# First Inelastic Neutron Scattering from a $SrRuO_3$ Thin Film

***SIKA** makes it possible to investigate the magnetic property of single-crystal epitaxial thin film with inelastic neutron scattering*

A bulk crystal or multiple crystals of mass of order gram are necessary for a successful detection of extremely weak signals. No successful inelastic neutron scattering (INS) measurement on films has been reported, but most materials are difficult to grow into large high-quality crystals, and some of them can be grown as high-quality single-crystal films. Pushing the INS measurement to the limit of a film is now extremely crucial. Hsiung Chou of National Sun Yat-sen University and his collaborators have used $SrRuO_3$ single-crystal epitaxial thin films (**Fig. 1**) to investigate the magnon dispersion curve in this ferromagnetic system to extend the limitation of INS measurements and to understand better the underlying mechanisms. This limitation imposes a strong constraint on the applicability of neutron inelastic-scattering instruments. Even though many materials can be grown as single-crystal films, their small mass makes this limitation a significant barrier. If the material has, however, a specific property that has a strong correlation with the low excitation phase along a specific direction and is measured with a highly sensitive and low-noise neutron inelastic-scattering instrument, this limitation might be overcome. Taiwan has built a state-of-the-art neutron inelastic-scattering instrument, **SIKA**, in Australian Nuclear Science and Technology Organisation (ANSTO), which has the potential to undertake neutron inelastic-scattering measurement on thin films.

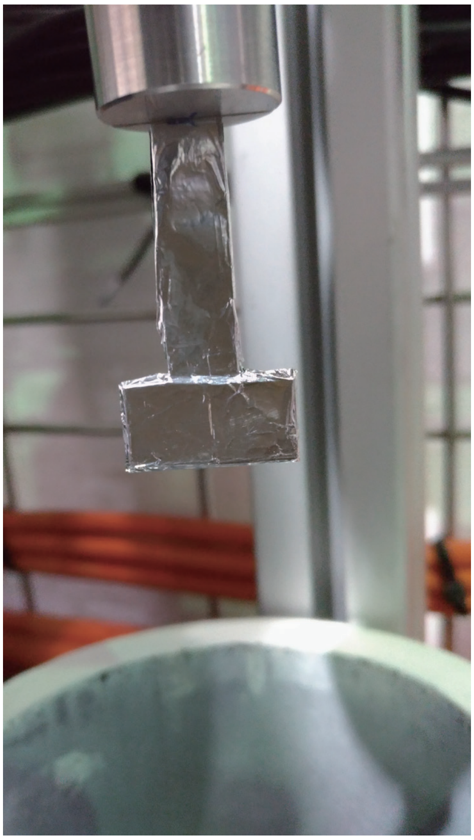

**Fig. 1**: Four 1 × 1 $cm^2$ $SrRuO_3$ films, stacked with the film's surface in contact with each other and placed side by side on an aluminium sample holder. [Courtesy of Chun-Ming Wu]

Chou's group has publised an example[1] on choosing $SrRuO_3$ (SRO), which is one of few itinerant ferromagnetic materials from the 4*d*-transition-metal group widely used as a conducting electrode in multilayer device applications, magnetic tunnel junctions, electronic transport tuning, dynamic random-access memory applications, switchable acoustic-wave resonators and spintronic devices, among others. Unexplained phenomena such as the non-saturated magnetization at a large magnetic field, changing of the sign of Hall coefficients, an unbelievable high upper-limit-temperature ($T \leq 30$ K) for Fermi liquid conduction and non-Fermi-liquid behavior within $90 \leq T/K \leq 150$, are, however, waiting to be explored. Chou's team has hence a great motivation to challenge the unbreakable limitation for inelastic neutron scattering on a thin film as well as to understand the exotic magnon dispersion profile of $SrRuO_3$ films.

To confirm that their observed signal is really contributed by a magnon and not by phonons or instrumental errors, it was necessary to compare the result at high temperature at which the material is in a paramagnetic state.

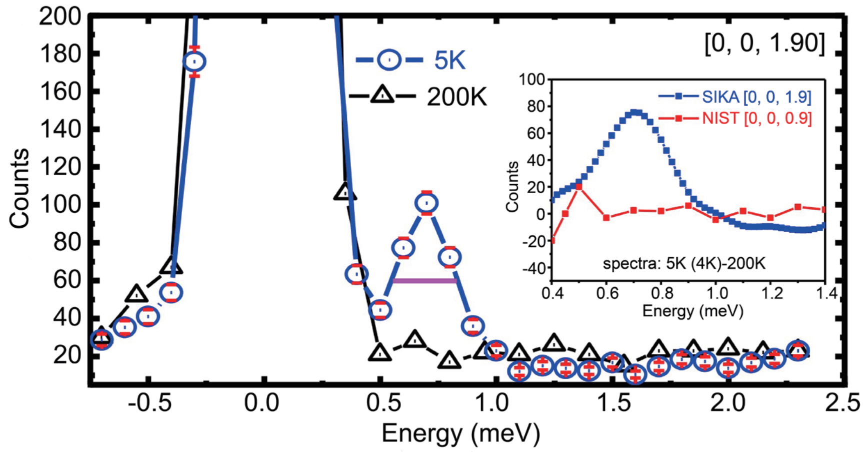


**Fig. 2**: Direction [002] shows the largest count difference, which indicates that the magnon dispersion curve that extends along this direction should the most readily detectable. INS spectra of L = 1.90 at 5 K and 200 K. [Reproduced from Ref. 1]

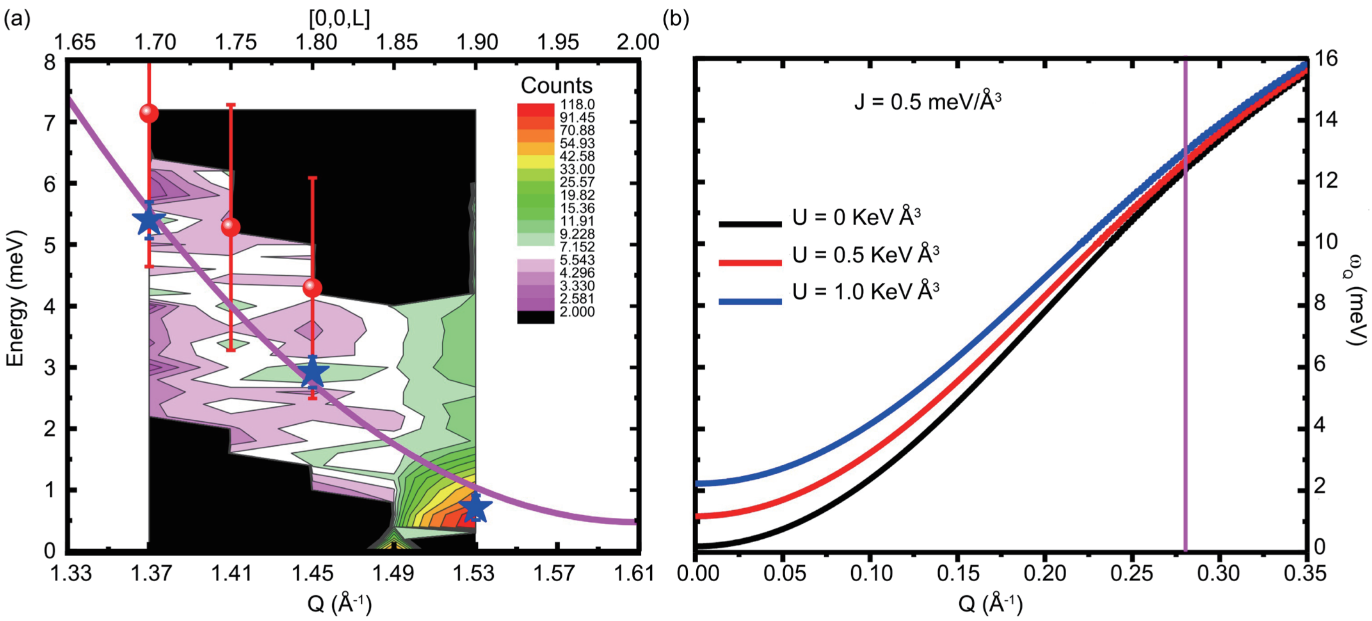


**Fig. 3**: (a) Relation between E and L (or Q). The magnon spectrum follows the dispersion relation ($E \propto Q^2$). The data points presented as red circles are obtained from Ref. 2. The data points obtained from Chou's measurements match well with Ref. 2 and are situated well within their FWHM. (b) Magnon dispersions for varied Coulomb U at temperature T = 0. Magnetic coupling J = 0.5 meV $Å^{-3}$, conduction-band electron density $n_e = 1 \times 10^{-4}$ $Å^{-3}$ and Ru occupation $c_{Ru} = 10^{-3}$ $Å^{-3}$. [Reproduced from Ref. 1]

The same measurement results at 5 K and 200 K are plotted on a linear scale (**Fig. 2**). The center signals at 0 meV overlap perfectly whereas the signal about 0.7 meV at 5 K disappears at 200 K. This observation confirmed a magnon peak and also showed a successful breaking of the concept of an inability to measure INS of films.

Using the present identified magnon signal, they further obtained a dispersion curve, in **Fig. 3**. Fitting the data points with the dispersion relation yielded J = 1.88 meV. This magnon band gap 0.32 meV is much smaller than Itoh's 2 meV[2] and slightly smaller than 1 meV estimated from a FMR measurement calculated from the anisotropy energy estimated with bulk magnetization.

In summary, Chou and his collaborators successfully demonstrated that measuring a low-energy excitation with inelastic neutron scattering on a single crystal film is possible. Because of the strong strain effect at the STO/SRO interface, the crystal structure of SRO was tuned to a tetragonal structure with out-of-plane lattice parameter slightly larger than the in-plane lattice parameter, about 0.1%. This change suppresses the structural distortion and symmetry and produces a smaller magnon gap. (Reported by Chun-Ming Wu)

*This report features the work of Hsiung Chou and his collaborators published in Physical Review B **101**, 054403 (2020).*

### ANSTO SIKA – Cold Neutron Triple-axis Spectrometer

- INS
- Ferromagnetism, Magnon, Inelastic Neutron Scattering, Epitaxial Single-Crystal Thin Film

### References

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2. S. Itoh, Y. Endoh, T. Yokoo, S. Ibuka, J.-G. Park, Y. Kaneko, K.-S. Takahashi, Y. Tokura, N. Nagaosa, Nat. commun **7**, 11788 (2016).