実験報告書様式（一般利用課題・成果公開利用）

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CROSS TOKAI **Experimental Report** J-PARC	承認日 Date of Approval 2016/6/22 承認者 Approver Ryoichi Kajimoto 提出日 Date of Report 2016/6/22
課題番号 Project No. 2015A0029 実験課題名 Title of experiment Search for ferromagnetic fluctuations in p-wave superconductor Sr_2RuO_4 実験責任者名 Name of principal investigator K. Iida 所属 Affiliation CROSS	装置責任者 Name of Instrument scientist R. Kajimoto and M. Ishikado 装置名 Name of Instrument/（BL No.） BL01 実施日 Date of Experiment 9/6/2016 – 15/6/2016

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.

Co-aligned five single crystals Sr_2RuO_4 using ^3He cryostat.

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.

First of all, we would like to appreciate K. Kuwahara, S. Itoh, and K. Kaneko for ^3He cryostat, goniometer, and motor driver, respectively. In addition, we also thank A. Nakao, K. Munakata, M. Ishikado, and Y. Inamura for their help on ^3He cryostat. Co-alignment of crystals was done by help from T. Moyoshi. Because we need special condition (T < 1 K), we could not perform our experiment without their help. We would also appreciate MLF technical staffs. The vacuum pump at 4SEASONS was broken, and they replaced the pump very quickly even though it happed on Sunday.

Despite many theoretical and experimental studies done since the discovery of superconductivity below T_c = 1.5 K, the origin of the superconductivity in a strontium ruthenate, Sr_2RuO_4, is still under debate. The t_{2g} electrons of Ru^{4+} ions form three bands near the Fermi surface. The d_{xz} and d_{yz} orbitals form quasi-one-dimensional α and β sheets while the d_{xy} orbital forms a two-dimensional γ sheet. The former sheets generate incommensurate (IC) magnetic fluctuations while the latter appears as ferromagnetic fluctuations. The

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

superconducting order parameter was proposed to be a *p*-wave state with a chiral $p_x \pm ip_y$ symmetry; the origin of the *p*-wave superconductivity was originally thought to be ferromagnetic fluctuations due to the γ sheets. To examine this scenario, several experiments were done, but they are not fully consistent. The imaginary part of dynamic spin susceptibility obtained by inelastic neutron scattering measurements mainly shows the IC magnetic fluctuations around **Q** = (0.3, 0.3, *L*), and their properties do not change below and above T_c. On the other hand, in ^{17}O-NMR measurements, $^{17}1/T_1$ shows ferromagnetic correlations. To investigate this issue, we performed time-of-flight neutron scattering measurements on superconducting state in Sr_2RuO_4.

We used co-aligned five single crystals for neutron scattering measurements as shown in Fig. 1, which was put in a copper sample can (Fig. 2). The can was attached to a ^{3}He cryostat (heliox). The measurements were mainly done at 0.3 and 2.8 K (T_c = 1.25 K). The Fermi chopper was rotated in 200 Hz frequency, giving rise to a set of incident neutron energies of E_i = 7.38, 11.02, 18.20, 35.67, and 99.11 meV. T0 and two disk choppers were operated in the conventional condition. An oscillating radial collimator (2.5°vibration range with speed of 1° in 3 seconds using the “shift mode”) was installed after sample to reduce background. A set of slits was 45(w) – 50(h) – 40(w) – 45(h). Horizontal scattering plane was (*HHL*), and at 0.3 K, we rotate crystals by 100° from both $\mathbf{k}_i$//(001) and $\mathbf{k}_i$//(00-1) directions (200° in total).

As shown in Fig.3, in addition to IC fluctuations at **Q** = (±0.3, ±0.3, 1), we clearly observe additional signals around the Γ point [(001) is not Γ point but “in-plane” Γ point], which is, we believe, the signature of ferromagnetic fluctuations. Note that the peak positions do not locate exactly at **Q** = (0, 0, 1) instead at **Q** ~ (±0.08, ±0.08, 1), which is consisted with the previous band calculation [see Fig. 6 bottom in the reference: N. Kikugawa *et al*., Phys. Rev. B **70**, 134520 (2004)]. Since we performed present experiment under special condition as mentioned above, the background was considerably large. To clarify the origin of the peaks around the Γ point, we are now treating the data as carefully as possible we can. We also plan to perform measurements above T_c with a “low-background” condition, which will provide us the details on fine structure of the ferromagnetic fluctuations.

Figure 1

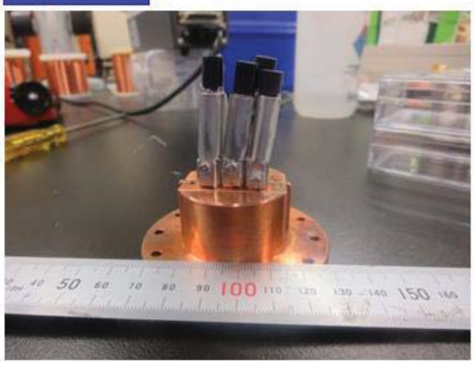

Figure 2

Figure 3

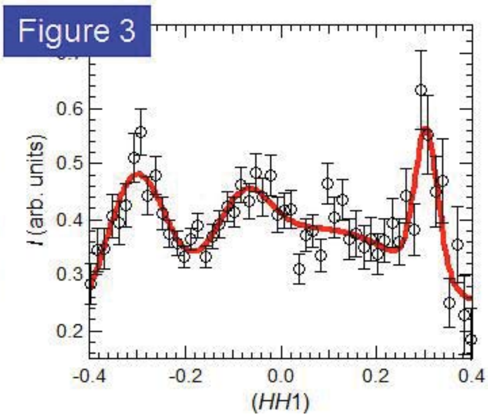

Fig. 1. Picuture of co-aligned Sr_2RuO_4 single crystals. Fig. 2. Sample can attached to the ^{3}He cryostat. Fig. 3. Constant energy cut along (*HH*1). Energy transfer, $K\bar{K}$, and *L* were integrated in [4, 5.5] meV, [-0.06, 0.06] rlu and [0.6, 1.4] rlu. Solid line is given by a Gaussian fitting.