NUCLEAR REACTION ANALYSIS BY USING QUASI- ELASTIC SCATTERING OF ULTRA LOW INTENSITY ELECTRON BEAMS

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Abstract

High sensitivity nuclear reaction analysis method has been developed by the use of direct nuclear reaction (e,e') with electron bombardment. Huge X-ray burst caused by the bremsstrahlung could be suppressed by the use of ultra low intensity electron beams. Consequently, the neutron emitted by (e,e'n) reaction was measured successfully. The linearity between the neutron count and the concentration of target element was verified experimentally. The method is considered to be useful for the non-destructive analysis of heavy elements such as U and Th.

INTRODUCTION

A beam pulse of an ordinary electron linear accelerator has about 10^{13}electrons. In some cases, the radiation is too intensive. We have attempted to develop an ultra low intensity electron beam system by modifying an electron linear accelerator [(1)]. The minimum beam charge about several aC/pulse has been generated [(2)]. The accelerated electrons are basically mono-energetic, controllable, collimatable and synchronized with the accelerator, which are more favorable features compared with those of β-ray sources. In this study, a new analysis method has been developed by the use of the ultra low intensity electron beam developed.

NUCLEAR REACTION INDUCED BY ELECTRON BOMBARDMENT

Energetic electron beams higher than several MeV occasionally induce direct nuclear reactions with the target nuclei. These processes are attributed to the quasi-elastic scattering of electrons (e,e') with the target nuclei and similar to the photo-nuclear reactions. Theoretically, the reactions are explained that the bremsstrahlung emitted near the nucleus with the electron bombardment (virtual photon) interacts to the same nucleus directly. The experimental results for heavy elements were few, because the reaction becomes to the competitive process with the normal photo-nuclear reaction by the bremsstrahlung emitted from neighboring nuclei. Figure 2 shows an experimental data of electron-disintegration (e,e'n)+(e,e'f) cross section for ^{238}U [(3)] and photo-fission cross section of ^{238}U [(4)]. The figures show that the (e,e') cross section are about one order of magnitude small in comparison with that of the photo-nuclear reaction. However, the following advantages are considered for the purpose of developing a practical nuclear reaction analysis method.

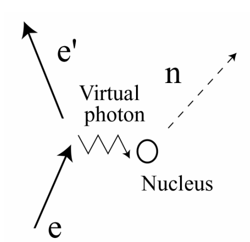

Figure 1: Quasi-elastic scattering of electron

1) The characteristics of the (e,e') reaction are similar to the photo-nuclear reaction. For instance, the both have the same threshold energy. Therefore, the nuclear reaction analysis by using (e,e') reaction has characteristics similar to that of the photo-nuclear reaction analysis. The (e,e') reactions are considered to be effective for analyzing of heavy elements such as U and Th.

2) In the case of the tracer level analysis, the total amount of X-ray burst is far less than that of the photo-nuclear reaction analysis. The X-ray burst is the most harmful phenomenon for the radiation measurement system used in the electron bombardment experiment. In the case of the photo-nuclear reaction analysis, the electron beams are completely transformed to X-rays by a X-ray target, while only partial electrons are transformed to X-rays in the case of the (e,e') analysis.

3) Electron beams are capable of focusing and scanning electrically. The method is considered to be easy of developing to a 2-dimensional analysis method only by the scanning of electron beam.

In the next section, the feasibility of the neutron detection with the electron bombardment are examined experimentally.

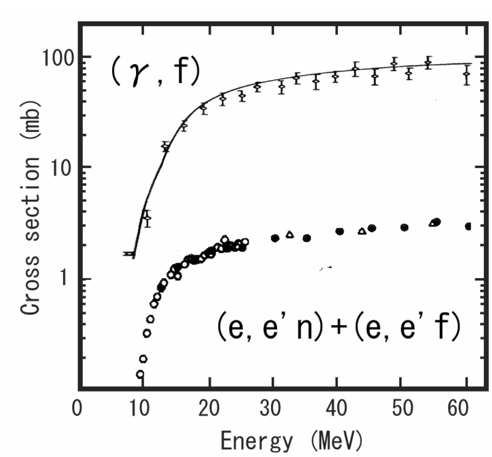

Figure 2: Photo-fission cross section [(4)] and electro disintegration cross section[(3)] of ^{238}U.

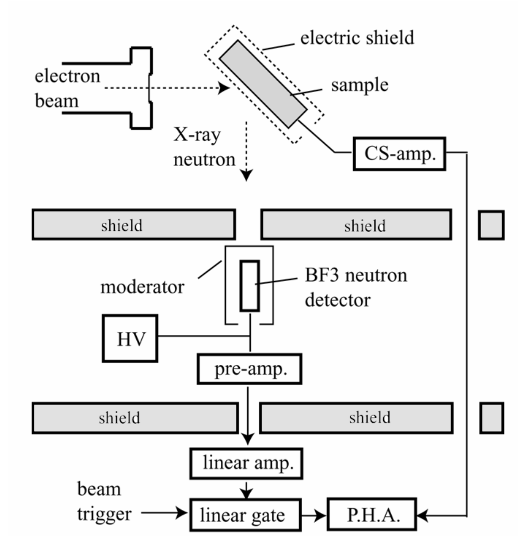

Figure 3: Experimental layout for the neutron detection accompanied with the (e,e') reaction.

NEUTRON DETECTION

Figure 3 shows the experimental layout of the neutron detection system. The neutrons emitted by the electron irradiation passed through a collimator and injected a moderator at a distance of about 2 m from the target. The neutrons were thermalized in the moderator and measured by a BF_3 neutron detector centered in the moderator. The output signals of the pre-amplifier were sent to a linear amplifier set outside of the shielded room. Finally, the signals were analyzed by a multi-channel pulse-height analyzer (PHA). Simultaneously, the beam charges of electrons deposited in the target were monitored by a high sensitivity charge-sensitive amplifier.

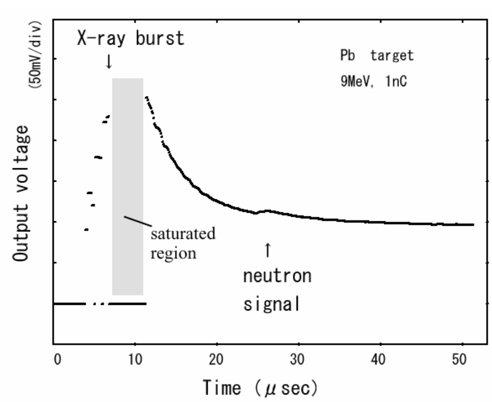

Figure 4: Output signal shape from the preamplifier of the BF_3 detector with electron irradiation.

X-ray Burst

Generally, high energy electron irradiation accompanies with strong X-ray caused by bremsstrahlung. Especially in the case of pulse beam accelerator such as an electron linear accelerator, they appear as a huge X-ray burst. It has been severe problem for radiation measurement, even in the case of the ultra low intensity electron beam. First, the effect of the X-ray burst on the neutron detection system was tested experimentally. Figure 4 shows an example of the output pulse shape of the BF_3 pre-amplifier at Pb target irradiation. In the left side of the figure, a large and distorted pulse appeared and a tiny neutron signal was seen after the X-ray burst. The charge of electron beam irradiated was only about 1nC, which was about three order of magnitude low compared with that of the normal electron beam. Nevertheless, a neutron detection system was not considered to operate normally under the condition. Some method for reducing the large response of the X-ray burst was required. In this study, we tried to reduce them by the use of a linear gate technique. The generation timing of the X-ray burst was fixed at the time of electron irradiation, while the thermal neutron signal was delayed about few tens micro-second correspond to the thermalization time of the fast neutron. In the detection system used, the response of the X-ray burst could be reduced by the use of the linear gate circuit inserted between the linear amplifier and the PHA. Regretfully, the X-ray burst such as shown in Fig.4 could not be reduced completely by this method, since the large burst signals were distorted and unstable. Then, the electron beam was additionally weakened by about twenty times. Figure 5 shows the result. The horizontal axis indicates the pulse height and the vertical shows the counting rate in logarithm. Figure 5(a) is a pulse height distribution with opening the gate. The pulse height of X-ray burst was larger than that of neutron signals even for an ultra low intensity electron such as about 50pC beam. However, these events were completely eliminated by closing the gate (see Fig.5(b)), while the pulse height distribution of the neutron was not degraded.

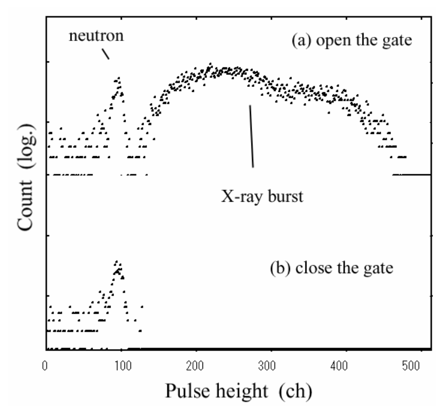

Figure 5: Effect of the linear gate operation.

Weakening of Electron Beam

The linear gate method was effective for reduction of the X-ray burst signal at the thermal neutron detection. However, the method can not apply on the other radiation measurement without the delay time such as fast neutrons and prompt γ-rays. Then, the suppression of the X-ray burst was attempted only by weakening of electron beam. Figure 6 shows the results. The figure shows pulse height distribution of the BF_3 detector for Pb target irradiation with electron charge of , (a) 150pC, (b) 40pC, (c) 15pC, (d) 5pC respectively. The linear gate was opened in all cases. The pulse height of the X-ray burst seemed to be lower according to weakening of the electron beam. Finally, the response disappeared in the case of 5pC beam, while the neutron response was remained at the same position. These results suggested that the X-ray burst could be reduced only by weakening of electron beam. The fast neutron and secondary γ-ray accompanied with the electron bombardment would be measured by the use of this method.

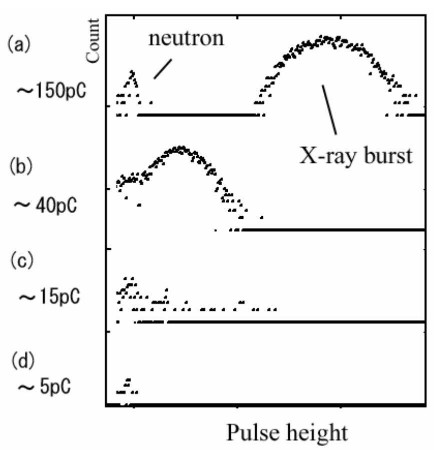

Figure 6: Effect on the pulse height of X-ray burst by weakening of electron beam without gating.

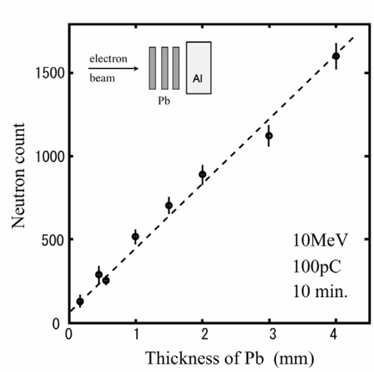

Figure 7: Relation between the neutron detection and the thickness of the Pb layer.

Detection Sensitivity

The relation between the neutron detected and the mass of the target element was examined by the use of the same experimental setup. The diameter of the electron beam was estimated about 3mmφ. Pb thin sheets were used for the target. Figure 7 shows the results. Nearly linear relation was obtained between the neutron and the thickness of the Pb layer. By considering of the beam spot size, one neutron detected by the system corresponded to the 170μg of Pb in the target.

Next, the U and Th sensitivity was measured. The following two samples were prepared, (1) monazite powder, (2) power of refractory bricks respectively. By the use of γray analysis, the sample (1) was estimated to contain 9mg U, 15mg Th and the sample (2) was 0.8mg U, 0.31mg Th. The sample was put into a polyethylene pouch with the surface of 3.5×3 cm^2 and analyzed by the electron irradiation. The results show in Fig.8. The excess neutron could be measured only in the case of sample (1). The results show that one neutron count corresponded to the 8μg of U+Th in the target. The sensitivity was evaluated about 30μg for U+Th by considering of statistical uncertainty.

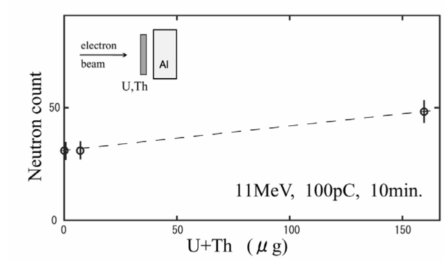

Figure 8 :Relation between the neutron and the mass of U and Th.

CONCLUDING REMARKS

High sensitivity nuclear reaction analysis system by the use of direct nuclear reaction (e,e') has been developed. The effect of X-ray burst caused by bremsstrahlung could be eliminated by the use of the ultra low intensity electron beams. The linearity between the neutron count and the concentration of target element was verified experimentally. The sensitivity was evaluated about 30μg for U,Th. The method is considered to be useful for the non-destructive analysis of heavy elements. In the next step, a two-dimensional analysis will be attempted by scanning of electron beam.

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