Observation of Antiferromagnetic Domains in the "Devil's Staircase" of CeSb using Polarizing Microscopy

K. Sasaki[a, b], T. Takeda[a], K. Watanabe[a], T. Iwata[a, b], A. Kimura[a, b, c], H. S. Suzuki[d], K. Kuroda[a, b, c]

[a]Graduate School of Advanced Science and Engineering, Hiroshima University,
Higashi-Hiroshima 739-8526, Japan
[b] International Institute for Sustainability with Knotted Chiral Meta Matter (WPI-SKCM^2),
Higashi-Hiroshima 739-8526, Japan
[c] Research Institute for Semiconductor Engineering,
Higashi-Hiroshima 739-8527, Japan
[d] Institute for Solid State Physics, The University of Tokyo,
Kashiwa, Chiba 277-8581, Japan

Keywords: Electronic nematicity, Antiferromagnetic domain, Devil's staircase

Antiferromagnets have long been regarded as difficult to translate into applications because they exhibit no macroscopic magnetization, which makes control by external fields difficult. In recent years, however, the emergence of spintronic functionalities such as magnetic memory effects and current induced magnetic switching has been increasingly reported as a consequence of underlying symmetry breaking associated with antiferromagnetic order. The origins of these phenomena are suggested to involve topological properties and electronic nematicity. In particular, in antiferromagnets, the emergence of electronic nematicity concomitant with antiferromagnetic order causes the electronic system to spontaneously break rotational symmetry and select a preferred direction, resulting in pronounced anisotropy in electronic responses such as charge transport and optical properties. Because external stimuli that impose directional symmetry breaking such as strain, electric fields, and electric currents can couple to the nematic order parameter arising from the antiferromagnetic order and select its orientation, switching controlled by various external fields is expected.

In the antiferromagnet CeSb, which is known to exhibit complex magnetic structure transitions called the devil's staircase and to host more than 14 distinct magnetic structures depending on temperature and magnetic field [1], anisotropy emerges in the 4*f* electron ground state accompanying the phase transitions. This is reported to be accompanied by a large lattice strain reaching about 0.1 % [2] and a reconstruction of the anisotropic electronic band structure [3], suggesting a correlated electronic state with strong coupling among orbital, spin, and lattice degrees of freedom. In contrast, there have been no experimental reports that directly capture domain evolution during the transitions or domain control by external fields.

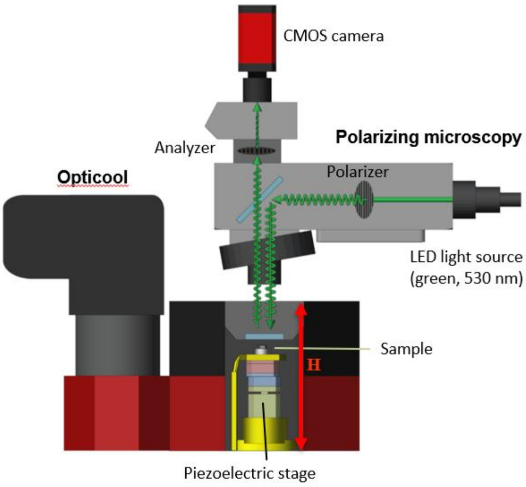

Fig. 1 : experimental setup

In this study, we used a polarization microscope equipped with an LED light source and a cryostat capable of reaching 1.7 K, installed in the HiSOR preparation building, and observed the temperature and magnetic field dependences of the domain structure by using birefringence originating from antiferromagnetic order (Fig. 1).

As a result, below the Néel temperature, we observed three types of magnetic domains reflecting the direction of the magnetic moments. Two are in plane domains shown in red and blue, and one is an out of plane domain shown in white (Fig. 2). Near the transition temperatures reported in previous studies, we confirmed prominent changes in both domain configuration and birefringence intensity. Furthermore, under applied magnetic fields, we observed a process in which domains evolve toward a single domain state near the transition fields. These results visualize domain dynamics associated with the devil's staircase in CeSb and indicate that the development of anisotropy in the electronic state plays a key role.

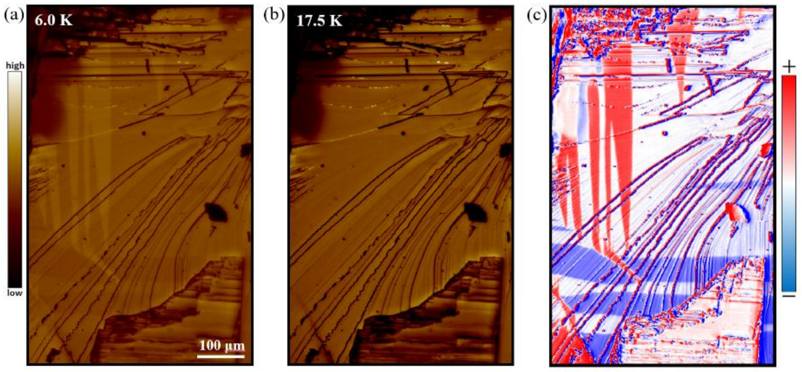

Fig. 2 : Polarized optical microscopy images of the cleaved CeSb (001) surface. (a) Antiferromagnetic phase at $T = 6.0$ K, (b) Paramagnetic phase at $T = 17.5$ K, and (c) difference image between (a) and (b).

REFERENCES

1. J. Rossat-Mignot *et al.*, J. Magn. Magn. Mater. **52**, 111 (1985).
2. F. Hulliger *et al.*, J. Low. Temp. Phys. **20**, 269 (1975).
3. K. Kuroda *et al.*, Nature Commun. **11**, 2888 (2020).