Searching for superconductivity in Mott-insulating vanadates

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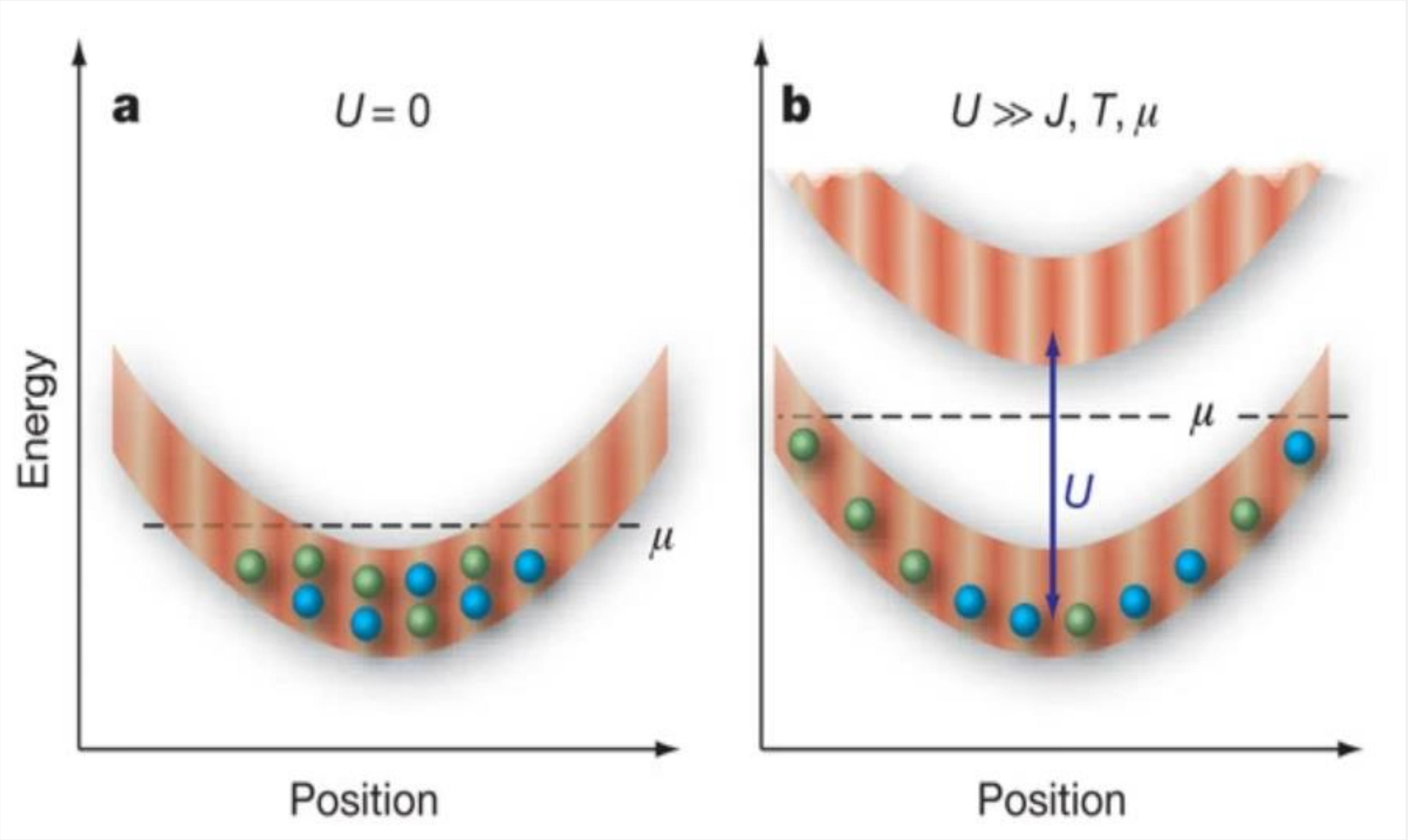


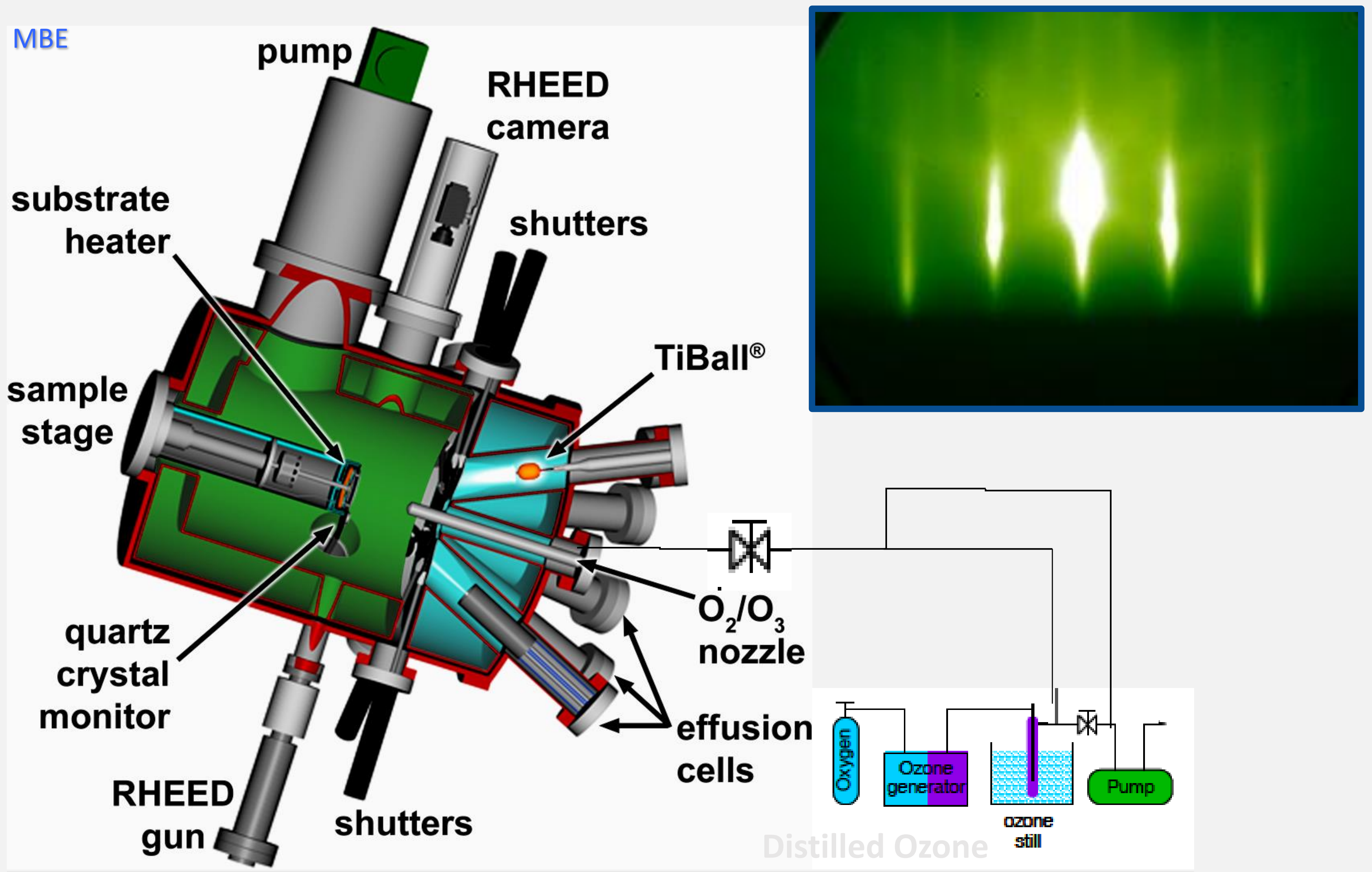
The Mott Insulator[1]

Whereas traditional insulators are characterized by a bandgap formed by occupied energy levels, the Mott insulator is a more classical analog. In some materials, the Coulomb interaction between electrons is too strong to be neglected as it is in band theory. In this case ("strong correlation"), electrons in a band will fill increasingly higher energy states rather than join an already half-filled energy level. When every state in this band is half-filled, the next electron must overcome the interaction energy *U*. This splits the band into two: the upper and lower Hubbard bands (UHB and LHB). This forms a gap that creates an insulator when the chemical potential of the material lies in between the UHB and LHB.

Superconductivity in Doped Mott Insulators

By switching out atoms in the crystal lattice with an atom with a different number of valence electrons, a vacancy or double occupancy in the LHB can be formed without needing to overcome *U*. The resulting excitation behaves like a particle of charge +2*e* (holon) or -2*e* (doublon). At low temperatures, these quasi-particles can behave like integer-spin conducting particles, travelling through the medium without scattering and thus without losing energy; the material has become a superconductor.

Many modern high-temperature superconductors, especially those based on copper oxides, have the same Mott-insulating crystal structure as $LaVO_3$ (perovskite structure), prompting our team to explore the synthesis and doping of $LaVO_3$ using MBE.

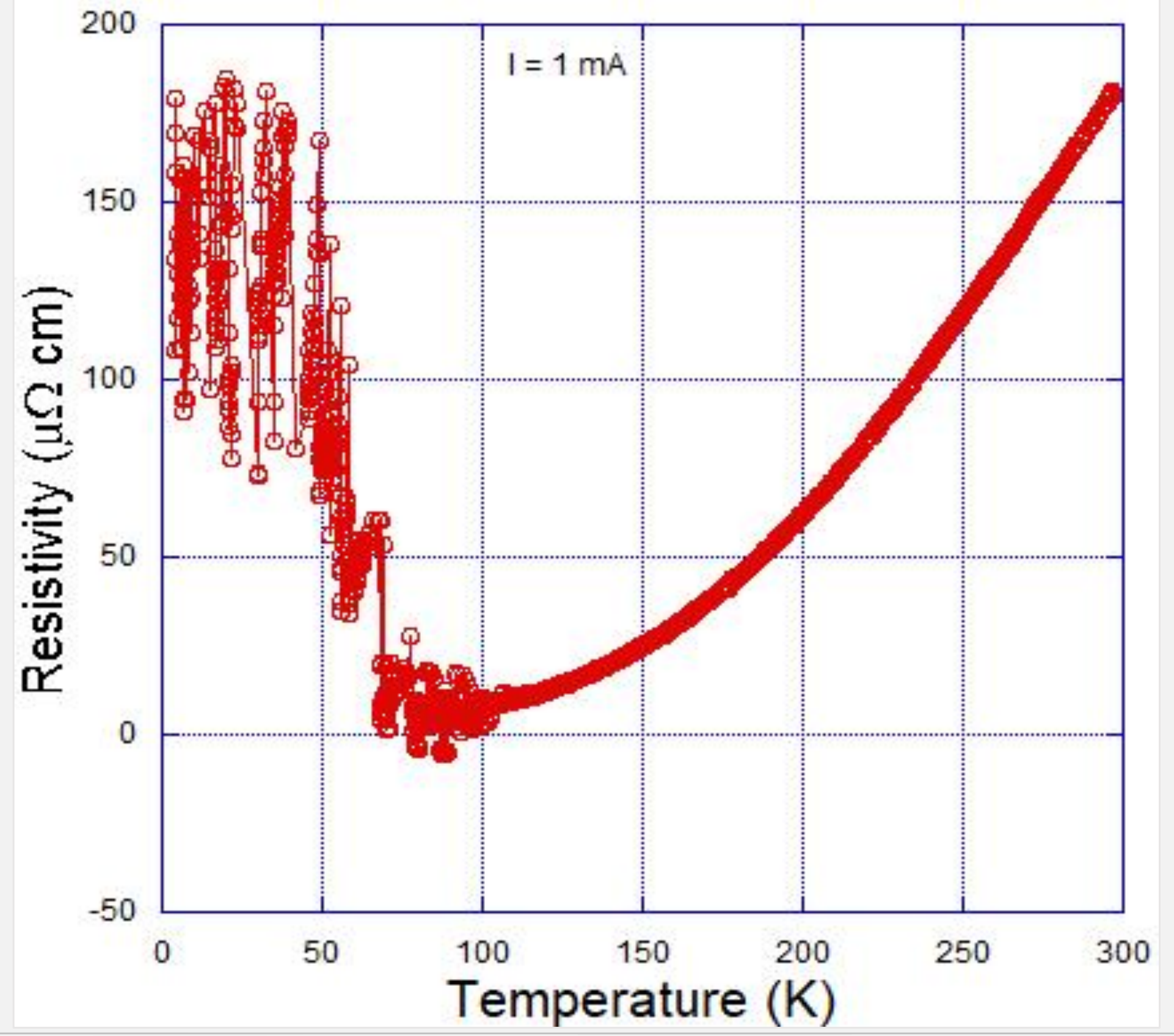


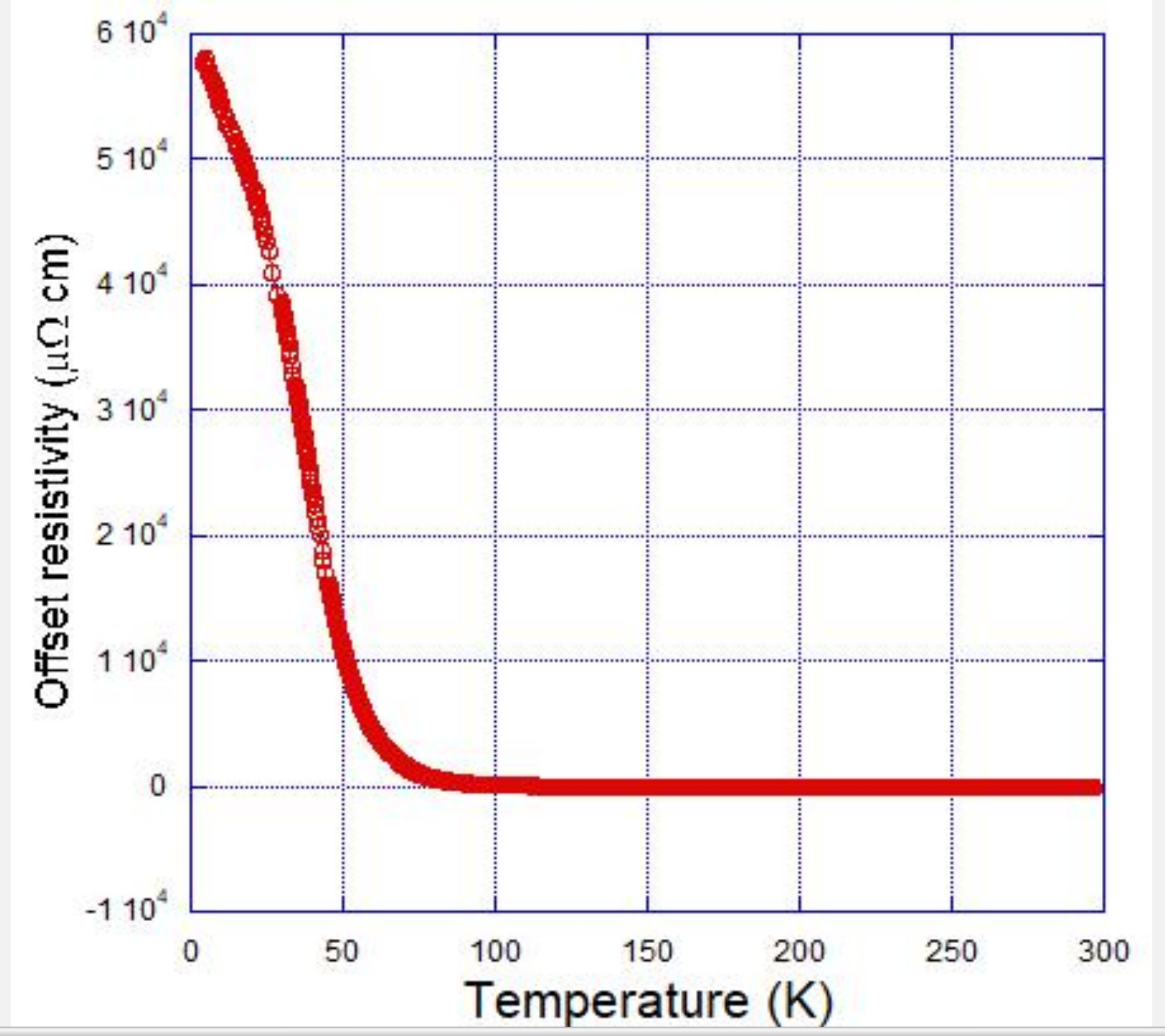
Thermal beams of neutral species → energies << 1 eV

Molecular Beam Epitaxy

Molecular Beam Epitaxy (MBE) is a technique to grow high-quality crystals of a desired composition using high-purity elemental metal beams deposited on a heated substrate. By controlling the temperature of each elemental source and the shutters, we can control the vapor pressure and thus the flux of different elements impingent on the substrate, allowing the synthesis of stoichiometric samples of materials such as $LaVO_3$, atomic layer-by-layer.

The quality of the crystal can be monitored during growth using Reflection High-Energy Electron Diffraction (RHEED), which produces a diffraction pattern (pictured in green) that characterizes the surface of the crystal and provides real-time feedback to optimize the sample.





$LaVO_3$ Resistivity Measurements

Resistivity measurements of our initial (undoped) $LaVO_3$ thin films were obtained using a bipolar current; a current was sourced in one direction across the material, the voltage was measured, the current was switched to the opposite direction, and the potential drop was measured again. The average of the two voltage measurements was taken and divided by the applied current to determine the resistance, which showed metallic behavior down to ~120 K. The difference between these two measurements, however, should remain zero. The anomalous offset resistivity that appears at low-temperatures may be indicative of a phase transition from a conducting state to a gapped insulating state. It may also explain the noise in the average resistivity measurements below 120 K.

What's Next?

Our initial undoped samples did not show a superconducting phase transition, which is not surprising, as the doping required for superconductivity was absent. However, because the sample became more conductive with decreasing temperature, the results are promising to further explore electronic transport properties in doped samples.

Further research would investigate the anomaly at 120 K as a possible transition to the Mott-insulating ground state. AC measurements may also reveal valuable information about the apparent gap that forms at this temperature.

We will explore annealing the current samples to produce oxygen vacancies in the material that could result in propagating charge excitations. Beyond investigating the Mott-insulating phase transition, we will also explore doping strategies to probe superconductivity in perovskite $LaVO_3$.

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[1] R. Jördens, N. Strohmaier, K. Günter, H. Moritz and T. Esslinger, A Mott insulator of fermionic atoms in an optical lattice, Nature **455**, pp. 204-207 (2008).