ORIGINAL PAPER

EXPERIMENTAL STUDIES OF PHOTON ABSORPTION IN SILICON AND NIOBIUM

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Abstract. *The absorption of photon through silicon and niobium is measured by using Si(Li) X-ray detector. We use* Fe^{55} *radioactive source to produce fluorescence lines from Si, Cl and Ti. The experimental results show that the absorption strongly depends on the energy of the incoming photon, material thickness and the atomic number of the absorber. The photon fraction absorbed is consistent when Nb and Si are placed together as an absorbing material and when they are placed one by one and resulting fraction is added. The experimental results agree well with the calculated values of the photons fraction absorbed at five different energies.*

Keywords: *photon, silicon, niobium, Si(Li) X-ray detector.*

1. INTRODUCTION

Photons are electromagnetic radiation and do not steadily lose energy via coulombic interactions because they don't have charge and mass [1]. When they interact with matter they are either absorbed or scattered through a significant angle with some energy loss. There are several processes through which photon interacts with matter. The relative importance and efficiency of each process is strongly dependent upon the energy of the photons [2, 3] and the nature of the absorbing medium (atomic number, density etc).

In photoelectric absorption process, a photon undergoes an interaction with an absorbing material and disappears completely by giving its energy to the bounded electron. As a result an energetic photoelectron is ejected from the atom with energy equal to the energy difference between incoming photon and the binding energy of the bound electron [4]. [This type of interaction cannot take place with free electrons since otherwise conservation laws would be violated.] In Rayleigh scattering, when a photon interacts with atom, it may or may not impart some energy to it. The photon may be deflected with no energy transfer. This process is most probable for photons with very low-energy. Another important process known as Compton scattering takes place when a gamma ray photon interact with a free or weakly bound electron ($E_\gamma >> E_b$) and transfers part of its energy to the electron which is then known as recoil electron. The electron becomes free with kinetic energy equal to the difference of the energy lost by the gamma ray and the electron binding energy. The probability of Compton scattering per atom of the absorber depends on the number of electrons available as scattering targets and therefore increases linearly with Z.

The third important interaction process of photon with matter is pair production. If the energy of the energetic photon is greater than 1.02 MeV it may interact with the nucleus to

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form an electron-positron pair [5]. This amount of energy is just sufficient to provide the rest masses of the electron and positron (0.51 MeV each). Excess energy will be carried away equally by these two particles which produce ionization as they travel in the material. This interaction process cannot occur below a threshold of 1.02 MeV, and dominates over Compton scattering above several MeV. In order to conserve momentum, this interaction can only occur in the presence of third body, usually a nucleus.

The probability that a photon will be removed from the beam increases with the increase of number of atoms in the interaction material, which means the probability of absorption increases with the thickness of the absorber. The quantitative measure of the degree of absorption of a material is given by its absorption cross section, or equivalently by its absorption coefficient.

2. EXPERIMENT AND DATA ANALYSIS

The experiment was performed in the EBIT Laboratory at Albanova University centreum Stockholm Sweden. The experimental arrangement is shown schematically in Fig. 1. The photograph of the absorber (Si) and aluminium plate used for collimating the emitted photon is shown in Fig. 2a. Also the photograph of the plastic tube when mounted on X-ray detector for experiment is shown in Fig. 2b. The X-ray detector used in the present measurements was Si(Li) detector having beryllium window of 1mm thickness and active area of 10 mm. The detector was connected to a high voltage biased and to a Multi Channel Analyzer (MCA) in a computer through the shaping amplifier. We use Fe^{55} X-ray source, which is placed inside the aluminium holder and is fixed with the help of a screw. The aluminium holder containing the X-ray source is fixed on the plastic tube as shown in Figs. 1 and 2b.

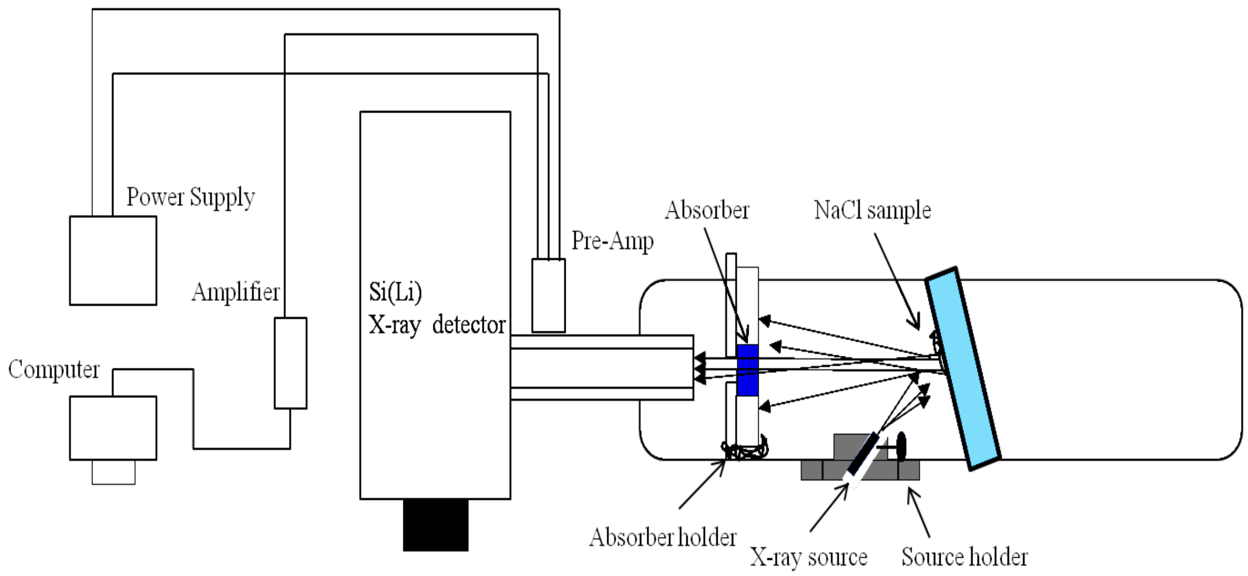

Fig. 1. Schematic representation of the experimental set up.

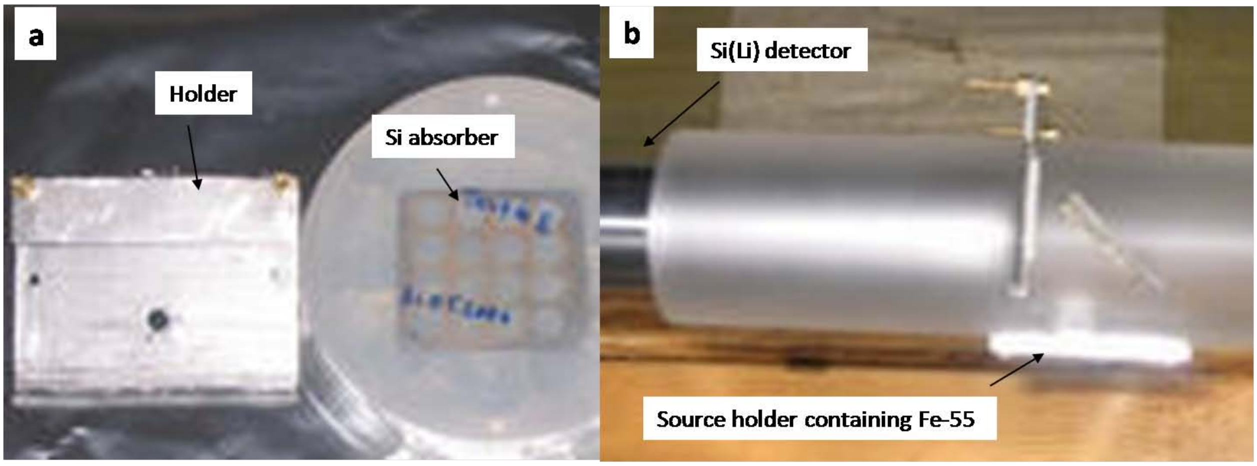

Fig. 2. Photograph showing experimental setup.

In order to measure the fraction of photon absorbed we first place the aluminium plate containing sample (without absorber) into the plastic tube in front of the detector window so that photons are allowed to pass through the small aperture. The aluminium plate geometry is such that the small hole/aperture comes into the centre of the plastic tube as well the detector window. We set the live time for 3000 seconds on the data collection software to record the data. An initial pulse height spectrum was obtained using a data acquisition system. The end result of multichannel analysis is a histogram (spectrum) of the detected output pulses, sorted by magnitude. The energy peak associated with the photon was identified, and the number of counts in the peak channel was recorded. We take several measurements to take the statistical error in each measurement. Then we take the average of these measurements that gives us the actual number of counts/intensity (N_0) without absorber. Now we place the absorber on the holder (one side of the aperture) as shown in figure 2b. We again take several measurements for the same time as without absorber and measure the number of counts N(x). Then we use the following equation to get the fraction of photon absorbed for different energies

$$N = N_0 e^{-\alpha x} \tag{1}$$

where α is the absorption coefficient taken form NIST webpage [6].

3. RESULTS AND DISCUSSION

In gamma ray spectroscopy application, the detector produce output pulses whose magnitude are proportional to the energy deposited in the detecting medium by the incident photons. The response of Si(Li) to low energy X rays and gamma ray photon has been shown to be very linear provided the applied voltage is high enough to avoid significant loss of charge from trapping and recombination. Fig. 3 show a linear fit between observed channel number and different X-ray photon energies.

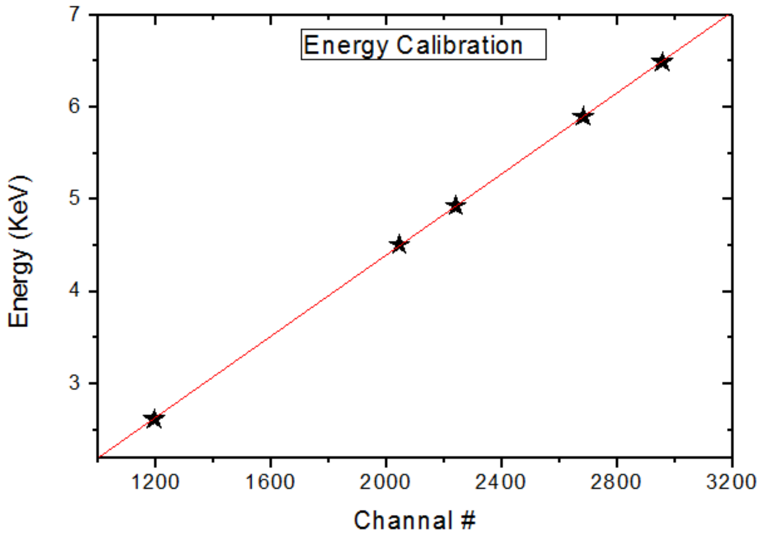

Fig. 3. Calibration curve of energy vs. channel number, using the positions of photo peaks obtained with Si(Li) detector.

Fig. 4 show the results when 0.59 µm thick Nb and 0.75 µm thick Si membrane are placed together as an absorbing material. The data is plotted both for calculated and measured values. The red dots are the calculated values of the absorption while the data points with error bars are the experimental results. Both the calculated data and the measured results show a very good agreement within the experimental error bars. From Fig. 4 we find that the fraction of photons absorbed in Nb+Si membrane for energy 2.62 keV is 83 percent of the total number of photons, while for energy 4.51 keV and 4.93 keV the absorption is 35 and 27 percent respectively. For two values of Mn energies 5.90 keV and 6.49 keV the absorption is 18 and 12 percent, respectively.

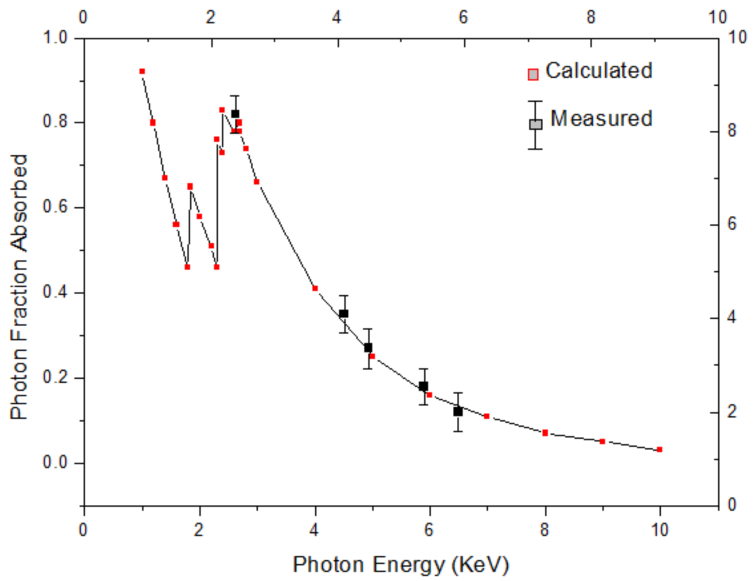

Fig. 4. Photon absorption as a function of photon energy through 0.59µm niobium+ 0.75µm silicon absorber.

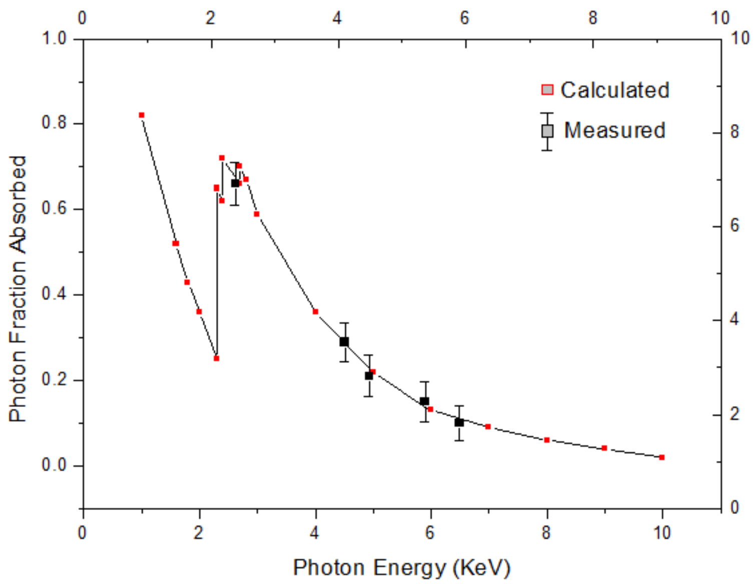

Fig. 5. Photon absorption as a function of photon energy through 0.59μm niobium absorber.

Fig. 5 shows the results for the absorption of photons through only one material i.e., Nb of having thickness 0.59 μm. In this case the absorption of photons is less compared to the case when Nb and Si were placed together. The fraction of photons absorbed having energy 2.62 keV is 65 percent, while the absorption of photons having energy 4.51 keV and 4.93 keV is 29 and 21 percent respectively. Also for photons of energy 5.90 keV and 6.49 KeV the absorption is 15 and 10 percent, respectively. In Fig. 5, we present the results of absorption of photons through 0.75μm thick Si absorber. For X-ray photons of energy 2.62 keV the photon absorption is 22 percent. For titanium energies 4.51keV and 4.93 keV the absorption is 6 and 4 percent respectively. The absorption of photons having energies 5.90keV and 6.49keV is approximately 3 and 2 percent.

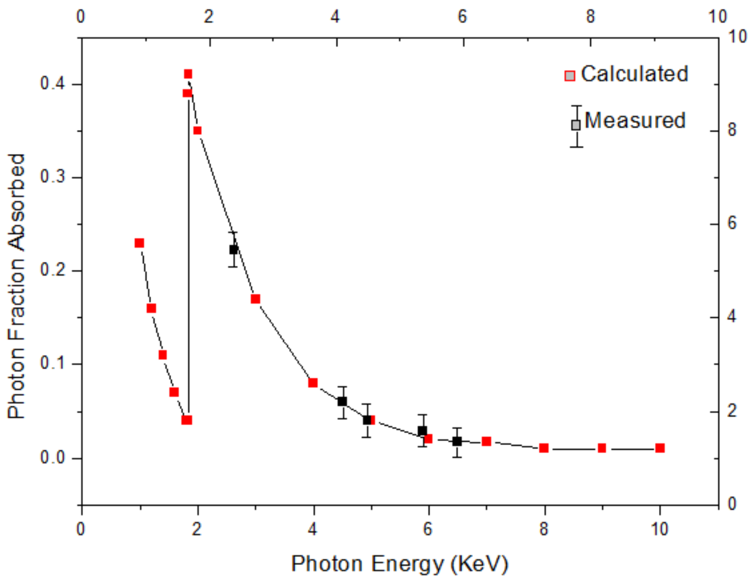

Fig. 6. Photon absorption as a function of photon energy through 0.75μm silicon absorber.

From the above results one can see how absorption of photon varies with the change in energy of the incident photons. For example the above values of absorption fractions are very different from each other because of the energy difference of photon from Ti, Cl and Mn. Also it is very interesting to note that the fraction of absorbed photons in Si with thickness of 0.75 μm is less than the absorption in Nb with thickness 0.59 μm. This shows a strong dependence of absorption on the atomic number Z. Also the absorption of photons in the case when Nb and Si were placed together is consistent with the fraction of photons added together from the results of Nb and Si separately. Both these results verify the consistency of our measurements.

4. CONCLUSION

We have investigated absorption of photons through different material at different energies. Our results show that the absorption of photons through matter strongly depends on the atomic number of the absorbing material, energy of the incident photons and the thickness of the absorbing material.

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