

# Raman Topography Studies of Eutectic Systems of Strontium Ruthenate and Ruthenium

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## Abstract:

We report unexpected phenomena observed on the  $\text{Sr}_2\text{RuO}_4$ -Ru eutectic system featuring ruthenium (Ru) islands embedded in  $p$ -wave superconductor strontium ruthenate ( $\text{Sr}_2\text{RuO}_4$ ) with a superconducting transition temperature ( $T_c$ ) nearly twice that of pure  $\text{Sr}_2\text{RuO}_4$ . This enhancement of a  $p$ -wave superconductor is significant because of its similar structure (perovskite) compared to  $d$ -wave superconductors (high  $T_c$  superconductors). It occurs at the atomically sharp interface between the two materials, with the electronic states modified strongly. To examine this, we employed Raman spectroscopy, a convenient method of measuring phonon stiffness. A laser was shone onto the sample, where excited electrons scatter phonons—energy dependent on specific bonding structure—and the emitted photon was recaptured and analyzed. As we performed line scans across the interface, we noticed the phonons hardened near the interface, suggesting the  $T_c$  of the eutectic phase correlates with phonons.

## Types of Superconductors:

The main theory for explaining superconductivity is the BCS Theory (named after Bardeen, Cooper, and Schrieffer), which, to put it simply, says that superconductivity relies on special electron-phonon interactions that create Cooper Pairs. If these Cooper Pairs can survive the vibrations of the crystal lattice (below a certain temperature  $T_c$ ), then the material is superconducting. This theory, however, only explains the simplest type of superconductor— $s$ -wave—which constitutes a majority of all superconductors. These  $s$ -wave superconductors typically have critical temperatures in the range of 0-10K. Another type of superconductor— $d$ -wave—is well-known and studied for its high critical temperature characteristics (highest 140K); however these have extremely complicated crystal structures. The superconductor system we are interested in composes of  $\text{Sr}_2\text{RuO}_4$ —a chiral  $p$ -wave superconductor [1-4] that has  $T_c$  in range of  $s$ -wave (1.5K), but exhibits similar structure as  $d$ -wave—and ruthenium metal —a conventional  $s$ -wave superconductor ( $T_c = 0.5\text{K}$ ). This eutectic system [5] is grown by adding ruthenium oxide

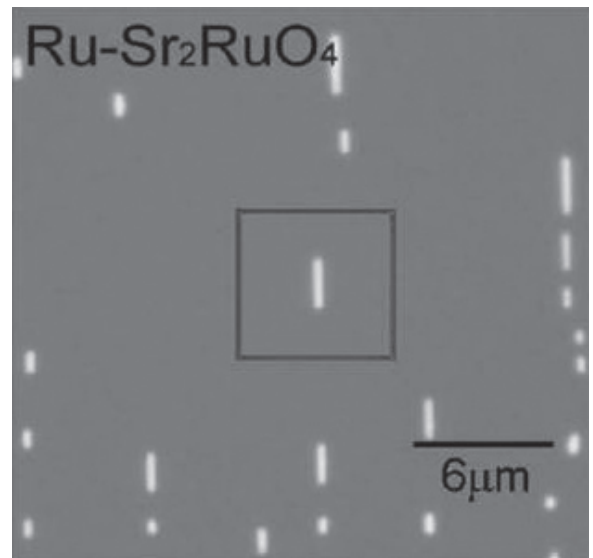


Figure 1: Eutectic system consisting of ruthenium (brightly lit areas) and  $\text{Sr}_2\text{RuO}_4$ .

to a strontium ruthenate substrate, with excess ruthenium forming islands about 1-2  $\mu\text{m}$  in width and as long as 10  $\mu\text{m}$  in length. The interface between these two materials exhibit an enhanced region of superconductivity:  $T_c = 3\text{K}$ . This is interesting because  $\text{Sr}_2\text{RuO}_4$  usually is extremely sensitive to impurities, which destroy its superconductivity. This project aims to find evidence of crystal restructuring through use of phonon detection.

## Procedure:

Raman spectroscopy discriminates materials based on bonding structure. To summarize, it works by shooting a photon at the sample, and collecting the inelastically reflected photon containing the “molecular imprint.” This is quantified by measuring its resulting shift in energy.

A 514.5 nm wavelength laser, operating at 13 milliWatts of power, was shone onto a sample of the eutectic phase of

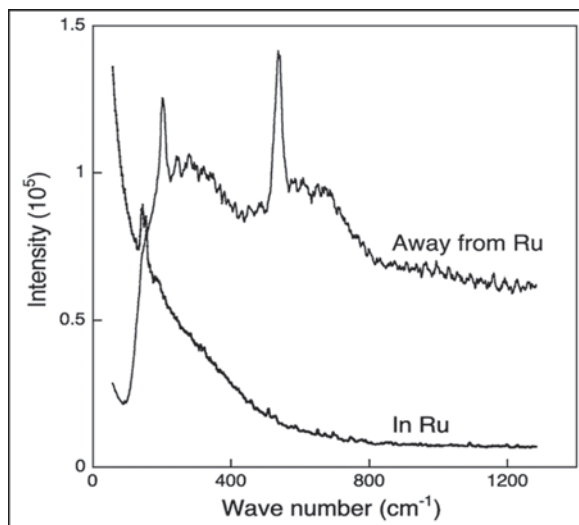


Figure 2: Spectrum of bulk ruthenium (bottom curve) and bulk  $\text{Sr}_2\text{RuO}_4$  (top curve).

$\text{Sr}_2\text{RuO}_4$ -Ru. Its spot size was determined using an optics formula, which came out to a 349 nm lateral resolution. First, we measured the Raman spectrum at bulk  $\text{Sr}_2\text{RuO}_4$ , which exhibited apex oxygen vibrations at  $537.5 \text{ cm}^{-1}$  and strontium vibrations at  $203.11 \text{ cm}^{-1}$ . We then measured the Raman spectrum at bulk ruthenium, which exhibited vibrations at  $190 \text{ cm}^{-1}$ . Since the enhanced phase occurs outside of the ruthenium island, we chose to measure the vibrational shift of  $\text{Sr}_2\text{RuO}_4$ .

We first performed line scans, starting at bulk  $\text{Sr}_2\text{RuO}_4$  and moving in 349 nm increments, collecting spectra at each point, until the strontium and oxygen vibrational modes disappeared inside the ruthenium island.

### Results:

We received data ranging from  $50 \text{ cm}^{-1}$  to  $1300 \text{ cm}^{-1}$ . First, we cropped out the irrelevant data, obtaining two sets (one for strontium and one for oxygen). We removed the linear bias associated with each region, and fit Gaussian peaks, recording its central peak position. We noticed a shift of about  $8.3 \text{ cm}^{-1}$  in the oxygen vibration, a change of about 1.3%, as well as a shift of about  $1.6 \text{ cm}^{-1}$  in the strontium vibration, corresponding to a change of about 0.8%. We were also successful at reproducing this phenomenon, through repeated line scans in different areas, and different islands.

### Conclusion:

Raman spectroscopy data gave evidence of so-called “phonon stiffening.” The change in the vibrational frequencies of both the strontium

and oxygen reflected a change in the phonons associated with the crystal structure. This change in crystal structure was correlated with the change in the critical temperature of the 3K enhanced phase, suggesting that phonons play an important role in the enhancement of the eutectic system.

Further suggested experiments include temperature-dependent as well as polarization dependent Raman spectroscopy measurements in order to further quantify this “phonon stiffening.”

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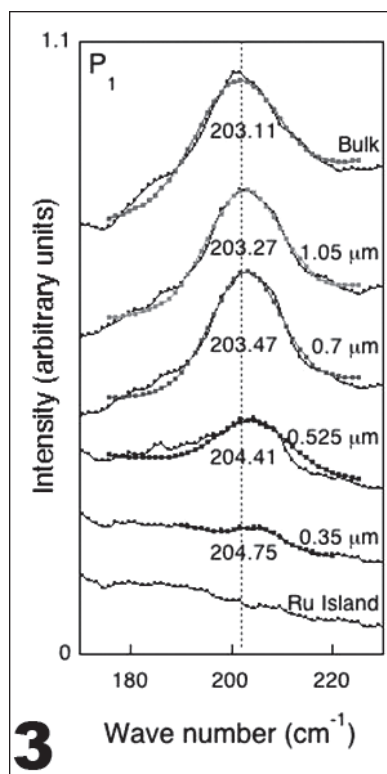


Figure 3: Sr vibration line scans with peak positions and distance from island.

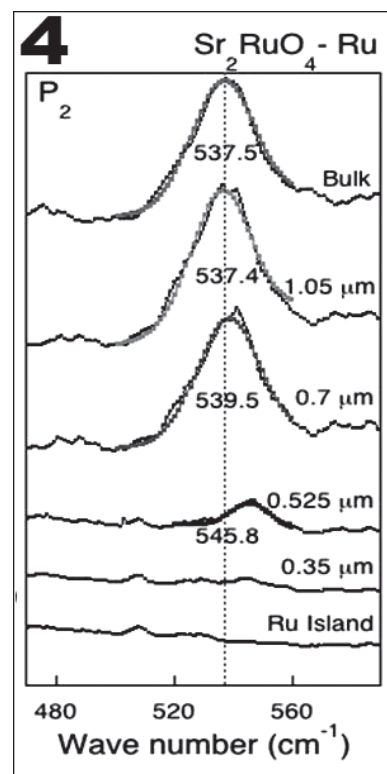


Figure 4: Oxygen vibration line scans with peak positions and distance from island.