Using Native Impurities to Extract the Superconducting Gap in Bi-2201

Zhuoming Tan '16

Sponsor: Professor Michael Boyer

Abstract: Bi-2201 ($Bi_2Sr_2CuO_{6+d}$) is a family of high-temperature superconductor. While conventional superconductors are understood on the microscopic scale, the mechanism for superconductivity in high-temperature superconductors is unknown. Impurities naturally occur in any material. Using scanning tunneling microscopy (STM), we probe how impurities affect the local electronic properties in Bi-2201. Recent analysis in the Boyer lab shows evidence that intentionally doped impurities can locally suppress the pseudo-gap phase, a competing phase to superconductivity, and be used to extract the superconducting gap size. Following this line of thought we use native impurities in a wide range of hole doping in Bi-2201 to extract the superconducting gap size as a function of doping.

High-Temperature Superconductors

HTSCs are superconductors with a critical temperature higher than the maximum predicted by the BCS theory.

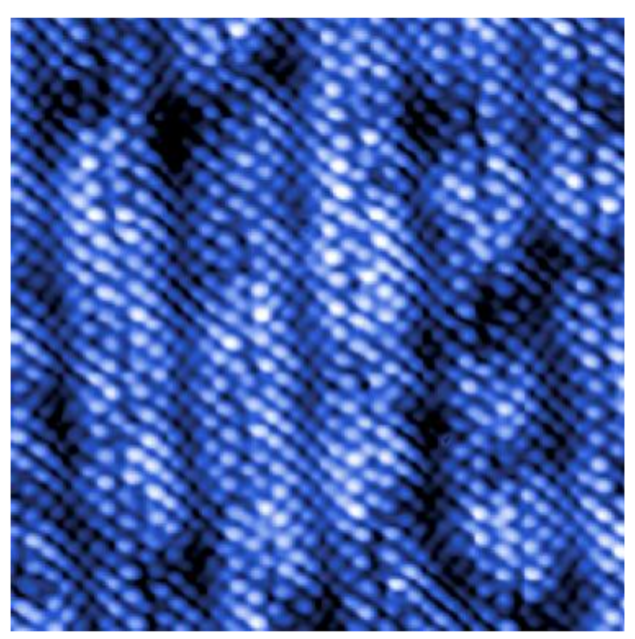

Fig. 1. Topographic STM image of Bi-2201, from referenced paper.

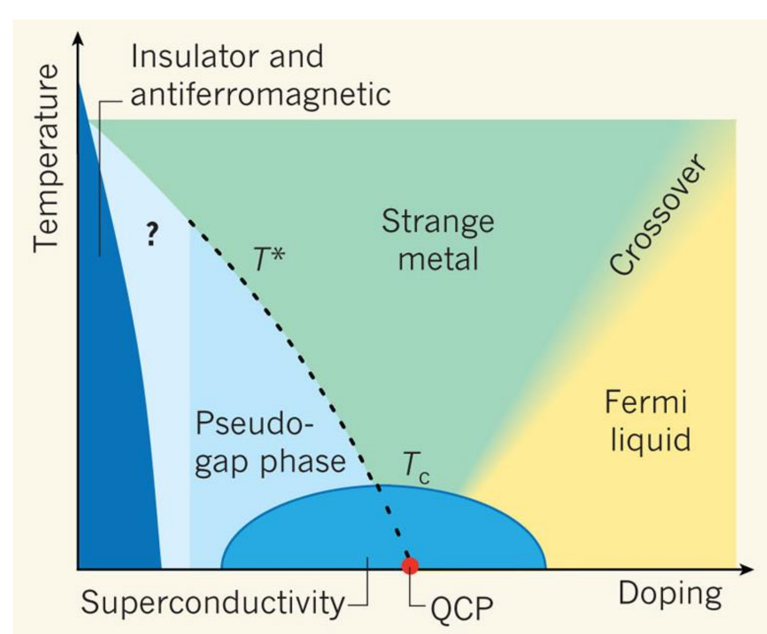

Fig. 2. Phase diagram, showing pseudo-gap phase and superconductive phase.

The material is quasi-2-dimensional along the CuO_2 charge plane.

Scanning Tunneling Microscopy

Scanning tunneling microscope uses quantum tunneling effect to obtain atomic resolution image of a conducting material. A atomically sharp metallic tip is moved along the sample surface, voltage applied between surface and tip.

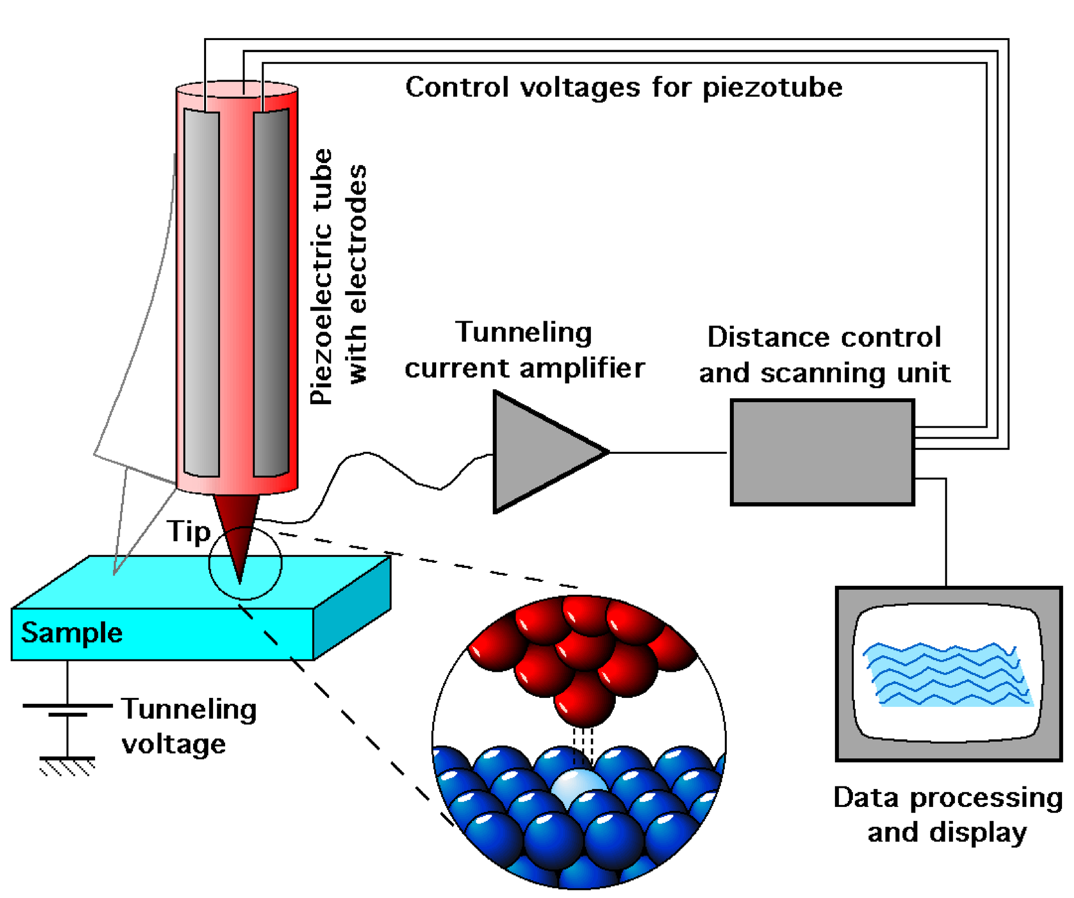

Fig. 3. STM demo, taken from The IAP/TU Wien STM Gallery.

Classically no current could pass through the gap, but quantum theories predict a finite possibility that the electron could jump through the forbidden area, and thus the tunneling current. The current is held at constant by a feedback system compensating the bumps of the surface when taking a topography. It is also able to take spectroscopic data for each atom to probe its electronic properties.

Analysis

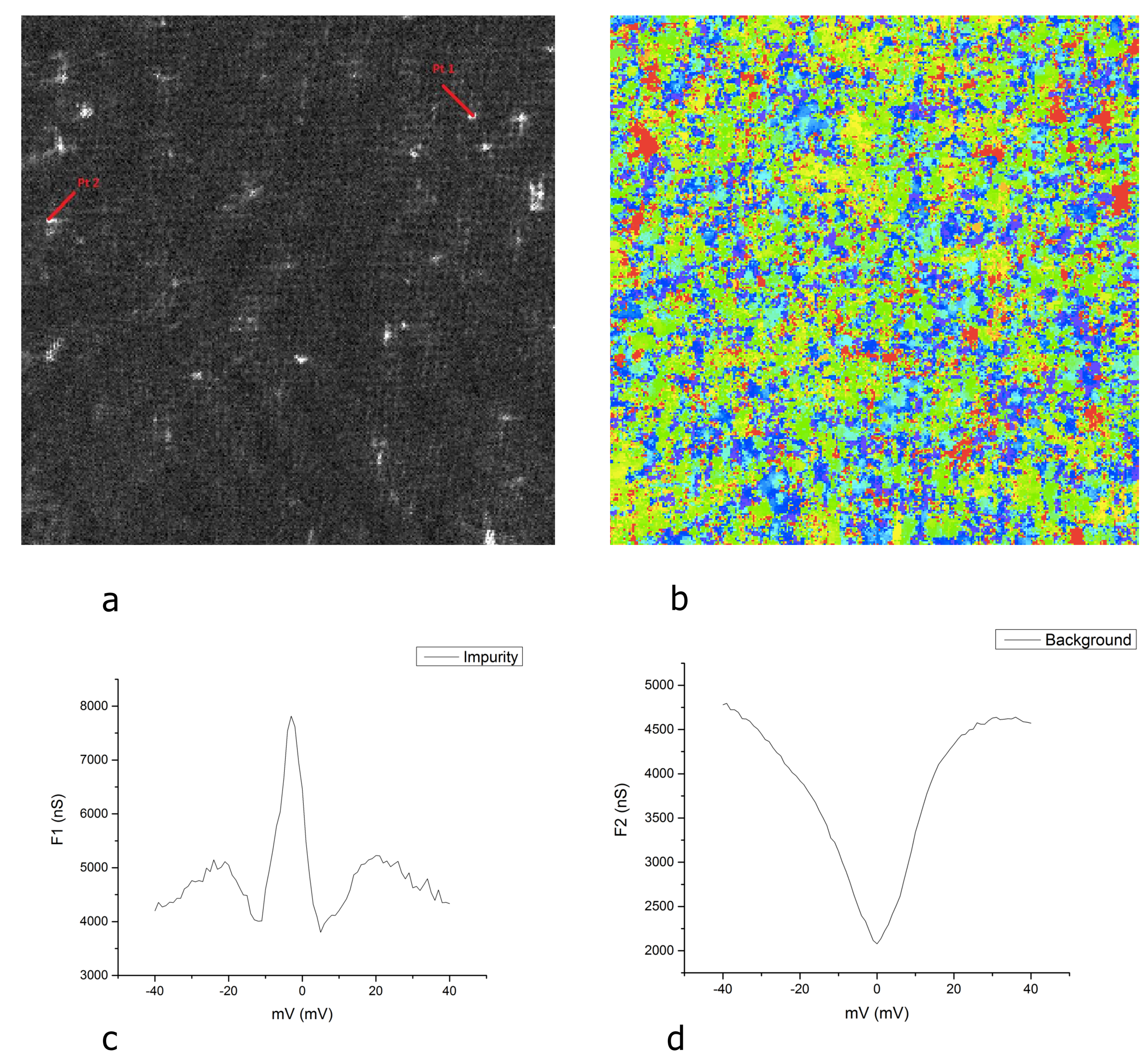

Fig. 4. (a) A layer spectral image showing density of states of a 32 K under-doped sample of Bi-2201 at 0 mV, indicating points being taken as impurities. (b) A Gap map of the image. (c) A spectrum taken from the impurity of a 25 K under-doped sample, showing main peak in the center and resonance peaks at approximately ±20 mV. (d) A spectrum taken as background from the same sample, showing a gap in the center.

The first step was averaging spectra for each type: impurity effected regions and non-effected regions, and then normalized the former one with the latter one. And then the energy level of the resonance peak was found by peak fitting, a process to determine peak locations using Gaussian model.

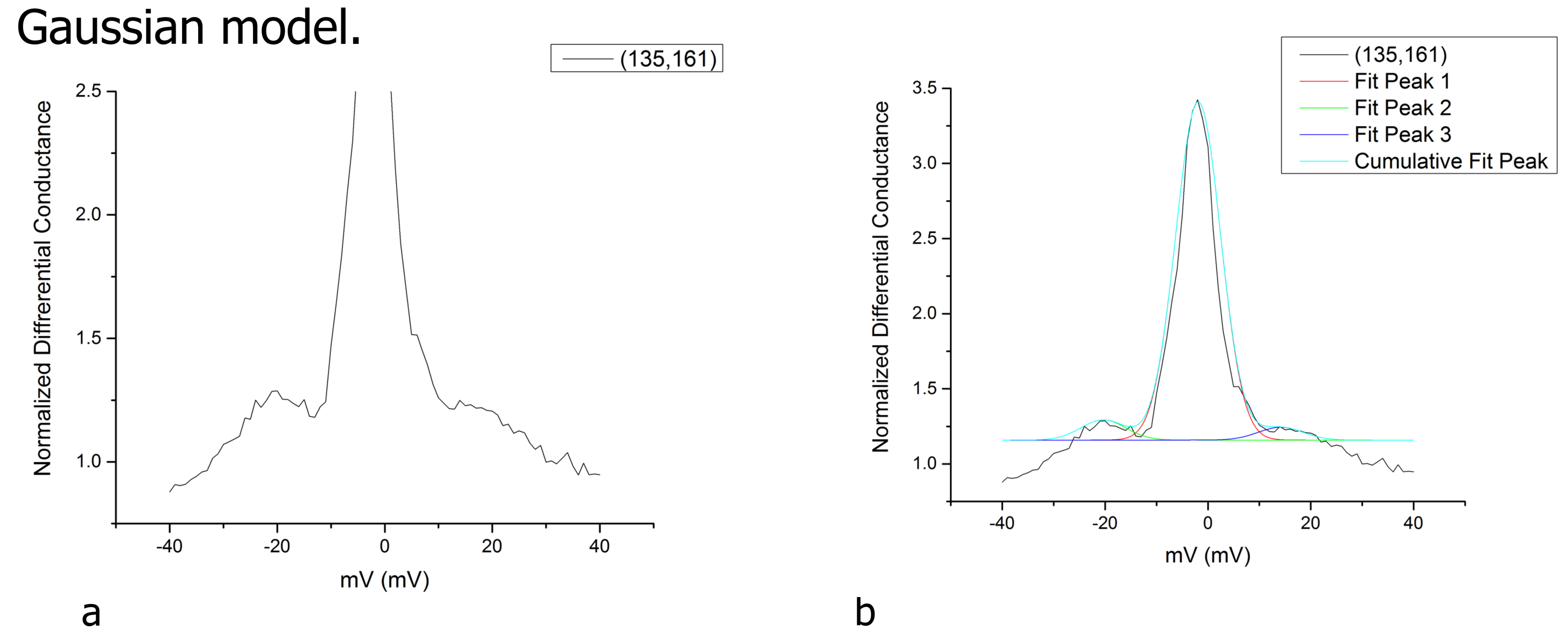

Fig. 5. (a) A normalized spectrum with resonance peaks of the 25 K sample mentioned above. (b) A peak fit of the same normalized differential conductance graph.

The comparison was done according to Presland formula $\frac{T_C}{T_{C_{\mathrm{Max}}}} = 1 - 82.6(x - 0.16)^2$, for various doping.

Table 1. Calculated Peak Data for Different Hole Doping

Hole Doping Number	Critical Temperature (K)	Positive Peak Position (mV)	Standard Deviation	Negative Peak Position (mV)	Standard Deviation
0.1012	25 K UD	10.218	4.53526	-14.492	5.84540
0.1074	27 K UD	15.818	3.49337	-11.924	7.15135
0.1278	32 K UD	17.087	5.25707	-20.102	0
0.16	35 K Opt	19.489	6.45345	-13.354	0
0.2367	18 K OD	17.457	7.69387	-17.041	8.79488
0.2432	15 K OD	8.108	2.86123	-10.765	1.53074

Fitting of these spectra are difficult when peaks are often not very pronounced. Negative peaks are especially more evasive and harder to find, giving less data points and more inconsistency. Data is plotted below.

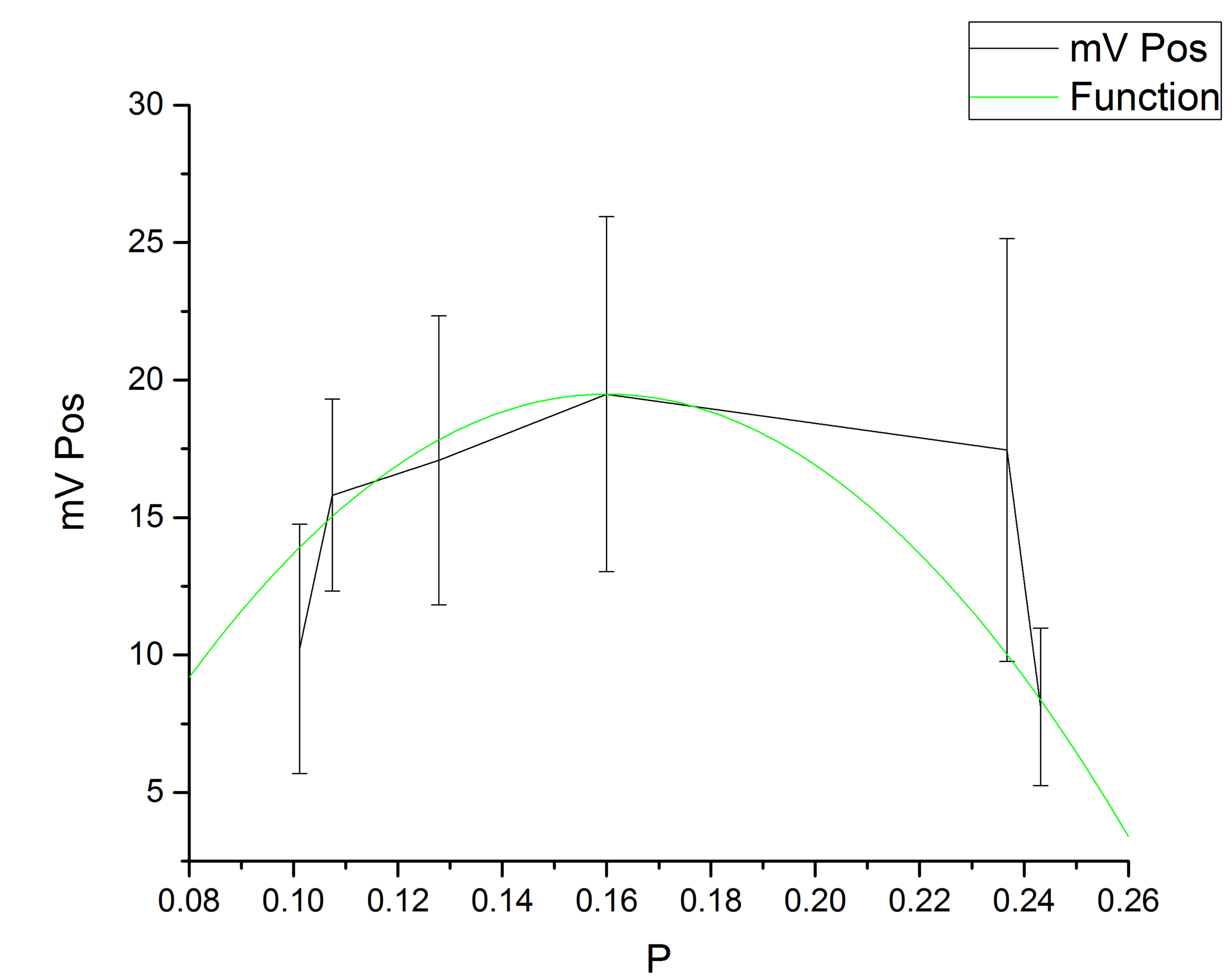

Fig. 6. Statistics on multiple data from various hole doping numbers, positive side. Expected value shown in green line.

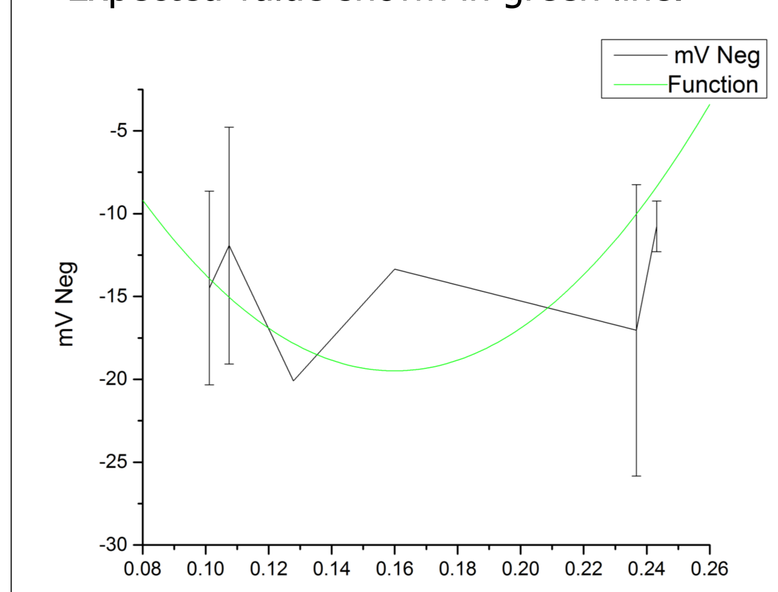

Fig. 6. Negative side. Expected value shown in green line.

Summary: It is demonstrated that the extracted gap values as a function of doping of Bi-2201 impurities are consistent with the expected values from the Presland formula. Hence, STM of impurity affected regions may be helpful in extracting superconducting gap size which is often obscured by a coexisting pseudo gap spectral signature.

Reference: Michael Boyer, Investigating the Relationship Between the Superconducting and Pseudogap States of the High-Temperature Superconductor Bi-2201 Using Scanning Tunneling Microscopy (2006).