ICANS XIX,
19th meeting on Collaboration of Advanced Neutron Sources
March 8 – 12, 2010
Grindelwald, Switzerland

MCP BASED NEUTRON CONVERTOR RESEARCH

Nianhua Lu
Department of Engineering Physics, Tsinghua University,
Key Lab of Particle and Radiation Imaging, Ministry of Education,
Beijing, 100084, P.R.China

and

Yang Tian and Yigang Yang
Department of Engineering Physics, Tsinghua University,
Key Lab of Particle and Radiation Imaging, Ministry of Education,
Beijing, 100084, P.R.China

ABSTRACT

High detection efficiency, good spatial resolution and high count rate are all favorable in neutron detection in CPHS (Compact Pulsed Hadron Source). We present in this paper the simulation research of improving neutron detection efficiency by coated MCP (micro channel plate) combined with MPGD (micro pattern gaseous detector). $^{nat}Gd_2O_3$ with thickness of 0.1μm to 1μm is plated on the inner surface of MCP in simulation. When the incident angle of neutron is controlled to be less than 5 degree, the detection efficiency of 25.3meV neutron could achieve >70%. The ALD (Atomic Layer Deposition) technique may perform the coating task.

1. Background

As a fundamental particle, the neutron has many unique attributes that provide a variety of contrast mechanisms enabling many imaging techniques [1]. However, neutron imaging is less developed than X-ray or Gamma ray imaging as a result of the limitation of neutron source.

Recent progresses in advanced neutron facilities, particularly those in high intensity pulsed spallation neutron source, give rise to the rapid development of neutron imaging. In our department, the Compact Pulse Hadron Source (CPHS) is under construction [2]. The future experiments in CPHS neutron facility require several kinds of neutron detectors, of which 2D neutron imaging detector is in great need.

In order to make full use of the facility, the desirable detector should have high detection efficiency (>50%) for thermal neutron, good spatial resolution (FWHM 100μm) , high counting rate capability and reasonable n/γ ratio. The coated MCP combined with MPGD may serve as a promising candidate.

2. Design of the Detector

2.1. MCP Based Neutron Convertor

Both solid state detector and gaseous detector are widely used in neutron detection. Solid detectors have high position resolution because of the large stopping power for charged particle which is the product of neutron absorption reaction. They are compact and easy to use. Gaseous detectors have large area with good uniformity, large signal to noise ratio if gas avalanche exists, and simple electronics. They are cost effective for neutron imaging. To combine the advantages of these two types of detectors, we choose MCP as the carrier of neutron absorption nuclides.

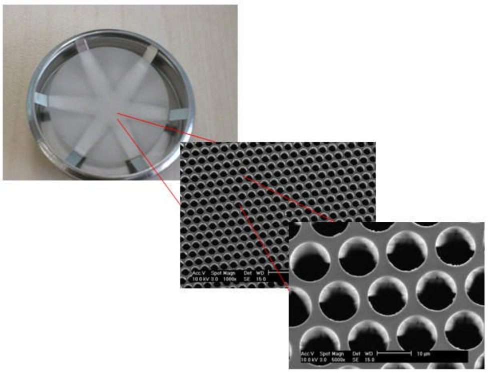


Fig. 1 Micro Channel Plate

The MCP we use is a thin glass plate with apertures of high density, as shown in Fig. 1. The detector benefits a lot from the geometry structure of MCP. The glass wall of the apertures can limit the range of neutron induced energetic charged particles, which contributes much to the detector's position resolution. The apertures serve as an ideal place for the charged particles to produce original electrons which may form the signal of the detector (Fig. 2).

2.2. The Selection of Absorption Nuclides

To effectively absorb incident neutron, neutron absoption nuclides need to be introduced into MCP, to make up an effective neutron convertor. The desirable nuclide should have large absorption cross section. After each absorption, there should be a large probability to produce charged particle with appropriate energy for detection. ^{nat}Gd perfectly meets such demands.

2.3. Methods to Combine MCP and Absorption Material

There are two methods to combine ^{nat}Gd with MCP, coating and doping. To dope, the nuclide becomes an ingredient of MCP glass. According to the manufacturer of MCP, the proportion of the absorption nuclide in the glass is very small (3.48 mol% for Gd_2O_3), significantly limiting the detection efficiency of neutron. As for coating, the purity of the coating material is nearly 100%. Using $^{nat}Gd_2O_3$, the density of the absorption nuclide can be much larger in the coating layer, providing larger detection efficiency. Besides, the thickness of the coating layer is controllable, convenient to the designing and optimizing of the convertor.

2.4. Detector Design

The coated MCP is then coupled with MPGD (MSGC is employed as an instance in Fig. 2). This design is very successful in X-ray imaging [3]. The mechanism of the electrical signal developing is similar. The design of the detector is illustrated in Fig. 2.

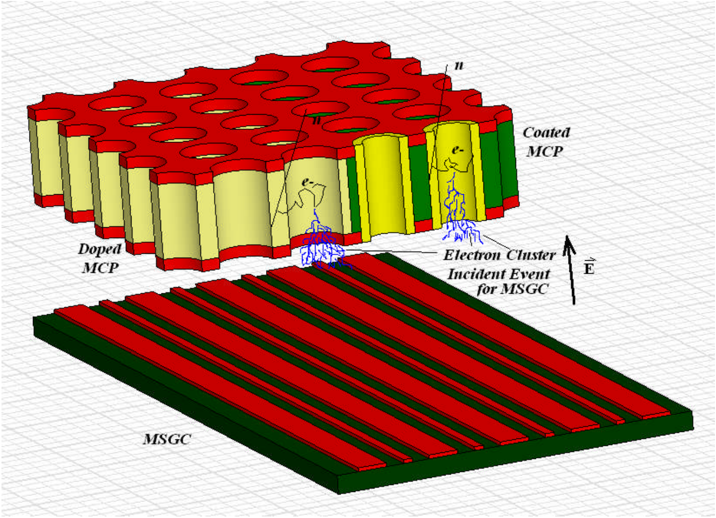
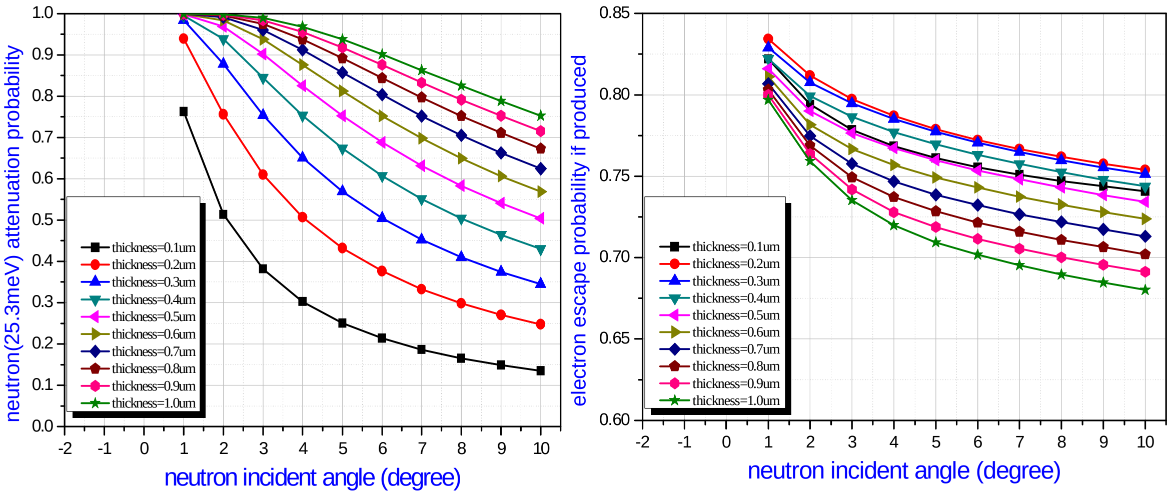


Fig. 2 The design of the detector

3. Simulation

We simulated the detection of thermal neutron, which can be divided into three consecutive steps. First, uncharged neutrons are converted into charged particles. We use P_1, P_{ne} to characterize this process. P_1 is the absorption probability of neutron by the coating layer. P_{ne} is the probability that the absorbing reaction releases charged particles. Second, the charged particles escape to the pores and produce original electrons therein (Fig. 2). P_2 is the escaping probability. Third, the original electrons migrate and multiply in the detecor and induce an electrical signal able to be detected. Here we define P_3 which means the detection efficiency of the original electrons in the MCP pores.

MCNP was employed for the simulation work. For P_1, the attenuation of thermal neutron (25.3 meV) by $^{nat}Gd_2O_3$ coated MCP was calculated. As the absorption crosssection of ^{nat}Gd is very large, attenuation means being absorbed in the $^{nat}Gd_2O_3$ layer. The results are shown in Fig. 3a.



a) b)

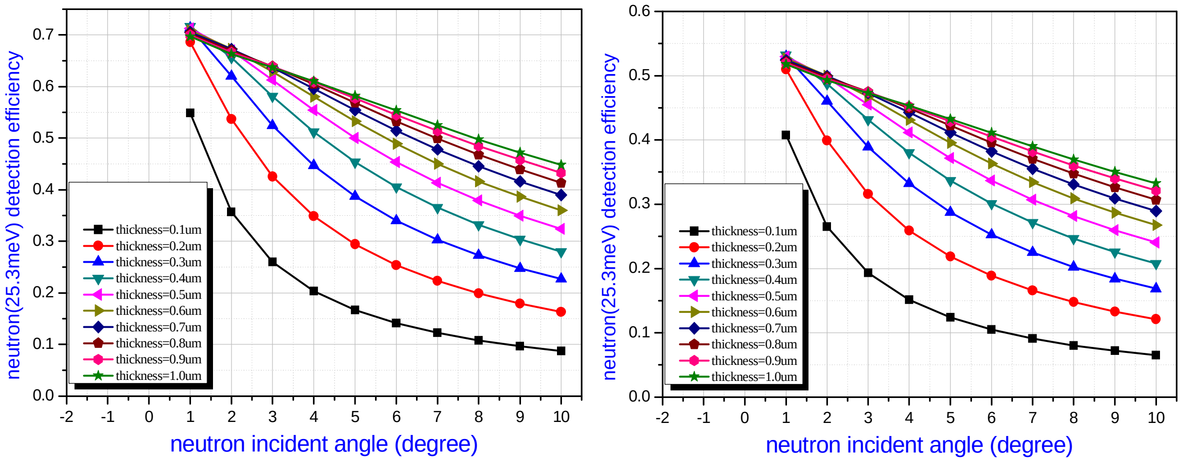
Fig. 3 The simulation results of P_1 and P_2

For P_2, according to the attenuation of neutron, one can get the probability distribution function p(x) of the original position x of the electrons which are products of neutron absorption reaction with ^{nat}Gd. For each position x, electron energy spectrum of ^{nat}Gd after neutron absorption was used to calculate the escape probability e(x). Then P_2 can be determined by Eq. 1. Practically, we selected enough different positions to calculate the summary rather than calculating this integration. Fig. 3b shows the results of P_2.

$$P_2 = \int p(x)e(x)dx \tag{1}$$

According to the research of MCP using as X-ray convertor, detection efficiency of the original electrons in the MCP pores can be approximately 100% [3]. According to the research by R. C. Greenwood [4], P_{ne} is equal to 0.875 for ^{nat}Gd. But another researcher gives a different value, 0.65 [5]. Here we used both of these two values to calulate the detection efficiency for thermal neutron. The detection efficiency P is determined by Eq. 2. The results are in Fig. 4.

$$P = P_1 \times P_{ne} \times P_2 \times P_3 \tag{2}$$



a) b)

Fig. 4 Neutron detection efficiency, a) P_{ne}=0.875; b) P_{ne}=0.65

4. Performance

4.1. Detection Efficiency

The neutron incident angle with respect to the wall of the pores should be larger than 1.35 degree given by Eq. 3, to guarantee that all the neutrons run into the coating layer. In Eq. 3, L and D is the length and diameter of the pores, the values being 510μm and 12μm respectively. At 1.35 degree, 0.3μm thick coating layer is enough to achieve detection efficiency >50% for 25.3 meV neutron. If 0.875 is used for P_{ne}, the efficiency can be better than 70%.

$$\theta = \arctan(D/L) \tag{3}$$

4.2. Spatial Resolution

Simulation also suggested that the neutron induced electrons may penetrate at most three walls of MCP. As the migration and multiplication are all limited within the pores of MCP, the largest electron cluster size extracted from MCP to MPGD is smaller than 50μm, which is much smaller than that of 6 keV photoelectron at 1 atm. For 6 keV X-ray, the position resolution of typical MPGD can be better than 100µm [6]. Thus, for this neutron detector, spatial resolution of 100µm is achievable.

4.3. Counting Rate Capability

There is a limit of counting rate for MCP, caused by the accumulation of ions in the electron multiplication on the coating layer. So the counting rate capability is limited by the conductivity of MCP's inner surface. For hydrogen reduced MCP, the conductivity is large enough to sustain high counting rate up to 10^4 counts/mm^2/s [7]. But after coating, the conductivity and counting rate capability need to be studied by experiments.

5. Realization

It is difficult to coat the inner surface of MCP as a result of the small size of each aperture. Normal coating technique doesn't work in this case. ALD (Atomic Layer Deposition) technique may perform this task. $^{nat}Gd_2O_3$ was successfully coated on silicon wafer. Fig. 5 shows the X-ray spectrum of the coated wafer hit by 20 keV electrons from the EDS (Energy Dispersive X-ray Spectrometer). The Gd characteristic peaks clearly show the existence of $^{nat}Gd_2O_3$. The huge Si peak reflects a small thickness of the coating layer. But the coating of MCP dose not succeed yet. The current technique in China needs to be improved to coat the surface of glass.

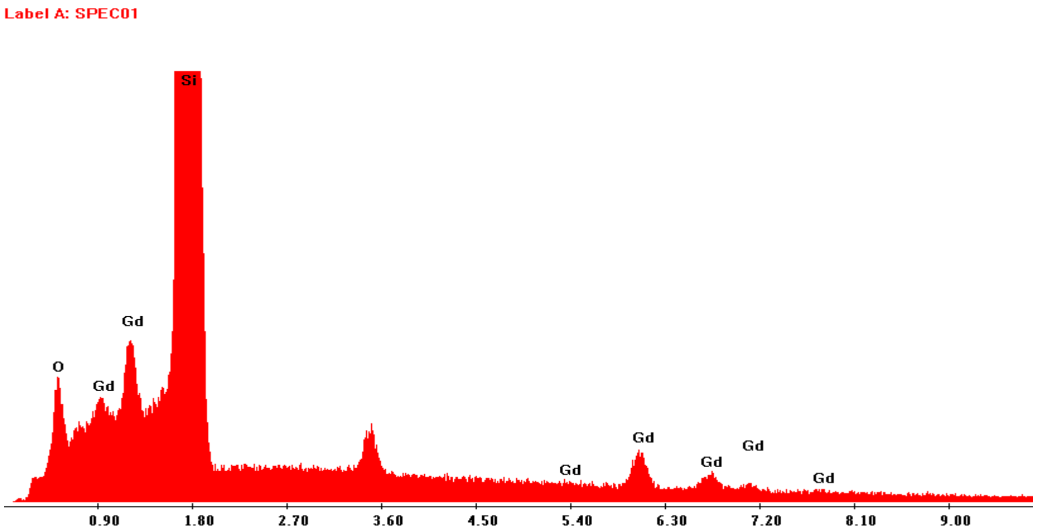


Fig. 5 The original spectrum of EDS

6. Conclusion and Future Work

According to our simulation, $^{nat}Gd_2O_3$ coated MCP combined with MPGD may have >50% detection efficiency for 25.3 meV thermal neutron and good spatial resolution. Our future work will focus on the coating of MCP using ALD and the specific experiments on the detector's performances. The simulation of ^{10}B coated MCP is on-going now.

7. Acknowledgements

This work is supported by the National Natural Science Foundation of China under Grant No. 10735020. The author would like to acknowledge Start Science Ltd for the aid of coating process.

8. References

1. I. S. Anderson, R. L. McGreevy, and H. Z. Bilheux, *Neutron Imaging and Applications*, (Springer Science+Business Media, LLC, New York, 2009) p. 3.
2. Jie Wei and Chun Loong, *Neutron News*, **vol. 20** (2009) 17-18.
3. C. Iacobaeus, T. Francke, B. Lund-Jensen, J. Ostling, P. Pavlopoulos, V. Peskov, and F. Tokanai, *IEEE Trans. Nucl. Sci.*, **vol. 53** (2006) 558.
4. R.C. Greenwood, C.W. Reich et al. *Nucl. Phys. A*, **vol. 304** (1978) 327.
5. Private communication with E. V. Glazunov in IEEE2009 NSS/MIC.
6. L. Shekhtman, *Nucl. Instr. and Meth. A*, **vol. 494** (2002) 135-136.
7. C. Iacobaeus, A. Breskin et al. *Nucl. Instr. and Meth. A*, **vol. 525** (2004) 43.