

# Design of a new vacuum Compton gamma-ray detector with clad metal electron-converter plate

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**Abstract:** A newly designed vacuum Compton gamma-ray detector with Ta-Al clad-metal electron converter plate is described. The detecting efficiency for 1.25 MeV gamma-ray is  $7.85 \times 10^{-3}$  electron/ $\gamma$ , which is 2.5 times higher than that with Fe converter plate. The designed detector has the merits of well processed and static vacuum keeping and can be used for intense pulsed gamma ray detecting.

**Keywords:** pulsed gamma ray; electron converter; Compton detector

## 1 Introduction

In the field of intense pulsed gamma ray detection and diagnosis, two types of current-mode detectors are often used to measure the intensity and variation of the radiation. One type is scintillation-photoelectric detector. The gamma ray deposits part of its energy in the scintillator, then the deposit energy is transfer to photons, these photons can be measured by photoelectric devices such as Photo Multiplier Tube (PMT). The upper measuring limits for these detectors are determined by the hardness of the scintillator and the linearity of the devices. When the energy fluence of gamma-ray is higher than  $10^{20}$  MeV/(s·cm<sup>2</sup>), the scintillation detector is hard to measure the absolute intensity. Another type of current-mode detector is called charge-collecting detector such as Compton detector. Vacuum Compton detector (VCD), which has the merits of large dynamic linearity range, simple structure, is suitable for the intense pulsed ray measurement<sup>[1-3]</sup>.

A VCD detector is composed of radiation incident window, exit window, electron emitter and a cylindrical airproofed wall. When collimated parallel beam of gamma rays passes through the incident window, plenty of electrons will produced from the windows and the emitter by photoelectric effect, Compton effect and pairs effect. The sensitivity is mainly contributed by the emitters. By measuring the net charge or the current of the emitters, the intensity of the gamma ray can be measured. The detecting efficiency is related to the material of the emitter and the structure. Hsiao-Hua

Hsu<sup>[4]</sup> introduced a VCD with thin incident window structure, the gamma ray converting efficiency can be  $4.68 \times 10^{-3}$  e/ $\gamma$ . Another VCD with a thick incident window is also designed, and the sensitivity is  $3.16 \times 10^{-3}$  e/ $\gamma$ <sup>[1]</sup>. For the thin incident window structure, the efficiency is higher than that of thin window structure, however, it is hard to maintain a long-time vacuum, the sensitivity is not stable.

This paper introduces a new VCD with thick incident window. In order to increase the sensitivity, a clad metal emitter is designed.

## 2 Characteristics of electron-emitting for metal

The sensitivity of VCD is determined by the number of emitted electrons from the emitter. When gamma ray interacts with materials, the number and the angular distribution of ejected electrons from the surface is related to several aspects such as the density, the atomic number, the cross section, the thickness of the materials and the gamma energy<sup>[3,4]</sup>.

Using the Monte Carlo code MCNP 4C<sup>[5]</sup>, the relationship between the electron-ejecting ability and the material thickness for different metals is shown in Fig.1 and Fig.2. The gamma energy is fixed to be 1.25 MeV and the diameter of the parallel beam is 40 mm.

According to the calculations, when the thickness is less than 1 mm, the high  $Z$  ( $Z$  is the atomic number) materials have higher back-ejecting ability and lower forward-ejecting ability than low  $Z$  materials.

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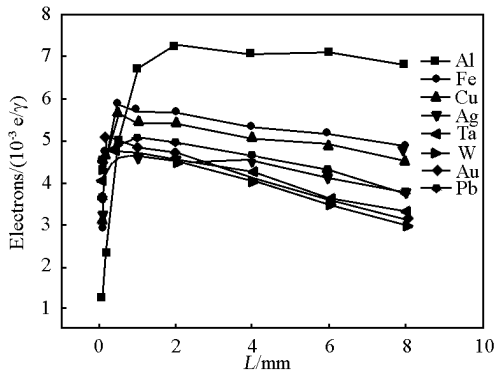


Fig. 1 The forward emitting efficiency of secondary electron

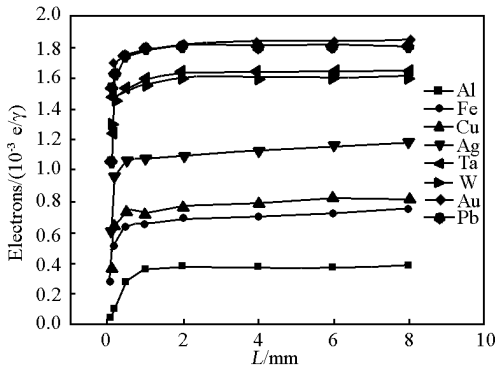


Fig. 2 The backward emitting efficiency of secondary electron

### 3 The electron emitter

The sensitive unit of Compton detector is the electron emitter which is closed in a vacuum chamber. Aluminum material is a good choice as an emitter, the front electron emission efficiency can be  $7.3 \times 10^{-3} e/\gamma$ . However, electrons generated from the window can also reach the emitter, that will reduce the net charge and reduce the detection efficiency. According to the result of Fig. 2, the back emission efficiency of tungsten, aurum, tantalum and lead material is high. If we choose aluminum and high Z material as a clad composite emitter, both the front and back emission efficiency will be high. In order to reduce the gamma-ray attenuation by the high Z material, the thickness of high Z material should be very small.

We choose a silver material with a thickness of 1.5 mm as the incident window, and the distance between the window and the composite emitter is 30 mm. For gamma-ray with fixed energy 1.25 MeV, the calculated back-emission efficiency varies with the thickness of the high Z material, which is shown in Fig. 3.

From the results, when the thickness of high Z material is larger than 200  $\mu\text{m}$ , the back-emission effi-

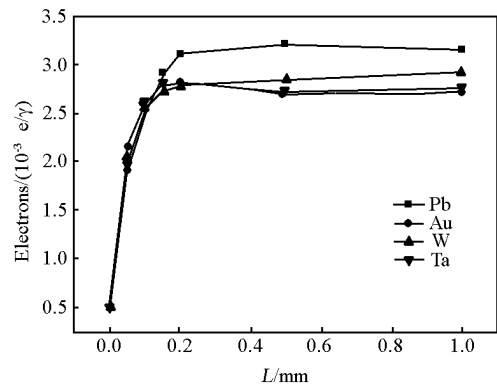


Fig. 3 Backward emitting efficiency varies as the thickness of clad-metal

ciency begin to be stable. The back-emission efficiency of lead is highest, but its melting point is less than 400  $^{\circ}\text{C}$ . For this reason, it is hard to take the high-temperature baking method of dealing with vacuum degassing. The physical and chemical performance of tungsten, tantalum and aurum are stable. If we choose these material as the clad material combined with Al material, the total electron emission efficiency can be  $10^{-3} e/\gamma$ , which is about 60 % higher than that of Fe emitter.

### 4 Structure of detector and detection efficiency

The designed structure of Compton detector is shown in Fig. 4 and the parameters are listed in Table 1. The distance between the emitter and the incident window is 50 mm, and the distance between the emitter and the exit window is 55 mm.

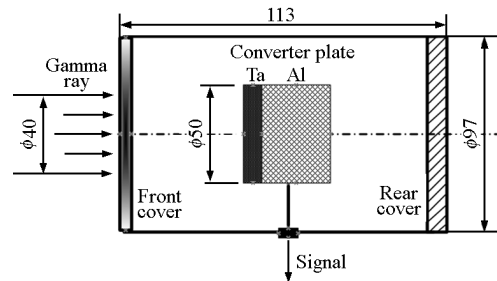


Fig. 4 Schematic diagram of the detector

Table 1 Structure of the detector

Unit of VCD	Material	Diameter/mm	Thickness/mm
Incident window	Ag	97	1.5
High Z material of the emitter	Ta	50	0.2
Base plate of the emitter	Al	50	2.0
Exit window	Fe	97	4.0
Body	Fe	100	3.0

When gamma-ray with energy of 1.25 MeV passes through the incident window, the angular distribution and the energy spectrum of emitted electrons from the silver window are shown in Fig.5 and Fig.6.

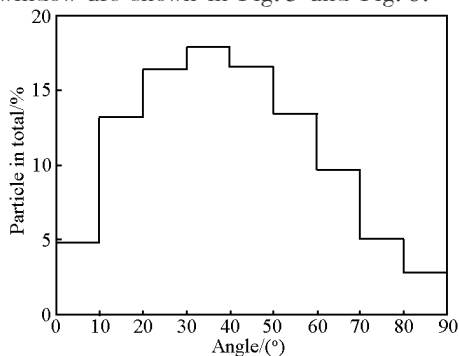


Fig. 5 Angle spectrum of forward electrons for 1.5 mm Ag

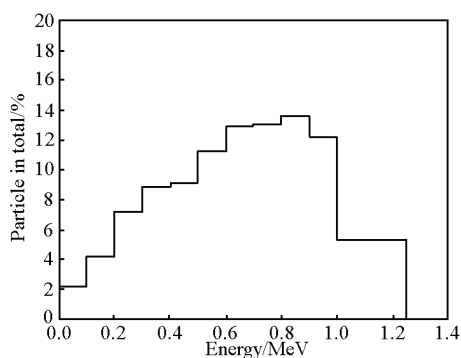


Fig. 6 Energy spectrum of forward electrons for 1.5 mm Ag

The average energy of emitted electrons from the window is about 0.63 MeV, and only half of them can reach the emitter. The electrons enter and leave the emitter from both the front surface and the rear surface, which is shown in Table 2.

Table 2 The number of electrons enter and leave the emitter

1.25 MeV/ $\gamma$	Enter/ $\times 10^{-3}$	Leave/ $\times 10^{-3}$
Front surface	2.26	1.19
Rear surface	7.08	0.300

### Author

Han Hetong, male, was born in 1967. He graduated from Tongji University in 1991 and now is a researcher at Northwest Institute of Nuclear Technology, Xi'an, China. Mr. Han has published over 4 papers. His current research focuses on pulse radiation detection. He can be reached by E-mail; hht2003123@163.com

According to Table 2, the electrons enter the emitter are mainly from the incident window. The detection efficiency of the whole detector is

$$S = (2.26 + 7.08 - 1.19 - 0.30) \times 10^{-3} = 7.85 \times 10^{-3} e/\gamma$$

Because the fly distance is small, the flying time for gamma-ray and electrons are less than 0.5 ns and 1 ns respectively. When the detector is used to measure the gamma-ray with nanosecond order, this effect can be ignored for the time performance of detectors.

## 5 Conclusion

Due to the structure design and the choose of clad emitter, the gamma sensitivity of VCD can be larger than  $7.85 \times 10^{-3} e/\gamma$  which is 2.5 times than that of VCD with Fe emitter structure. On the other hand, using the thick incident window the VCD can be well processed and the static vacuum can be long-time maintained. In our design, some aspects such as the purity of the material and the residual gas of the vacuum are ignored. The actual gamma sensitivity can be measured in a gamma source with high activity. The energy response of the detector should also be further studied.

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