MLF Experimental Report	提出日 Date of Report
課題番号 Project No. 2010A0034 実験課題名 Title of experiment High Magnetic Field Neutron Diffractions in Frustrated Multi-ferroics 実験責任者名 Name of principal investigator Hiroyki Nojiri 所属 Affiliation Institute for Materials Research, Tohoku University	装置責任者 Name of responsible person Fujio Maekawa 装置名 Name of Instrument/（BL No.） BL10 実施日 Date of Experiment 2010.10.18-2010.10.20 2010.11.07–2010.11.15

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.

$MnWO_4$ single crystal
$BiFeO_3$ single crystal

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 purpose of our experiment is to conduct neutron diffraction in very high magnetic field above 40 T and to investigate the mechanism of multi-ferroic compounds. In the previous proposal: 2009B0019, we have made the first application of pulsed magnetic field up to 40 T on the standard sample of NaCl. We have also examined the magnetic structure of multi-ferroic compound $BiFeO_3$, however, for the weak intensity of the beam, it has not been completed.

In the present proposal, we have conducted two experiments, (1) Investigation of magnetic structure change of multi-ferroic compound $BiFeO_3$ at the metamagnetic like transition, (2) Investigation of an field induced incommensurate-commensurate transition in $MnWO_4$. The beam intensity at this period is about 100 kW and so the intensity is not very strong. Considering this, we have used most of the time for the subject one. Despite the lack of the intensity, the system works fine and the experimental procedure for the high magnetic field neutron diffraction has been established up to 40 T. It is the world record of high magnetic field in neutron diffraction. An important technical improvement is that we have enabled the back scattering condition where the scattering vector is parallel to the magnetic field. By using the back scattering and forward scattering, we can know more information about the spin orientation, since the orientational factors are different in two cases.

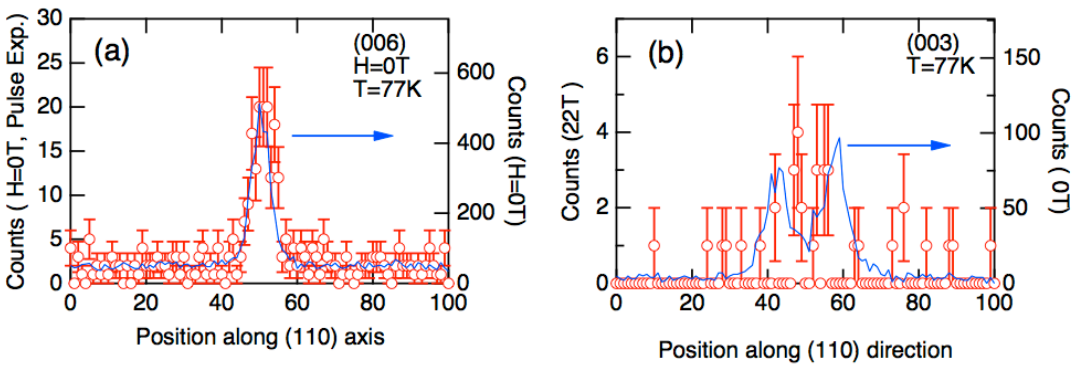

Fig. 1 (a) Nuclear Bragg peak (006), (b) Comparison between (003) magnetic Bragg peaks at 0 T and at 22 T.

$BiFeO_3$ is one of most welknown multiferroic compounds with both ferroelectric and magnetic transition temperatures are above room temperature. It exhibits one of highest electric polarization values, including archetypal ferroelectric materials. There have been enormous studies that went into basic understanding of its physical properties. However, one of the most notable properties from the viewpoint of magnetism is that it undergoes an antiferromagnetic transition at 650 K with an extremely large period of 630 Å. The origin of this incommensurate structure is believed to be a competition between exchange interaction of neighbouring Fe moments and Dzyaloshinskii-Moriya interaction.

According to recent studies, magnetization shows a metamagnetic transition around 20 T, above which the magnetoelectric current displays a drop of about 40 nC/cm^2. This transition is conjectured to be due to a metamagnetic transition, above which the magnetic structure becomes collinear.

We report on the field dependence of magnetic (003) peak by using the pulsed magnetic field set up at Noboru of J-PARC. To have a good resolution, we set the sample in the back scattering condition with longer wave length and in fact we can see the clear splitting for incommensurate structure. In Figure (a) and (b), we plotted the data of nuclear (006) and magnetic (003) Bragg peaks taken at zero field and 22 Tesla. The zero field data were accumulated for 15 min, whereas we had to spend as much as 48 hours of beam time for the high field experiment: the repetition rate of our pulsed magnet was just over 2 min. First of all, we note that within the experimental resolutions we did not observe any change in the peak position of the nuclear (006) peak. It indicates the lattice clamping at the transition is very small.

The zero field data of the magnetic (003) peak in Fig. 1 (b) displays a clear splitting due to the incommensurate magnetic structure of Q=[0.0045 0.0045 0]. Upon increasing magnetic fields above the metamagnetic transition, it is found that the splitting does not change much but the intensity decreases about 30 %. Note that the magnetic moments perpendicular to the magnetic field contributes to this scattering in the back scattering condition. This means that the field perpendicular component does not increase at the transition. As a result, we speculate that the transition is caused by the modulation of the incommensurate pitch and not by the simple flip of the magnetic moments.

In conclusion, we have examined the change of magnetic structure at the metamagnetic transition in $BiFeO_3$ and found that the high magnetic field phase is also incommensurate phase.