TOHOKU UNIVERSITY

IMR KINKEN Research Highlights 2007

Institute for Materials Research, Tohoku University

Research

NMR Study on High-T_C Cuprate and Organic Superconductors

NMR explores in solids with a microscope of nuclear spins, which detects phenomena with no spatial coherency, and hence being not visible through scattering techniques. We have utilized this microscopic probe to study the two phenomena in an organic superconductor and a high-T_C cuprate, the quantum vortex slush state and the incoherent buckling in CuO_2 plane.

In superconductors with a quasi-two-dimensional structure and a high critical temperature, the quantum fluctuation is expected to have a large effect on the vortex state when the high magnetic field is applied perpendicular to the conduction plane so that the intrinsic pinning has little effect on the motion of vortices. Sasaki *et al.* found that in κ-(BEDT-TTF)$_2$Cu(NCS)$_2$, one of the most anisotropic superconductor in κ-type organic complexes, there persists a finite resistive state, the quantum vortex slush state down to the dilution temperature region under high fields near H_{c2}.

We have investigated the temperature dependence of the longitudinal nuclear spin relaxation curves to reveal that a large number of vortex glass fragments appear in slush phase. These dense fragments, which act as nuclear spin relaxation centers, wash out the dilute centers such as lattice defects preexisting in the liquid state, and make the system uniform. Figure 1 shows that as lowering the temperature the nuclear spin relaxation curve loses its curvature and tends to be a straight line (α=1), which is an indicative of a uniform system. This is considered to be the first microscopic evidence for the vortex slush state in organic superconductors. The figure also shows the divergence of T_1^{-1} due to the critical slowing down at the vortex liquid-vortex glass transition at low fields.

La-based high-T_C cuprates shows an anomalous suppression of T_C at the specific hole carrier concentration at around x=1/8, where the one dimensional segregation of holes and spins known as the stripe order emerges. Though the dynamically fluctuating stripe is believed to be one of the candidate for the mechanism of the high-T_C superconductivity, it destructs the superconductivity when stabilized by the pinning effect of the underlying lattice, that is, a buckling pattern in the CuO_2 plane corresponding to the symmetry of P4$_2$/ncm space group. However, in $La_{2-x}Sr_xCuO_4$, no evidence of macroscopic buckling structure of P4$_2$/ncm has so far been reported by scattering experiments, though the significant dip in the x-T_C curve exists at x ≈1/8.

By utilizing NMR technique and high-quality single crystals, we have successfully observed the change in the direction of the principal axis of the crystal field tensor at the Cu site at low temperatures, indicating the evolution of the incoherent local structure of P4$_2$/ncm, which cannot be seen by scattering techniques. Figure 2 shows the change in the NMR peak splitting pattern with lowering temperature indicating the emergence of the local structure corresponding to the space group P4$_2$/ncm. The figure also shows the appearance incoherent structure in the vicinity of the critical temperature of the macroscopic structural phase transition from I4/mmm to Bmba phase.

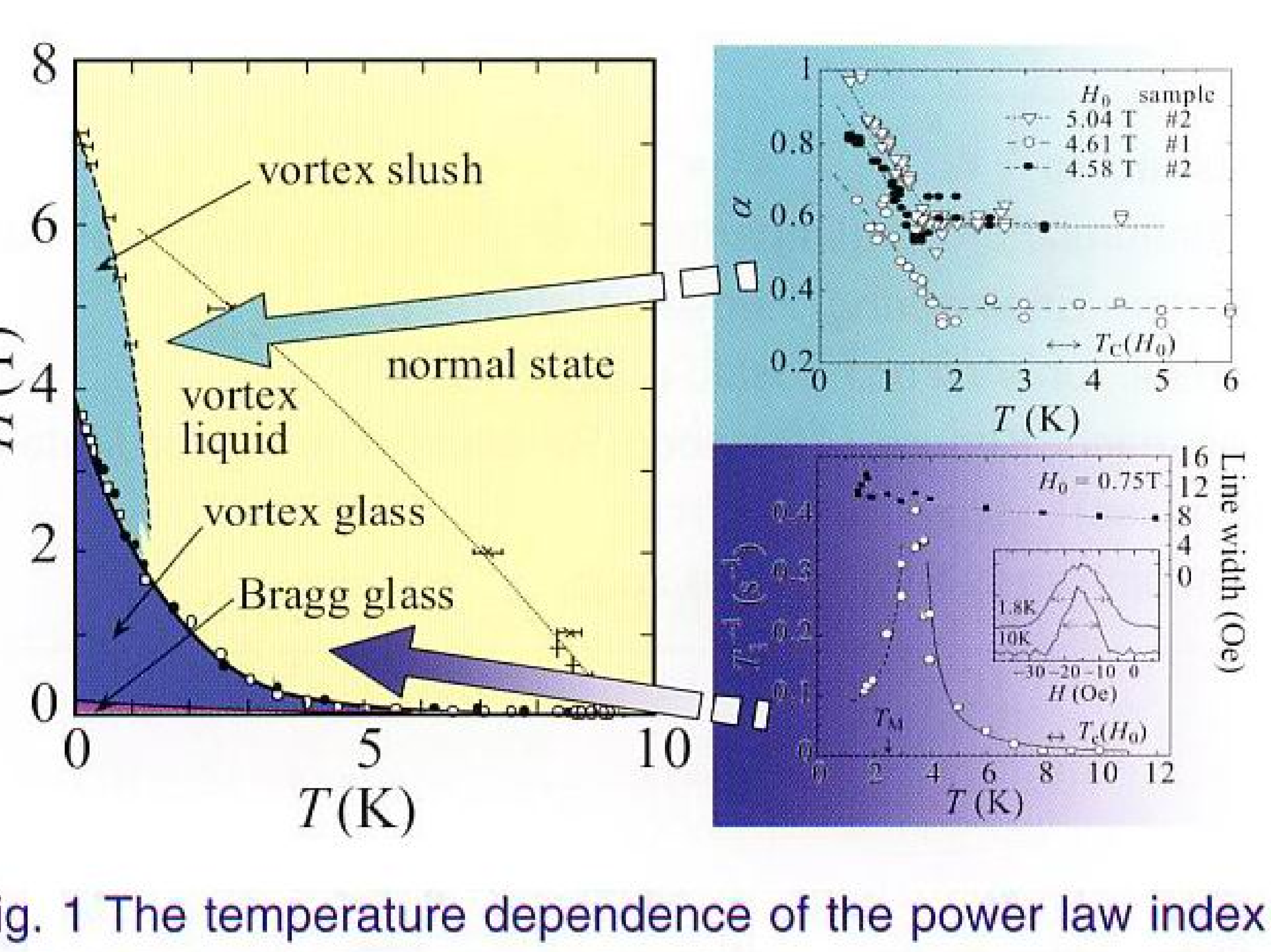

Fig. 1 The temperature dependence of the power law index of the nuclear relaxation curve at the vortex liquid-vortex slush transition, and of the nuclear spin lattice relaxation rate T_1^{-1} at vortex glass-vortex liquid transition in κ-(BEDT-TTF)$_2$Cu(NCS)$_2$ by NMR-T_1.

References

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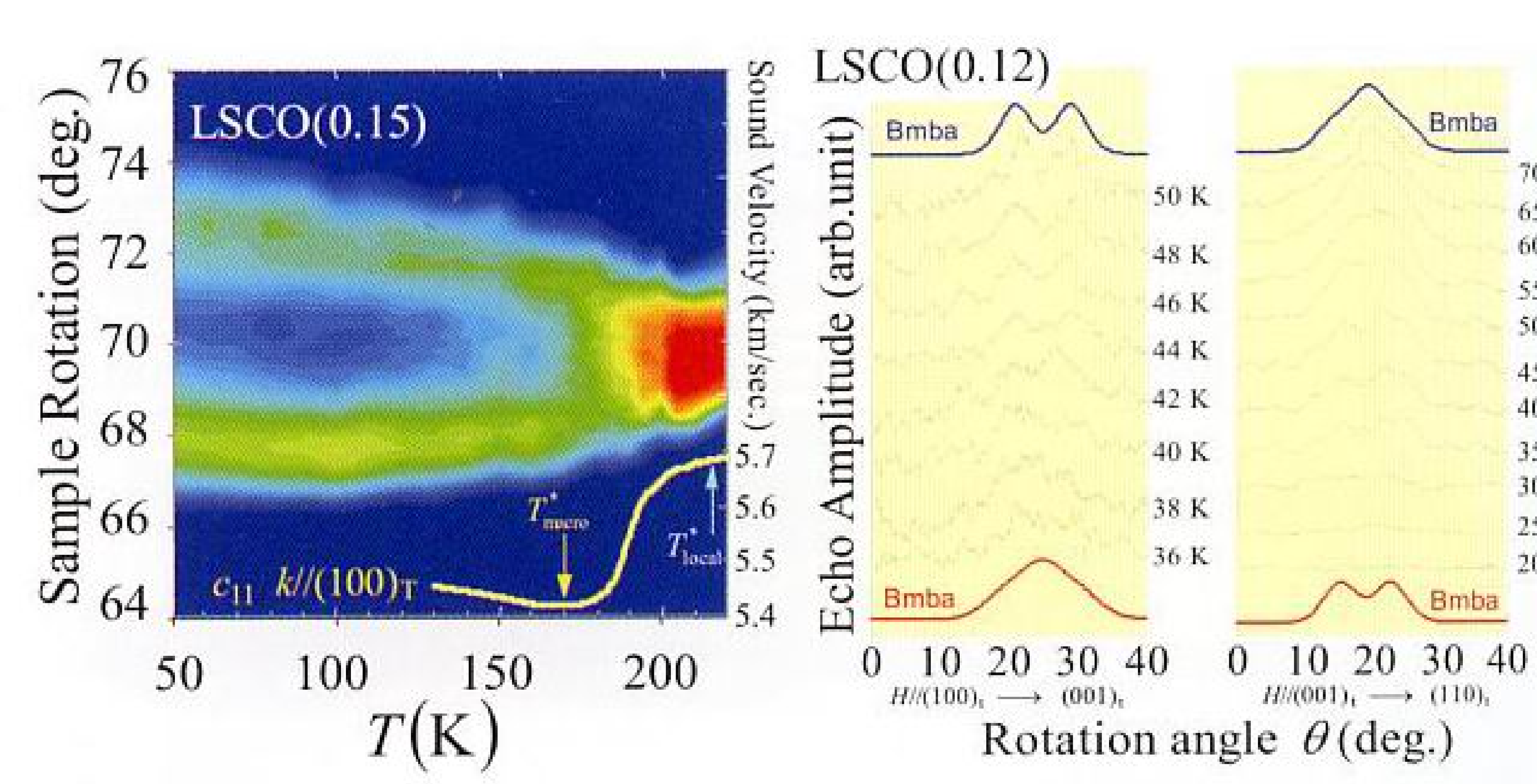

Fig. 2 Detection of the incoherent buckling of the CuO_2 plane in $La_{2-x}Sr_xCuO_4$ by NMR spectra. In x=0.15 (left), an incoherent buckling corresponding to the Bmba phase appears far above T^*_{macro}, the macroscopic critical temperature of the structural phase transition from I4/mmm to Bmba phase. In x=0.12 (right), NMR peak splitting width changes as the incoherent structure of P42/ncm emerges at low temperatures. The splitting pattern depends on the angle between the applied field and buckling direction.