MLF Experimental Report	提出日 Date of Report 2015/11/13
課題番号 Project No. 2014B0120 実験課題名 Title of experiment Error rate evaluation of MRAM with perpendicular magnetic tunnel junction under fast neutron irradiation 実験責任者名 Name of principal investigator Yuzuru NARITA 所属 Affiliation Yamagata University	装置責任者 Name of responsible person Kenichi OIKAWA 装置名 Name of Instrument/（BL No.） NOBORU (BL No. 10) 実施日 Date of Experiment 2014/12/15〜2014/12/16 2015/ 3/20〜2015/ 3/23

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.

In this study, 436 p-MTJ (magnetic tunnel junctions with a perpendicular magnetic easy axis) devices equipped with an MgO/CoFeB/Ta/CoFeB/MgO double-interface recording structure formed on a 40×40 mm^2 (3-inch) SiO_2/Si wafer (Fig. 1) were fabricated at Tohoku University. Each p-MTJ has a stacked profile structure from the SiO_2/Si substrate side: Ta (5)/Ru (10)/Ta (5)/Pt (5)/[Co (0.4)/Pt (0.4)]$_6$/Co (0.4)/Ru (0.4)/[Co (0.4)/Pt (0.4)]$_2$/Co (0.4)/Ta (0.3)/CoFeB (1.0)/MgO (1)/CoFeB (1.6)/Ta (0.4)/CoFeB (1.0)/MgO (1)/Ta (5)/Ru (5), where the numbers in parentheses are the nominal thickness in nanometers, and the subscripts indicate the number of Co/Pt multilayers. The stack is processed into circular D = 40 nm MTJs using electron beam lithography and Ar ion milling, followed by annealing at 300 °C under vacuum with a perpendicular magnetic field of 0.4 T for 1 h. The sample was the same as that used in the 2014A0102 experiment.

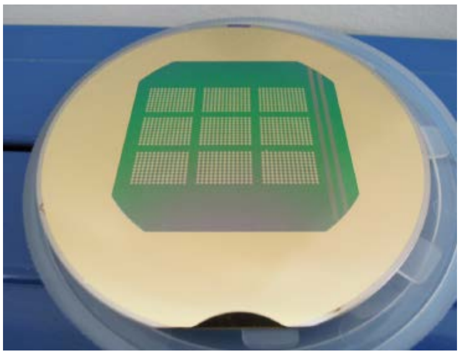

Fig. 1: Photograph of p-MTJ device.

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.

The neutron irradiation experiment was conducted using the BL10 beamline. The neutron beam irradiation area was approximately 80×80 mm^2. Low-energy neutrons were separated from the neutron beam using 5-mm-thick B4C slits while gamma radiation was blocked using a 25-mm-thick Pb block. During irradiation, gamma radiation was monitored using an alanine dosimeter set near the p-MTJs within the beam irradiation area. The tunnel magnetoresistance (TMR) ratio for each p-MTJ was determined from resistance-magnetic field (R-H) measurements.

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

In this experiment, fast neutron irradiation of p-MTJ devices with D = 40 nm was performed for 4 days. The beam time was used in two separate periods (1 day + 3 days) to measure the influence of fast neutron irradiation. The beam powers of the first (2014/12/15 – 2014/12/16) and second (2015/3/20 – 2015/3/23) periods were 0.3 and 0.4 MW, respectively. The total fast neutron fluence (1 MeV equivalent neutrons/cm^2) with BL-10 was calculated to be 2.1×10^{12} neutrons/cm^2 in this study. The number of neutrons irradiated on a junction with D = 40 nm was approximately 26.

In the 2014A0102 experiment, a single p-MTJ junction with D = 40 nm was irradiated with a total of approximately 5 fast neutrons. Figure 2(a) shows a comparison of the TMR ratios before and after irradiation with 5 fast neutrons. 436 p-MTJ devices with TMR ratios above 70% were used. After irradiation with 5 fast neutrons, the TMR ratio of two p-MTJ devices was significantly improved; however, the TMR ratio of the other devices slightly deteriorated. In this experiment, a single p-MTJ junction with D = 40 nm was additionally irradiated with approximately 26 fast neutrons, where the same sample from the 2014A0102 experiment was used. Figure 2(b) shows a comparison of the TMR ratios before and after irradiation with 31 (5+26) fast neutrons. The TMR ratios before irradiation on the horizontal axis were the same as those in Fig. 2(a). After irradiation with 31 fast neutrons, the TMR ratios for many of the p-MTJ devices were changed. Although a slight degradation was observed for devices with an original TMR ratio of >90%, a significant improvement was observed for devices with an original TMR ratio of approximately 70%. While the main cause of this phenomenon has not yet been elucidated, the effect of fast neutrons irradiated to the p-MTJ devices correlates with a change in the TMR ratio. To obtain more reliable results, we will continue this experiment in the 2015A proposal round.

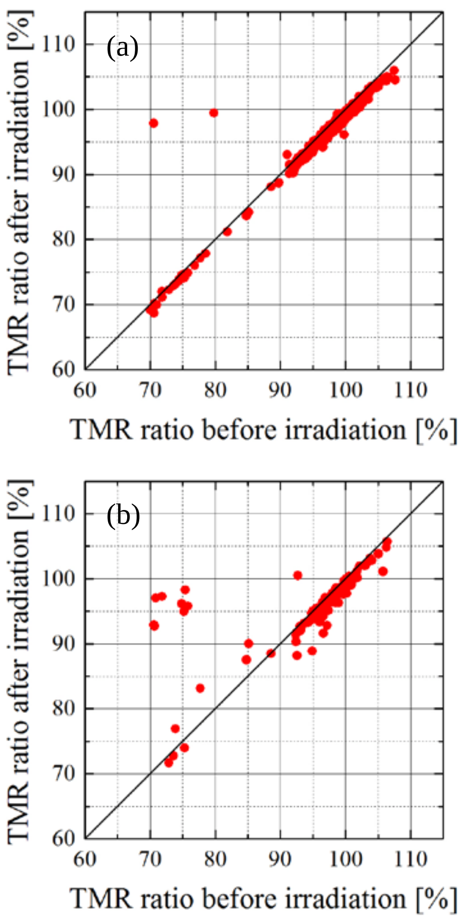

Fig. 2: Comparison of TMR ratio before and after fast neutron irradiation. One p-MTJ junction with D = 40 nm was irradiated with approximately (a) 5 and (b) 31 (5 + 26) fast neutrons.