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 2011/07/15
課題番号 Project No. 2010A0008 実験課題名 Title of experiment Spin dynamics of new multiferroic $BiFeO_3$ single crystal 実験責任者名 Name of principal investigator Je-Geun Park 所属 Affiliation Seoul National University, Korea	装置責任者 Name of responsible person Je-Geun Park 装置名 Name of Instrument/（BL No.） AMATERAS/BL14 実施日 Date of Experiment 2011/11/07 – 2011/11/12 2011/11/15 – 2011/11/19

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.

Bismuth ferrite, $BiFeO_3$

9 pieces of single crystal coaligned with the total mass of about 1.7g

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.

Recent discoveries that certain materials can have both magnetic and ferroelectric ground states, so-called multiferroic materials, have led to surge of interest in this rather unusual class of materials. With immensely huge future applications as well as some fundamental issues, these multiferroic compounds have recently become one of most challenging topics in the condensed matter physics [1].

Although several systems are now known to have multiferroic behavior, there are very few multiferroic materials that have both magnetic and ferroelectric transition temperatures above room temperatures. Probably $BiFeO_3$ is the only one exception with Neel temperature at T_N=650 K and Curie temperature at T_c=1100 K [2]. Furthermore, it has been reported to have extremely large polarization when made in thin film [3].

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

One of fundamental issues about these multiferroic materials is how such an unusual coexistence of magnetism and ferroelectric is realized despite a long-held and traditional view precluding such a possibility. For example, one of the two key mechanisms of ferroelectricity, the ligand-field hybridization specifically requires that d orbitals are fully unoccupied. The other issue is how the seemingly separate order parameters are interconnected, allowing control of one by the other, or associated conjugated fields of E or B.

Regarding these two fundamental questions, a spin-lattice coupling was suggested to play some important role, understanding of which is going to be crucial in furthering our current knowledge of these technically as well as scientifically challenging class of materials [4].

The aim of this experiment was to study the spin dynamics by taking advantage of the large single crystal and provide the basic spin Hamiltonian describing the spin dynamics. This information will then be used to address some of the key questions of multiferroic compounds such as a possible spin-lattice coupling. For this experiment, we aligned 9 pieces of $BiFeO_3$ single crystal using FCD beamline at the HANARO, KAERI with the total mass of about 1.7g.

We performed the first two experiments for 42 hours at a base temperature of 4 K and for 39 hours at 290 K with the incident beam parallel to the [001] direction. In order to cover the wide range of energy in the dispersion curve, we choose the incident energies at 94.154, 23.630, 10.513 and 5.9178 meV.

In the figures below, we have plotted momentum-energy graphs along the [0,h,0] and [2k,-k,0] directions, respectively. As one can see, all the data show clear signs of magnetic excitations. It is to be noted that such signatures appears in energies greater than 60 meV along the [0,h,0] direction.

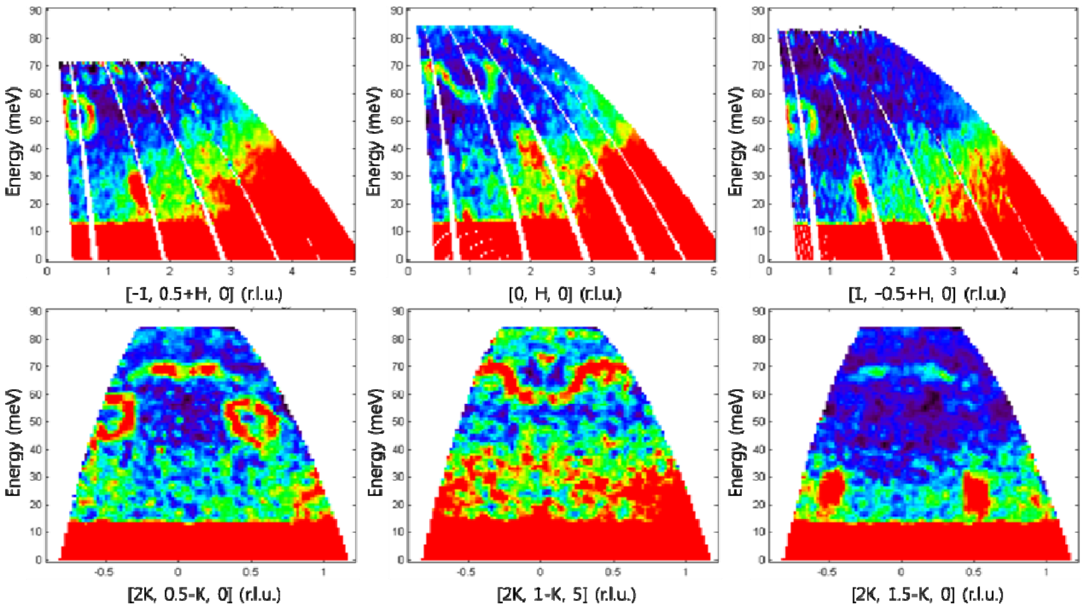

Fig. 1. Representative data cut along the [0,H,0] and [2K,-K,0] directions

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

We note that rather unusual shape of excitations is observed simply because we are cutting particular trajectory in the E-Q space for a three-dimensional spin-wave. To analyze these data, we calculated the energy of particular excitations as shown in Fig. 2 and the resulting experimental spin wave is shown in Fig. 3. For comparison, we have also added data points from MAPS experiment in the figure. As one can see, the overall agreement between the two data sets is noticeable.

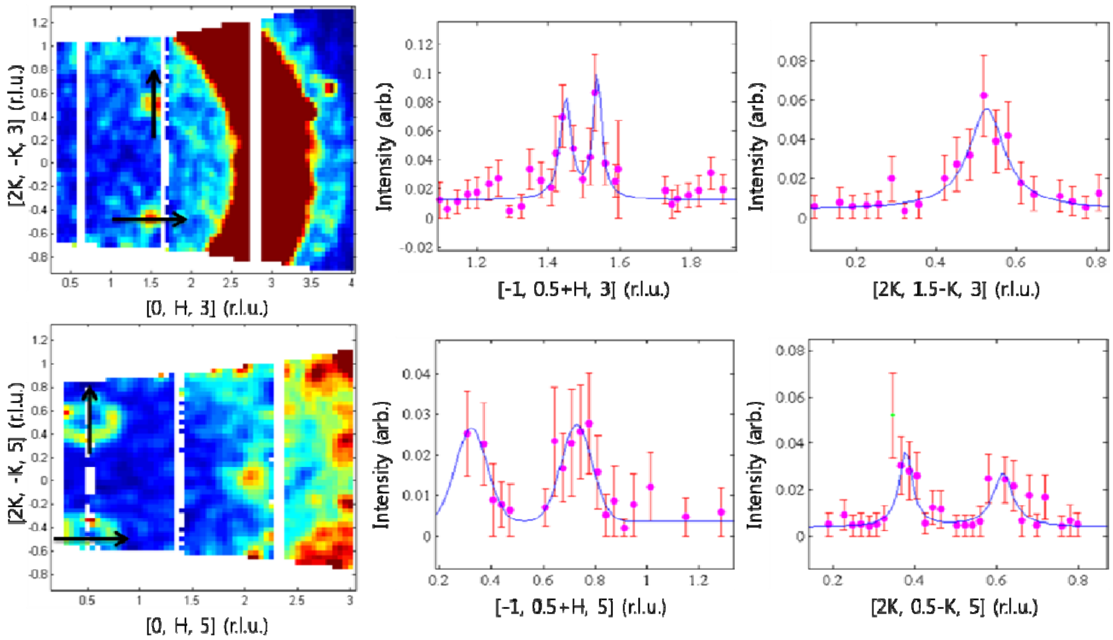

Fig. 2. Representative data (middle and right) are taken from the data shown on the left.

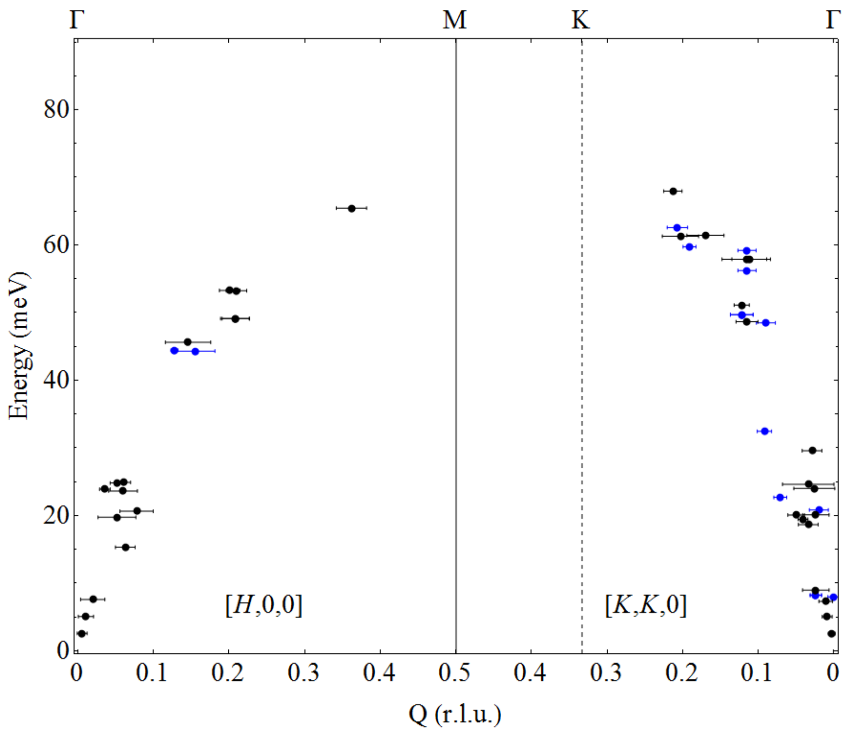

Fig. 3. Experimental spin-wave

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

In order to analyze the data further, we are currently carrying out theoretical calculations of spin wave using various Hamiltonians. At the same time, we plan to carry out further experiments to map out the entire three-dimensional spin-wave.

[1] S-W. Cheong and M. Mostovoy, Nature Materials **6**, 13 (2007)

[2] I. Sosnowska *et al.*, J. Phys. C: Solid State Phys. **15**, 4835 (1982)

[3] J. Wang *et al.*, Science **299**, 1719 (2003).

[4] Seongsu Lee, J-G Park *et al.*, Phys. Rev. B **71**, 180413(R) (2005) ; Nature **451**, 805 (2008)