Pulsed Neutron Flux Measurement Based on Diamond Detector

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Abstract: A neutron flux measurement system based on CVD diamond detector was established, and system response characteristics of neutron and gamma was analyzed. Pulsed neutron flux measurement was carried out under different working mode at Xi'an Pulsed Reactor (XAPR). The signal of diamond detector was coincidence well with that of Pulsed Power Meter in time response, which can show the variation of neutron flux with time. Finally, a comparative analysis of the signal amplitude of diamond detector and pulse peak power of the XAPR was conducted.

Wide bandgap semiconductor detector has strong radiation resistance performance and fast pulse response, and its dark current is usually in the order of pA when working in the current mode, the Full Width of Half Maximum response to the repetition frequency of nanosecond pulse hard X-ray source is about 2.2 ns, diamond detector can also be used for neutron flux measurement.

Xi'an pulsed reactor (XAPR) has two kinds of operation mode, steady mode and pulse mode. Both of which can carry out electronic components and subsystem steady neutron radiation effect and the transient radiation effect research in the irradiation experiment apparatus. In order to study the transient radiation effect, it is necessary to obtain the radiation parameters such as the neutron flux over time to evaluate the radiation effects of electronic components and subsystem under the pulse radiation condition. In this paper, the fast neutron flux measurement under different pulse conditions was carried out using the single crystal diamond detector working in the current mode, Fig. 1.

Fig. 1. Single crystal diamond detector.

Radiation response of diamond detector

Neutron spectrum of the displacement damage effect experiment apparatus in the XAPR can be measured by multiple foil activation method, the cumulative flux measurement under different pulse conditions is also using the activation method, with the ^{58}Ni(n, p), ^{47}Ti(n, p) threshold activation detector. First of all the average cross section can be obtained according to the neutron energy spectrum and the reaction cross section, therefore the cumulative flux can be calculated using the activation rate of the detector activation rate and the average cross section. Neutron gamma ray ratio of the damage displacement effect experiment apparatus in the XAPR is up to 7.7×10^{9} n•cm^{-2}•rad^{-1}, Fig. 2.

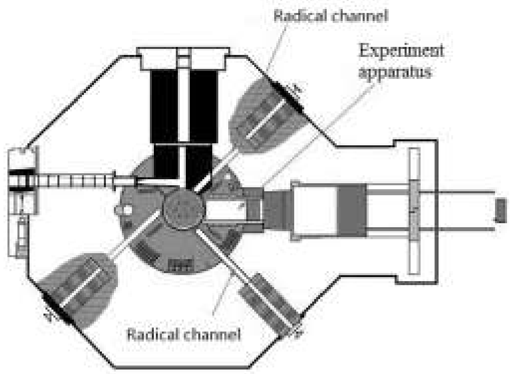

Fig. 2. XAPR and experiment apparatus.

The diamond detector response to the neutrons and gamma ray has been simulated by Monte-Carlo method based on the neutron energy spectrum, gamma dose rate which has been measured. In the simulation, we need to know the gamma dose rate of the radiation field, and the gamma energy spectrum which cannot be measured of the radiation field. Here, the Monte Carlo method is used to model the reactor and the radiation experimental apparatus. The gamma-ray energy spectrum and dose rate which can be obtained by measurements of the experimental position have been simulated. They can be both used to simulate the response of diamond detector.

The crystal size of the diamond detector used in this paper is Ø5 × 0.4 mm. The response of the diamond detector to the neutron and gamma rays of the radiation field needs to be simulated separately by the Monte Carlo method. The interaction between neutron and diamond detector is mainly composed of scattering and absorption with C nucleus, simulating the energy deposition of a series of charged heavy ions, such as C recoil nucleus, proton, α particle, etc. in diamond detection. The diamond detector used for pulsed neutron flux measurement needs to work in current mode, so the sum of energy deposition of each charged particle in the diamond detector should be recorded in the simulation. Gamma rays deposited energy with C atom of diamond detector by photoelectric effect, Compton effect and electron pair effect, and only recorded the average energy deposition. The ratio of neutron and gamma ray in the irradiation apparatus has been determined by measurement. According to this ratio, the average energy of neutron and gamma in diamond detector can be obtained respectively, the result is shown in Table 1.

Table 1. Simulate Results

Diamond detector	neutron（MeV）	gamma（MeV）
Energy deposition	1.0524E-01	1.0202E-03

The simulation results show that the accumulative deposition energy of neutron is two orders of magnitude higher than that of gamma ray deposition, which is mainly caused by two reasons. First, the shielding materials of the radiation experimental apparatus absorb most thermal neutrons, epithermal neutrons and gamma rays in the radiation field. The residual neutron in the radiation field is mainly fast neutrons and a small amount of residual gamma rays, and the ratio of neutron and gamma is relatively high. Secondly, the diamond materials used in the diamond detector have a low atomic number and a thin thickness, and the gamma ray can only have a very low mass energy absorption coefficient, and it is difficult to deposit all the energy of the secondary electrons produced by the action in such a thin detector. Therefore, it can be inferred from the simulation results that the signal in the current mode detector is mostly the contribution of neutrons, and the contribution of gamma rays to the signal can be neglected. The simulation results show that the diamond detector has a very high signal-to-noise ratio (SNR) without any converters and can be used to measure the neutron flux rate in the radiation field of the reactor.

System and experiment

Hence the current signal can be ignored that generated by gamma ray, the diamond detector used to measure neutron Flux rate in pulsed radiation field works in current mode, In order to obtain the neutron flux over time, single crystal diamond detector working in current mode has been adopted, whose signal can be recorded by oscilloscope and electrometer for measuring pulse, trailing-edge respectively.

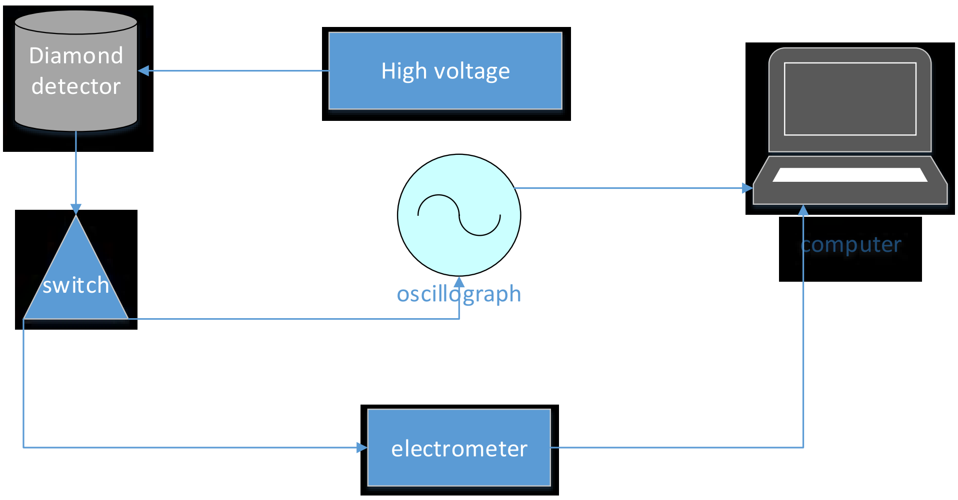

Fig. 3. Diamond detector measuring circuit.

The system used for neutron flux measurement in reactor irradiation experiment apparatus includes diamond detector and package, high voltage power supply, oscilloscope, electrometer and signal recording device, etc. The destination of this experiment is to measure the variation of neutron flux rate along the pulse and back edge with time. The measurement of diamond detector signal is divided into two parts: the oscilloscope is used to record the detector current signal during the pulse process. Because the signal resolution of the oscilloscope decreases during the descent of the pulse, it is needed to switch the detector current signal to the electrometer in the process of the signal descent. The measuring circuit is shown in Fig. 3.

In this experiment, the working condition of Xi'an pulsed reactor is \$3.2 and \$2.0, and the corresponding half maximum width of the pulse is about 10 ms – 20 ms. The response of diamond detector to sub-nanosecond pulse X-ray is about 2.2 ns, which fully meets the measurement requirement of the pulse radiation field. In order to increase the signal-to-noise ratio (SNR) of the post-pulse signal, the measurement system is set up to switch the signal measurement from oscilloscope to electrometer after the oscilloscope triggers 25ms. After measurement, the signal of oscilloscope and galvanometer should be combined to obtain the complete signal of pulse radiation field. When diamond detector is used to measure the neutron flux rate, the relative neutron rate variation in the pulse radiation process can be obtained. In the radiation field pulse, the post-accumulative neutron flux is measured by activation method.

Results and discussion

When the XAPR working at \$3.2 and \$2.0, the measuring results in the displacement damage effect experiment apparatus are shown in the figure below. The full width at half maximum (FWHM) of the pulse is coincidence well with the Pulse Power Meter, the result are shown in Fig. 4.

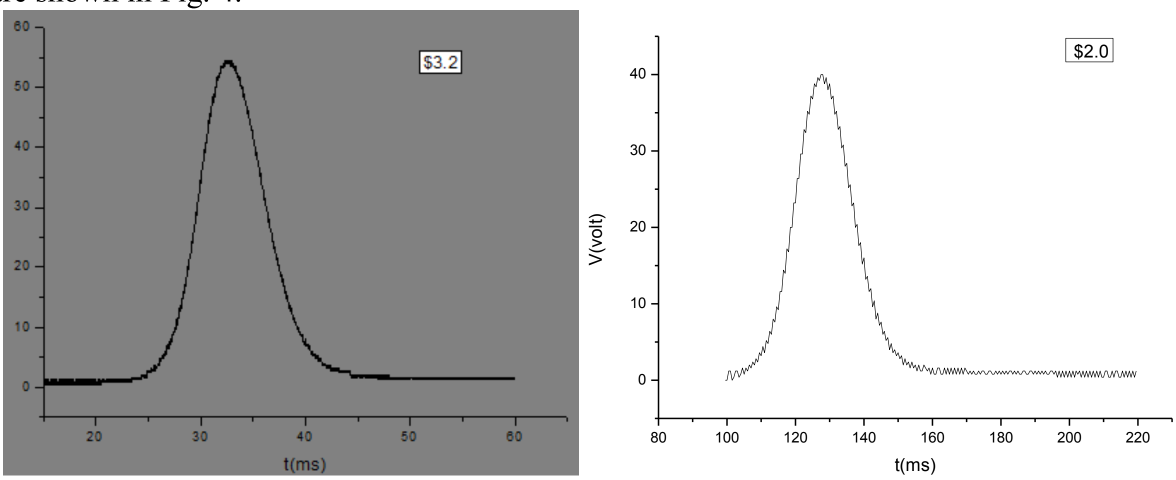

Fig. 4. Results for \$3.2 and \$2.0.

The current signal pulse in diamond and trailing-edge within a certain time has been integrated and normalized according to the activation measuring result of the cumulative neutron flux in different period of time, the analysis results are shown in table 2.

The current signal of single crystal diamond detector can reflect the changing of neutron flux over time, thus the radiation information such as accumulative neutron injection and peak neutron flux in different time periods can be obtained.

Therefore, the current diamond detection system can be used to monitor the neutron injection rate in the irradiated experimental device, and the output amplitude of the pulse signal is relatively linear to reflect the peak injection rate.

Table 2. Result for \$3.2 and \$2.0

Reactivity (\$)	FWHM (ms)	Accumulative Neutron (neutrons*cm^{-2})	Peak Neutron Flux (neutrons*cm^{-2}*s^{-1})
3.2	9.8	8.32 E+12	7.42E+14
2.0	15.3	4.71 E+12	2.86 E+14

Conclusion

The single crystal diamond detection system adopted working in current mode can be used to monitor the pulse neutron flux in the displacement damage effect experiment apparatus , so as to obtain radiation parameters, such as full width at half maximum, neutron flux over time.

References

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