実験報告書様式（一般利用課題・成果公開利用）

（ ※本報告書は英語で記述してください。ただし、産業利用課題として採択されている方は日本語で記述していただいても結構です。 ）

| MLF Experimental Report | 提出日 Date of Report<br>June 25, 2013 |
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| 課題番号 Project No.<br>2012B0250<br>実験課題名 Title of experiment<br>Study of neutron radiation hardness of Hybrid Avalanche Photo Detector for the Belle-II experiment<br>実験責任者名 Name of principal investigator<br>角野 秀一 Hidekazu Kakuno<br>所属 Affiliation<br>首都大学東京 Tokyo Metropolitan University | 装置責任者 Name of responsible person<br>及川健一 Kenichi Oikawa<br>装置名 Name of Instrument/(BL No.)<br>BL-10<br>実施日 Date of Experiment<br>2013 Feb. 16 – 2013 Feb. 19,<br>2013 Mar. 9 – 2013 Mar. 11 |

試料、実験方法、利用の結果得られた主なデータ、考察、結論等を、記述して下さい。（適宜、図表添付のこと）

Please report your samples, experimental method and results, discussion and conclusions. Please add figures and tables for better explanation.

1. 試料 Name of sample(s) and chemical formula, or compositions including physical form.

No samples are used in this experiment

2. 実験方法及び結果 （実験がうまくいかなかった場合、その理由を記述してください。）

Experimental method and results. If you failed to conduct experiment as planned, please describe reasons.

Hybrid Avalanche Photo Detectors (HAPDs) are used as the photon sensor of the Aerogel Ring Image Cherenkov (A-RICH) Counter at the Belle-II experiment. At the Belle-II experiment, high beam luminosity cause high fast neutrons flux, and any detector components are required to have sufficient neutron radiation hardness. HAPDs are made of Avalanche Photo Diodes (APDs). The fast neutrons could cause displacement damage in the bulk part of the APD. At the previous experiment (2012A0154) we tested the neutron radiation tolerance of the HAPD that is used for the mass production, and we found that the HAPD have sufficient performance up to 0.85 x 10^12 neutrons/cm^2 for 1MeV equivalent number of neutrons, while at the most recent Monte-Carlo simulation of Belle-II shows that the integrated neutron flux at the Belle-II is above 1x10^12 neutrons/cm^2 for 1MeV equivalent neutrons. The aim of this experiment(2012B0250) are :(1) to check the neutron radiation tolerance for the HAPD with 1x10^12 neutrons/cm^2 or more, (2) to check the sample or rod dependence of neutron radiation tolerance, and (3) to find a HAPD that have different specification and that have better neutron hardness.

We made four new HAPDs that are used for this experiment. One HAPD have same specification as the one used at 2012A0154 but is made from the different wafer. Other three HAPDs have different specification from those used at 2012A0154, and are used to find any new specification in terms of the better neutron radiation hardness.

## 2. 実験方法及び結果（つづき） Experimental method and results (continued)

At this experiment (2012B0250), those four HAPDs are set in a row in the neutron beam line. Total neutron flux is measured using small diodes that have known relation between neutron dose and leakage current. Fig.1 shows the measured total neutron flux at this experiment. This neutron flux is the total flux of two irradiation periods, 2013 Feb. 16 – 2013 Feb. 19 and 2013 Mar. 9 – 2013 Mar. 11. The total neutron flux (number of 1MeV equivalent neutrons / cm^2) is measured to be 2 x 10^12 neutrons / cm^2 for most upstream HAPD and 1 x 10^12 neutrons for most downstream HAPD. These numbers correspond to the total neutron dose estimated for the 10 years operation (or more) at the Belle II experiment.

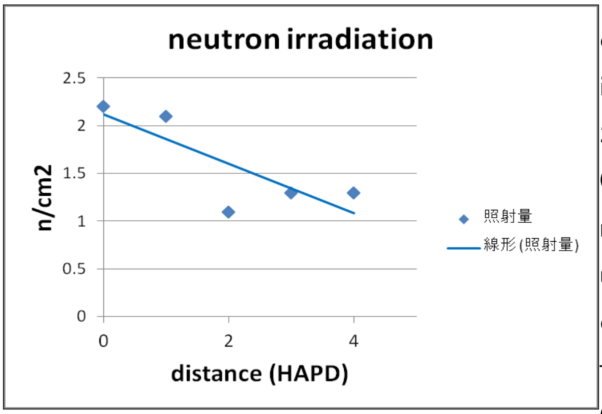


Fig. 1: Total neutron flux. VS ID of diodes.(upstream: ID=0, downstream: ID=4)

Performance of the HAPDs are checked before the neutron irradiation, right after the first irradiation period, one week after the first irradiation period, before the second irradiation, right after the second irradiation period, one week after the irradiation period, and one or two month after the second irradiation period. The performance check consists of measurement of the leakage current, measurement of the noise, and measurement of the gain for single photon. Fig. 2 shows the result of the leakage current measurement as a function of time. We found that the increase of the leakage current right after the irradiation is similar for all four types of HAPDs. We also found that the leakage current gradually decreases after stopping the irradiation for two HAPDs and increases for the rest two HAPDs. This result indicate that not only the bulk part but also surface part of APD can affect the neutron radiation hardness, since differences among these HAPDs are only in the surface part of the APD.

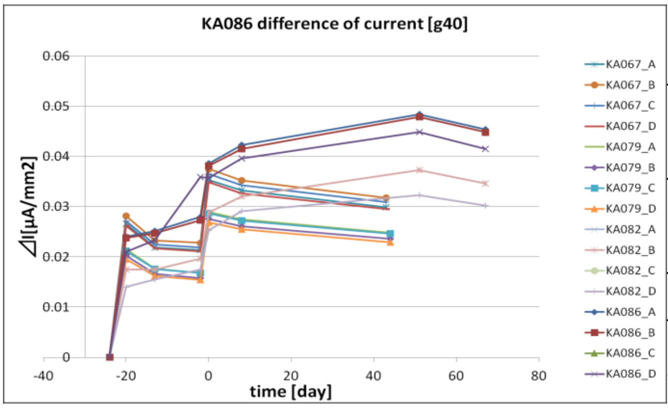


Fig.2: Leakage current VS　time (−20 day :first irradiation, 0 day: second irradiation)

The noise is measured as charge to be 7x10^3 electrons for the most upstream HAPD that is irradiated to 2.0x10^12 neutrons/cm^2. This result can be compared to the result at 2012A0154, where the noise is measured to be 4x10^3 electrons at 0.85x10^12 neutrons/cm^2. Increase of the noise is as expected and we found no sample dependence. The signal gain of the HAPD is measured using LED as the light source and signal-to-noise ratio (S/N) is measured to be 4.3 for the most upstream HAPD that is irradiated to 2.0x10^12 neutrons/cm^2. This S/N is acceptable as the photon sensor of the A-RICH counter at the Belle II experiment.

We conclude that the HAPD have sufficient neutron radiation hardness for the Belle II experiment.