**Nematic and metanematic transitions in iron-based superconductors**

Strongly interacting electrons can exhibit novel collective phases, among which the electronic nematic phases are perhaps the most surprising, as they spontaneously break rotational symmetry of the underlying crystal lattice [1]. In the iron-pnictide superconductors, such nematicity has recently been observed in several experiments, and has commonly been associated with the tetragonal-to-orthorhombic structural phase transition at $T_s$, below which a sizable difference between $a$ and $b$ lattice parameters is observed with an orthorhombicity on the order of $10^{-3}$.

We found in BaFe$_2$(As$_{1-x}$P$_x$)$_2$ systems (Fig. 1(a)) that the electronic nematicity sets in at $T^*$, which is much higher than $T_s$ [2]. The chemical composition dependence of the nematic transition temperature $T^*$ covers the superconducting dome, as shown in Fig. 1(b). The new phase diagram found in this study resembles the pseudogap phase diagram in high-$T_c$ cuprate superconductors, and may hold an important clue to the mechanism of superconductivity in this class of materials.

Magnetic torque measurements in small pure crystals under in-plane magnetic field rotation, which have recently been developed as powerful probes for rotational symmetry breaking [3], have shown that the two-fold oscillation associated with the electronic nematicity starts to develop below the $x$-dependent temperature $T^*$ [2]. The analysis of the phase of the two-fold oscillation reveals that the in-plane susceptibility shows elongated anisotropy along the Fe-Fe direction, which matches the orthorhombicity direction in the lower-temperature antiferromagnetic phase below $T_N ~ T_s$ (Fig. 1(c)).

To search for a tiny orthorhombic lattice...
distortion associated with the electronic nematicity, we have performed single-crystal structural analysis at beamline BL02B1 with a photon energy of 17.7 keV as a function of temperature at several different compositions $x$. We focus our attention to high-angle Bragg peaks $(h\ h\ 0)$ with $h = 7$ or 8, which are very sensitive to a small distortion along the Fe-Fe direction. Typical diffraction data as a function of temperature is shown in Fig. 2 for $x = 0$ and 0.27. At high temperatures above $T^*$, the Bragg peak is relatively sharp. Below $T_s$, the peak is completely split into two peaks, indicating the orthorhombic symmetry of the crystal. In the intermediate temperature range between $T^*$ and $T_s$, the Bragg peak is broader and has some tail structure, and it can be fitted to overlapping two peaks (Figs. 2(c) and 2(d)). This evidences a small but finite orthorhombic lattice distortion below the nematic temperature $T^*$. We stress that the high-resolution synchrotron X-ray measurements focusing on the high-angle Bragg peaks were the key for detecting such a small distortion in the electronic nematic state.

The orthorhombicity found in the temperature range below $T^*$ immediately indicates that the rotational symmetry in the system is already broken above $T_s$, at which the tetragonal-orthorhombic crystal structure transition was originally assigned. This raises a question why we have a big jump in the peak splitting at $T_s$. Our study implies that the true second-order phase transition occurs at the nematic temperature $T^*$, which accompanies the spontaneous breaking of the fourfold tetragonal symmetry, whereas the apparent transition at $T_s$ is not a true phase transition but rather what we refer to as a ‘meta-nematic’ transition in analogy to the theory of magnetism. A simple Landau free-energy analysis containing the electronic and lattice contributions leads to two different transition temperatures at which the electronic nematic and orthorhombic lattice order parameters set in, but when a coupling term between the electronic and lattice systems is introduced, both order parameters become finite below $T^*$ and show a jump at $T_s$ [2]. The fact that $T^*$ is higher than $T_s$ suggests that the nematic transition has an electronic origin.

The electronic nematic phases have been discussed for several strongly correlated electron systems, such as the pseudogap phase in high-$T_c$ cuprate superconductors [4], the hidden order phase of the heavy-fermion compound URu$_2$Si$_2$ [3], and the field-induced phase of Sr$_2$RuO$_4$ [5]. The high-resolution synchrotron X-ray used in the present study will be a useful tool for studying these intriguing phases.

References