclear technology, bioengineering.

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