

## Bulk-sensitive Photoemission on Ti-doped $\text{Sr}_2\text{RuO}_4$

$\text{Sr}_2\text{RuO}_4$  is the first layered non-cuprate perovskite found to display superconductivity ( $T_c \approx 1\text{K}$ ) [1]. As is the case for cuprate high-temperature superconductors, the fundamental issues to be addressed here refer to the pairing mechanism, and in particular, the role of electronic correlations. While the unusual spin-triplet pairing with p-wave symmetry suggests the importance of ferromagnetic fluctuations, in experiments, mainly evidence for antiferromagnetic fluctuations was found. Recently, it was observed that the substitution of the  $\text{Ru}^{4+}$  ion by the non-magnetic  $d^0$ -ion  $\text{Ti}^{4+}$  induces local-moment magnetism, which statically orders for  $\text{Sr}_2\text{Ru}_{1-x}\text{Ti}_x\text{O}_4$  with  $x \geq 0.03$  [2]. This behavior was confirmed by elastic neutron scattering in which the formation of a static incommensurate spin-density wave (SDW) for  $x = 0.09$  below  $T_{\text{SDW}} = 25\text{K}$  [3] is observed. The formation of this static SDW upon slight Ti-doping opens the possibility to study its effects on the electronic structure from a fundamental point of view and might give an important insight into the role of antiferromagnetic fluctuations in the superconducting parent compound as well.

To elucidate these questions we performed photoemission (PE) measurements (see Fig. 1) at high photon energies using BL25SU to investigate both a possible change of the Fermi surface (FS) upon doping and possible effects on the low-energy electronic structure along the high-symmetry lines of the Brillouin zone (BZ).

Knowledge of the FS topology is important because it determines the manifold of possible excitations on the FS for a given momentum. If there exist two-dimensional manifolds across the FS, which can be mapped onto each other by one single vector, the respective portions of the FS are said to be nested.

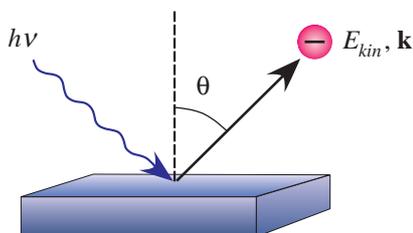


Fig. 1. Schematic of the photoemission process. Monochromatic photons kick out electrons from the surface of a solid. Due to energy and momentum conservation their kinetic energy and emission angle can be traced back to their energy and momentum in the crystal.

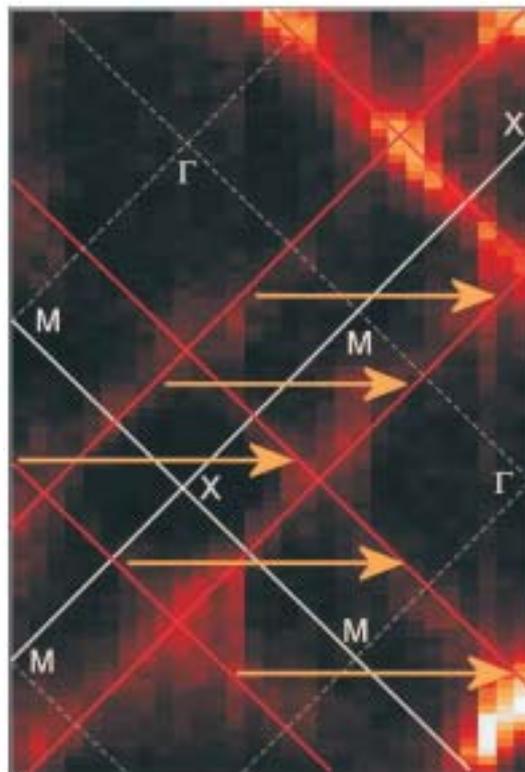


Fig. 2. FS map of  $\text{Sr}_2\text{Ru}_{0.91}\text{Ti}_{0.09}\text{O}_4$ . Indicated are the BZ (white lines), the underlying one-dimensional FS sheets (red lines), and the experimentally observed SDW vectors (arrows). The dashed white lines denote the irreducible parts of the BZ.

At these locations, the FS becomes intrinsically unstable and an SDW with a wavevector corresponding to the nesting vector may develop concomitant with an energy gap. Figure 2 displays an image of the FS of  $\text{Sr}_2\text{Ru}_{0.91}\text{Ti}_{0.09}\text{O}_4$ . Also indicated is the BZ. The arrows mark SDW vectors as experimentally observed by neutron scattering. Their starting and end points lie essentially on two mutually perpendicular pairs of FS sheets and thus give striking evidence that the SDW indeed is driven by FS nesting. They can be viewed as reflecting a hidden one dimensionality in the electronic structure. Note that the thus identified nesting vectors are also in agreement with the findings of band structure calculations. Surprisingly, the FS topology and especially the FS “volume” remain essentially unchanged in comparison with the undoped material [4], indicating that the Ti ions do not much affect the states close to the Fermi energy  $E_F$ .

If the electronic structure is not much affected right at  $E_F$ , one would nevertheless expect a relatively large

disorder potential to be induced by the Ti ions. This should be reflected by broadened structures and the lack of dispersion particularly of low-lying bands. A typical series of energy distribution curves along the high-symmetry line  $\Gamma X$  is shown in Fig. 3. Intriguingly, one finds sharp dispersing features over the entire valence band region, in particular at  $E_F$ , which is again comparable to the findings in the undoped compound.

Yet another important issue has to be addressed, which is a rather fundamental one and always a topic about PE spectroscopy. Since electrons strongly interact with matter, PE in general is a highly surface-sensitive technique. It is important to know this, especially in our case, since it was previously shown [5] that the undoped system, although two-dimensional in nature, exhibits a surface reconstruction which is actually also present in the Ti-doped compound as revealed by low-energy electron diffraction (not shown). This reconstruction imposes a new periodicity on the electron system at the surface, and hence, affects the electronic structure. For example, effects such as band backfolding, the occurrence of replicas of the FS sheets or even an overall change of the electronic structure may result. Indeed, all such effects

were found in PE spectroscopy of the undoped system using low-energy photons of approximately 30 eV [5]. High-energy photons of about 700 eV provided by BL25SU transfer much more energy to the electrons and thus give them a significantly higher chance to escape from deeper in the sample into the vacuum. Indeed, we do not see any signs of the above-mentioned effects and thus can conclude that our data truly reflects the intrinsic bulk electronic structure. Looking at the subtle effects of the SDW with a very high resolution (and hence, inevitably low photon energies) our data is urgently needed to disentangle the surface from bulk contributions.

In summary, both the FS image and the band maps recorded by high-energy PE surprisingly indicate that the essential overall electronic structure of  $\text{Sr}_2\text{RuO}_4$  is preserved upon slight Ti-doping. In particular, we observe sharp dispersing bands despite the large disorder due to the Ti ions. Our results are very important for deconvoluting the surface from bulk contributions if one carries on with studying the subtle effects of the SDW on the electronic structure at low photon energies. Such investigations are currently in progress.

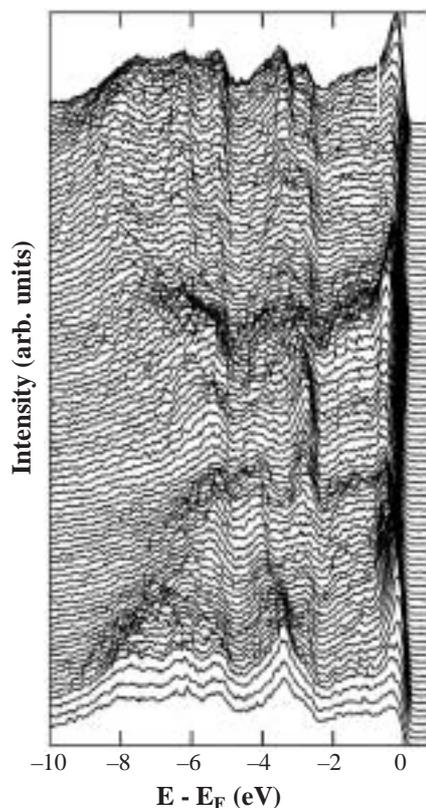


Fig. 3. EDCs along the  $\Gamma X$  high-symmetry line. Note the sharp dispersing features, in particular at the Fermi energy ( $E_F = 0$ ).

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