MuSR studies of Mott transitions in $RENiO_3$, V_2O_3 and $Ba(Co,Ni)S_2$: Progress report from the 2016 Reimei project:

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Abstract

With the financial support from the JAEA Reimei Project, Muon Spin Relaxation (MuSR) measurements of Mott transition systems $RENiO_3$ (RE = Rare Earth), V_2O_3 and $Ba(Co,Ni)S_2$ have been performed to study evolution from the antiferromagnetic insulator to paramagnetic metal state via quantum tunings with hydrostatic pressure in V_2O_3 and $BaCoS_2$, and with chemical substitutions in $RENiO_3$ and $Ba(Co,Ni)S_2$. In all these measurements, first-order quantum transition, associated with phase separation, has been found at the quantum phase boundary. In the quantum tuning of $RENiO_3$, V_2O_3 and $BaCoS_2$, static magnetic order is destroyed via the reduction of the ordered volume fraction while the ordered moment size in the magnetically ordered volume shows little change. The results on bulk specimens of $RENiO_3$ and V_2O_3 have been published in Nature Communications in 2016, while those on bulk $Ba(Co,Ni)S_2$ and a thin film of V_2O_3 are under preparation for submittal.

1. Research Objectives.

Mott transition from paramagnetic metal to antiferromagnetic (AF) insulator is a remarkable phenomenon caused by strong correlations among electrons. It has been known for some years that in thermal phase transitions of Mott transition systems, such as V_2O_3 and $RENiO_3$, the magnetic transition occurs as first-order phase transition, often associated with thermal hysteresis and accompanied by metal-insulator (M-I) charge transition and structural phase transition [1-3]. Evolution of magnetic quantum phase transition, however, has not yet been studied in details. The present study aims to elucidate details of magnetic order in these systems with quantum tuning via hydrostatic pressure and chemical substitutions. For this purpose, Muon Spin Relaxation (MuSR) is an ideal method, because MuSR can determine the volume fraction of the magnetically ordered regions and the local ordered moment size separately. In V_2O_3 thin film specimens, MuSR results can be compared with those from nano-scale real-space mapping of optical conductivity (nano-optics) and x-ray diffraction. This comparison is expected to shed new light in understanding interplays of charge (M-I), magnetic (AF-Para) and structural phase transitions.

2. Research Contents

The present project has been performed in the following subjects and steps:
(A) Bulk $RENiO_3$ and V_2O_3: MuSR measurements at TRIUMF in $RENiO_3$ at ambient pressure and at PSI in V_2O_3 under applied pressure in 2014-15; data analysis and preparation of publication in 2015 -16; publication accepted and printed in 2016 [4]. (B) Thin film V_2O_3: Low energy MuSR measurements at PSI on a 100 nm film in 2015-16; data analyses and preparation of publication: 2016 [2]; Low energy MuSR at PSI on a 300 nm film being planned in 2017 summer. Optical conductivity measurements by Basov and collaborators on a 300 nm film: performed in 2014-15; published in 2016 [5]. Nano optics studies on a 100 nm film: performed in 2016. (C) Bulk $BaCoS_2$: MuSR measurements under applied pressure in 2016 at PSI; $Ba(Co,Ni)S_2$ MuSR measurements at TRIUMF at ambient pressure in 2016: data analyses and preparation of publication in 2017. Neutron scattering beamtime proposal at ORNL accepted in May 2017; neutron experiments planned in the fall of 2017.

3. Research Results

Figure 1(a) and 1(b) show the phase diagrams of V_2O_3 and $BaCoS_2$ with pressure tuning. The metal insulator transition in V_2O_3 is accompanied by a structural phase transition, while there is no structural transition in $BaCoS_2$. MuSR results in Figs. 1(c) and 1(d) demonstrate that in both of these systems the volume fraction of the magnetically ordered region decreases with increasing pressure and becomes clearly smaller than even a half of the total volume near the quantum critical region. We also observed that the frequency of Zero-field MuSR signal exhibits almost no dependence on pressure at low temperatures near the disappearance of the static magnetic order, and there was no signature of critical slowing down of spin fluctuations in the paramagnetic state. There features clearly demonstrate that the quantum phase transition is first order in nature. Similar results were obtained in $RENiO_3$ with composition tuning [4], while the local ordered moment size shows significant composition dependence in $Ba(Co,Ni)S_2$ in ambient pressure, due possibly to the effect of disorder and/or charge doping.

Figure 1(f) shows the comparison of the temperature evolution of the volume fraction of the magnetically ordered region in V_2O_3 100 nm film with those for insulating volume fraction from nano-optics measurements and for the monoclinic structure derived from x-ray Bragg-peak intensity. The comparison indicates that these three orders follow nearly the same temperature evolution, but there may be subtle differences. Since the 100 nm film exhibits more disordered pattern in nano-optics as compared to 300 nm film (Fig. 1(e)), we plan to perform low-energy MuSR measurements of a 300 nm film at PSI in the summer of 2017.

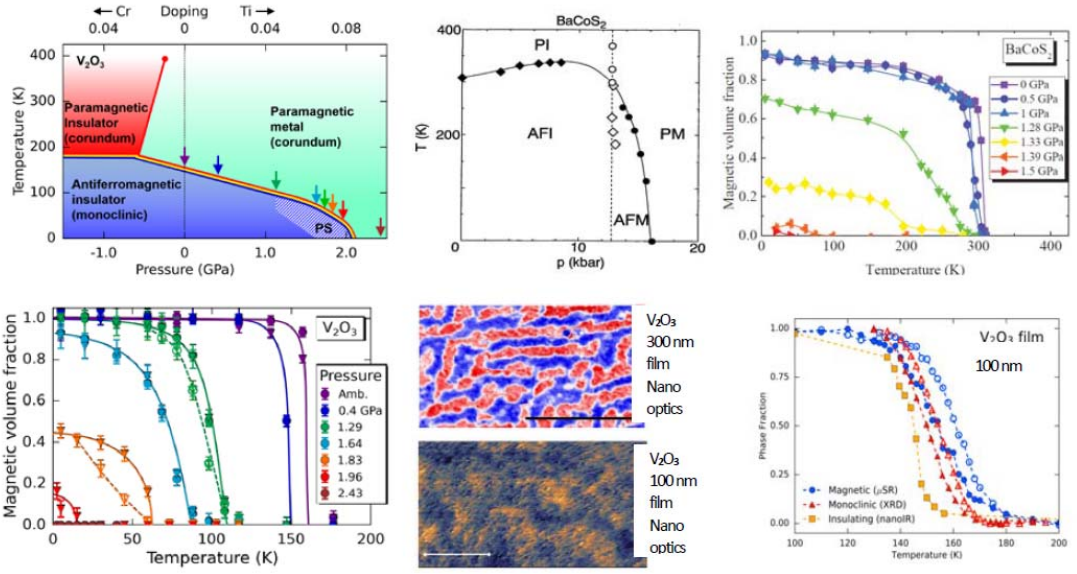

Fig. 1: (a, top left) Phase diagram of V_2O_3. PS shows the phase separation region [4]; (b, top center) Phase diagram of $BaCoS_2$; (c, top right) Magnetic ordered volume fraction of $BaCoS_2$ (unpublished); (d, bottom left) AF ordered volume fraction in V_2O_3 [4]; (e, bottom middle) Nano-optics imaging for metallic and insulating regions in V_2O_3; (f, bottom right) Magnetic, structural and insulating volume in 100 nm V_2O_3 film (unpublished).

4. Conclusions

These results clearly indicate that quantum phase evolution in can be regarded as first order transition, associated with phase separation, in prototypical Mott transition systems V_2O_3, $RENiO_3$ and $Ba(Co,Ni)S_2$, in both composition tuning and pressure tuning, regardless of whether the transition is associated with structural transition or not. We are presently preparing a manuscript to report MuSR results on $Ba(Co,Ni)S_2$, and planning to perform inelastic neutron scattering studies on that system at ORNL to seek for analogue of the magnetic resonance mode found in unconventional superconductors.

5. References

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