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REDUCTION OF PATIENT RADIATION DOSE IN THE CASE OF X-RAY MEDICAL IMAGING

Abstract: *Compound semiconductors with wide gap and high atomic number Z proved to be suitable for high resolution detectors operating at room temperature. In this paper, we consider GaAs, InP, CdTe, HgI2 and CsI and taking into account their physical properties we calculate patient radiation dose in range of 20-120 keV. Finally, considering good image quality and lower radiation dose, we propose the best detector material for specific area of medical imaging from mammography to bone radiography.*

Key words: radiation detectors, GaAs, InP, CdTe, HgI_2, CsI, x-ray medical imaging.

INTRODUCTION

Medical radiography deals with the problem of acquiring an image of a certain part of the body that was shortly exposed to x-rays. In recent years, there has been a campaign whose aim is to introduce digital radiographic methods. These methods have many advantages over conventional methods. Procedures of acquiring images are much simpler. An image can be obtained and analyzed immediately, quality of the image is high and it can be digitally processed and easily archived. The most important benefit for the patient is early detection of potential diseases with decreased radiation doses.

In this paper, we focused on the problem of choosing the best material for medical imaging in the energy range between 20- 120 keV. We developed a model of a pixelated planar detector and calculated the size of the smallest object that can be detected with different semiconductor materials for the energies that are usually used in mammography, dental radiography and lung radiography. We also calculated radiation doses which are necessary for the detection of the same size objects with different materials. Based on these calculations, we made comparison between the materials that are currently in use (CsI, CdTe) and the materials that are potentially interesting (GaAs, InP, HgI2) for medical planar detectors.

MATERIALS AND METHODS

Materials which can be used for the detection of x-rays at room temperatures need to fulfill many criteria. One of them is that the material has a gap which is relatively wide in order to reduce electronic noise, but at the same time not too wide in order to maximize the number of electron-hole pairs per X-photon. The selected material should have high atomic number Z in order to provide the large efficiency of photon absorption. The mobility of the carriers and their lifetime should be high so they could be collected on the contacts more efficiently. It is expected that the chosen material has the small number of defects, uniform electric properties; good spatial resolution and that it can be produced using standard technologies.

The most developed production technology is for elementary semiconductors Ge and Si [1], [2], but both of them show high resolution only while cooled. They are suitable for detection of the low energy radiation, but not at the room temperatures. Consequently, compound semiconductors that have wider gap and higher atomic number Z have been studied as good candidates for the high-resolution detectors operating at room temperatures. Apart from detection efficiency, the quality of retrieved image is also considered. The fluorescence that degrades spatial resolution and contrast should also be taken into account. The yield and energy of fluorescence photons increase with atomic number Z [3], so when choosing suitable semiconductor for detector construction, a compromise should be made between the absorption efficiency (high Z) and decrease of Z, in order to obtain good contrast and spatial resolution.

CdTe is a dominant material for compound radiation detectors. It is still not available in large areas and its production is limited to a small number of companies [4]. InP and HgI_2 seem to be good candidates for high quality imaging detectors because of their atomic number and energy gap. GaAs and InP offer photon attenuation coefficients between those of Si and CdTe and are being developed principally for X-ray imaging applications. CsI has been the most used material in medical radiography till now.

MAMMOGRAPHY

Since the aim of medical imaging is detection of early changes inside the tissue, i.e. detection of objects as small as possible, we calculated minimum object size that could be detected in conditions of mammographic imaging, in order to choose the best material for detector construction. During mammographic imaging, a problem is to differentiate tumorous tissue due to surrounding tissue because of very similar absorption coefficients. According to Rose model [5], human eye

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is able to differentiate these changes if signal-to-noise ratio, SNR, is equal to 5.

We took this into account and used the following parameters to calculate minimum size of visible carcinoma in conditions typical for mammography: energy of x-rays E=20keV, linear absorption coefficient of tumorous tissue [6] (carcinoma) αc=0,85cm-1, linear absorption coefficient of surrounding tissue of thickness 5cm [6] αt=0,5 cm-1, pixel size 150Ccident photon flux $\Phi_0 = 5 \cdot 10^7$ photons/cm^2. Our results are presented in Table 1.

Table 1. *Minimum size of visible objects in case of mammography*

Material	GaAs	InP	CdTe	HgI_2	CsI
object (μm)	73	75	116	128	-

The results show that the smallest object can be detected with GaAs while it cannot be detected with CsI. The comparison between the materials considered is presented in Figure 1.

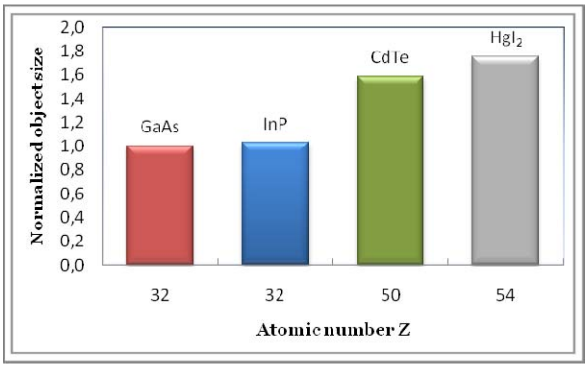

Figure 1. *Normalized object size vs. atomic number in case of mammography*

From the Figure 1 it can be seen that the smallest object is detected with GaAs and InP for the radiation energy of 20 keV and other specified parameters. For the same parameters, the object that is 1,6 and 1,8 times bigger can be detected with CdTe and HgI_2, respectively.

That means that the radiation dose must be increased for other materials in order to detect the same size carcinoma as with GaAs.

The radiation dose can be calculated from the following formula [7]:

$$D = 1.833 \cdot 10^{-8} \Phi_0 \cdot E \cdot (\mu / \rho) \quad (1)$$

where: Φ_0 is incident photon flux, E is the radiation energy, μ is the mass energy-absorption coefficient and ρ is the density of the material.

Using this formula, we calculated the radiation dose for GaAs needed to detect the object whose size is 73 μm. This value corresponds to the minimum value of SNR which is sufficient for human eye to differentiate tumorous tissue from surrounding tissue.

We have also calculated the value of radiation dose for other materials which are required to detect the object of the same size as with GaAs. These results are presented in Table 2.

Table 2. *Radiation doses in case of mammography*

Mat.	GaAs	InP	CdTe	CsI	HgI_2
D (μGy)	101	105	252	3834	303

Figure 2 represents normalized radiation dose vs. atomic number for the considered compound semiconductors. The radiation dose for GaAs (101 μGy) is taken as the referent dose.

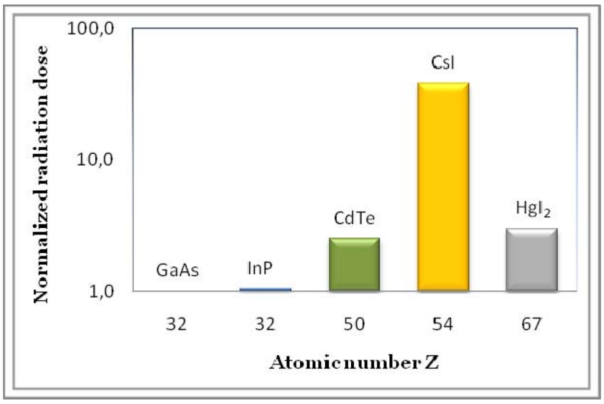

Figure 2. *Normalized radiation dose vs. atomic number in case of mammography*

Figure 2 shows that there are no significant differences between GaAs and InP and that almost the same radiation dose is required to detect the object. The radiation dose must be 2,5 times increased for CdTe, 3 times for HgI2 and even 38 times increased for CsI in comparison with GaAs.

DENTAL RADIOGRAPHY

We have also considered the problem of differentiating the carious tissue from the normal tissue of the teeth. For this case, we took typically dental imaging energy of 40 keV, incident photon flux $\Phi_0 = 10^6$ photons/cm^2, linear absorption coefficient of carious tissue [8] α_c =0,45cm^{-1}, linear absorption coefficient of surrounding tissue of thickness 1cm [8] α_t=1,65 cm^{-1} and pixel size 150 μm. Calculated results are presented in Table 3.

Table 3. *Minimum size of visible objects in case of dental radiography*

Material	GaAs	InP	CdTe	CsI	HgI_2
object (μm)	71	68	84	-	134

The results show that the smallest object (68µm) can be detected with InP, but for the chosen parameters, objects smaller than pixel size cannot be detected with CsI. For the same radiation dose, 1,2 times smaller carious tissue can be detected with InP than with CdTe and almost 2 times smaller than with HgI_2.

As in the previous case, we calculated the radiation doses required for the other materials to detect the object of the same size as with the most sensitive material, in our case InP. The calculated results are presented in Table 4.

Table 4. *Radiation doses in case of dental radiography*

Mat.	GaAs	InP	CdTe	CsI	HgI_2
D (µGy)	10	9	15	139	32

Comparison of these materials (Figure 3) shows that there are no significant differences in results between GaAs and InP. The radiation dose must be 1,7 times increased for CdTe, 3,6 times for HgI_2 and 15,5 times for CsI in order to detect the object whose size is 68µm.

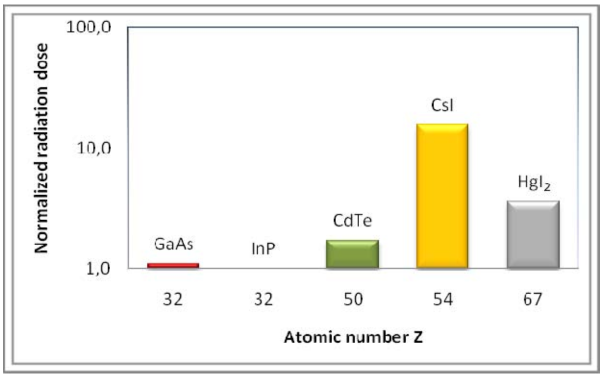

Figure 3. *Normalized radiation dose vs. atomic number in case of dental radiography*

LUNG RADIOGRAPHY

As in the case of mammography, we have also considered the problem of differentiating tumorous tissue from surrounding tissue in lung radiography. The kilovoltage of an x-ray beam used for chest imaging is typically 120 kVp, yielding a mean beam energy of 60 keV after passing through the thorax [9]. Other parameters that we used to calculate the minimum size of visible pulmonary nodule in conditions typical for lungs are: linear absorption coefficient of tumorous tissue [6] $\alpha_c = 0{,}2\ cm^{-1}$, linear absorption coefficient of surrounding lung tissue of thickness 3 cm [6] $\alpha_t = 0{,}05\ cm^{-1}$, pixel size 150 µm and incident photon flux $\Phi_0 = 6 \cdot 10^6$ photons/cm^2. The calculated results are presented in Table 5.

Table 5. *Minimum size of visible objects in case of lung radiography*

Material	GaAs	InP	CdTe	CsI	HgI_2
object (µm)	88	85	106	-	-

The results show that the smallest object can be detected with InP, The size of the object that can be detected with GaS isn't significantly different. In this case, the object smaller than pixel can be detected neither with CsI or HgI_2.

As in the previous cases, we calculated radiation doses needed for other materials to detect the object of the same size as with the most sensitive material (InP). These values are presented in Table 6.

Table 6. *Radiation doses in case of lung radiography*

Mat.	GaAs	InP	CdTe	CsI	HgI_2
D (µGy)	2,2	2,1	3,4	33	8

The comparison between materials presented in Table 6 can be seen in Figure 4. The radiation dose for InP (2,1 µGy) is taken as the referent dose.

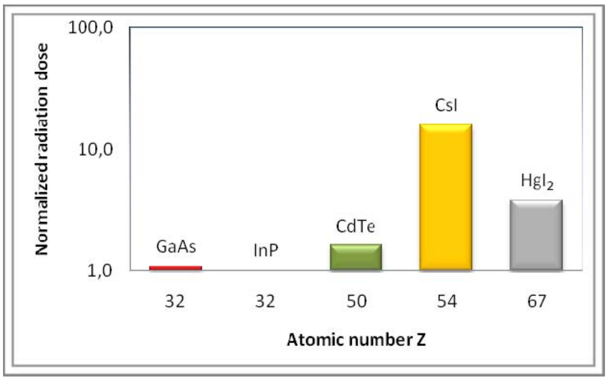

Figure 4. *Normalized radiation dose vs. atomic number in case of lung radiography*

Figure 4 shows that in the case of lung radiography, there are no significant differences between GaAs and InP concerning the value of the radiation dose. In this case, the radiation dose must be 1,6 times increased for CdTe, 3,8 times for HgI_2 and 15,7 times for CsI in order to detect the object of the size 85µm.

CONCLUSION

In this paper, we considered several compound semiconductors which are good candidates for the construction of planar detectors for medical imaging. We compared GaAs, InP, CdTe, CsI and HgI_2. Our conclusions are based on the calculations of the smallest object that can be detected with these materials for the specified radiation energy and of the smallest amount of the radiation dose required for detection of the same size object. The calculations are made for the conditions that are typical in the cases of mammography, dental and lung radiography.

On the basis of our calculations, we can conclude that in the group of materials being considered, the best materials used for medical applications, at room temperatures (energies of x-rays in the range of 20keV-120 keV), are GaAs and InP. GaAs showed somewhat better results for detection in the low energy range (20-30) keV and InP was a little better in the range (40-120) keV. We showed that the dose necessary to detect minimum object size in case of mammography can be 38 times smaller for GaAs detectors than for digital imaging detectors based on CsI scintillators. In the case of dental radiography, the usage of InP detectors can reduce patient dose 15,5 times compared to CsI detectors. Unfortunately, detectors based on InP, which is a very soft material, are limited with production technology. Future improvements in InP detector performance depend on the development of the rectifying contacts. GaAs in particular has relatively mature contact technologies, and there has recently been some progress in production of epitaxial large-area GaAs [10] with uniform electric properties and lowered defect concentration.

We can conclude that in the group of considered materials, GaAs seems to be the best choice for obtaining good response to X-ray radiation of energies 20-30 keV and InP of energies 40-120 keV, good contrast and lower radiation dose.

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BIOGRAPHY

Bojan Nikolić was born in Sarajevo, Bosnia and Herzegovina in 1983.
He received the diploma in electrical engineering from the Faculty of Electrical Engineering, University of Sarajevo. His main research interests include the application of telecommunication in power engineering, electrical engineering materials, etc. He is working as a teaching assistant at the Faculty of Electrical Engineering, University of Sarajevo.

SMANJENJE DOZE ZRAČENJA PACIJENTA KOD MEDICINSKIH SNIMANJA X-ZRACIMA

Bojan Nikolić, Maja Đekić, Hasnija Šamić

Rezime: *Složeni poluprovodnici sa širokom zabranjenom zonom i velikim atomskim brojem Z su se pokazali pogodnim za izradu detektora koji rade na sobnim temperaturama. U ovom radu razmatramo GaAs, InP, CdTe, HgI_2 i CsI i uzimajući u obzir njihove fizikalne osobine, računamo dozu zračenja pacijenata u opsegu 20-120 keV. Na kraju, uzimajući u obzir dobar kvalitet slike i malu dozu zračenja, predlažemo najbolji materijal za detekciju za određena područja medicinskih snimanja od mamografije do radiografije kostiju.*

Ključne reči: detektori zračenja, GaAs, InP, CdTe, HgI_2, CsI, medicinska snimanja x-zracima.