A Consistent Picture of Electronic Raman Scattering and Infrared Conductivity in the Cuprates

T.P. Devereaux[1] and A.P. Kampf[2]
[1]Department of Physics, University of Waterloo, Waterloo, Canada, N2L 3G1
[2]Theoretische Physik III, Universität Augsburg, 86135 Augsburg, Germany

Calculations are presented for electronic Raman scattering and infrared conductivity in a $d_{x^2-y^2}$ superconductor including the effects of elastic scattering via anisotropic impurities and inelastic spin-fluctuation scattering. A consistent description of experiments on optimally doped Bi-2212 is made possible by considering the effects of correlations on both inelastic and elastic scattering.

1. INTRODUCTION

Impurity effects in the cuprates have played a major role in clarifying the nature of unconventional superconductivity. However, the magnitudes of the scattering rates inferred from different experimental probes on the same sample widely vary. The magnitude of the impurity scattering needed to fit $\lambda(T)$ and the extrapolated $T = 0$ resistivity are generally much smaller than those needed to fit the measured frequency dependence of the infrared conductivity (IR) and the Raman response.

In this paper we explore the role extended impurities have on transport properties in an attempt to resolve the abovementioned discrepancies. In particular, we re-examine the IR and the electronic Raman response of Bi-2212 including the effects of electronic correlations on both inelastic and elastic scattering potentials, and compare our results with the extrapolated $T = 0$ normal state resistivity and the crossover temperature for $\lambda(T)$. We find that a consistent picture emerges when we include the extended range of impurity scattering as well as antiferromagnetic (AF) spin fluctuations.

We use an algebraic solution for the impurity T-matrix presented in Ref. [2] for a model which represents the effects of impurities in a metal with short range AF order on a square lattice. α is the control parameter which distinguishes between point-like ($\alpha = 0$) and extended ($\alpha \neq 0$) impurity potentials. Since here we are interested in only the low frequency behavior of the IR and Raman response, we take a simple route and include spin fluctuations in RPA, using $U = 2t$. The reader is refered to Ref. [3] for details.

The salient point of the calculations is that correlations produce both strongly anisotropic elastic and inelastic scattering potentials. Reflecting AF correlations, the potentials are strongest for quasiparticles located near the Brillouin zone (BZ) axes and smallest along the diagonals. As an important consequence, the IR and B_{2g} Raman response do not pick up regions where the scattering is large and is governed by small scattering along the BZ diagonals. However, the B_{1g} Raman is governed by scattering near the BZ axes and is thus extremely sensitive to AF correlations. Turning on α even slightly leads to an effective increase in the strength of the impurity potential and is manifest in the increasingly smeared spectra as well as the value of ω^*, defined as the frequency where the cubic frequency dependence of the B_{1g} channel becomes sub-dominant [4]. Therefore a much smaller concentration of extended impurities is needed to have the same effect as isotropic impurity scattering.

Fits to the Raman spectra taken at $T = 0.5T_c$ on Bi-2212 are presented in Fig. 1, while fits to the IR in both the normal and superconducting state on a similar sample with a slightly higher T_c taken by Wang *et al.* [5] are shown in Fig. 2. We find that theory underestimates the IR scale by only a factor of 1.5 (the fits in Fig. 2 are scaled by this factor). The results agree excep-

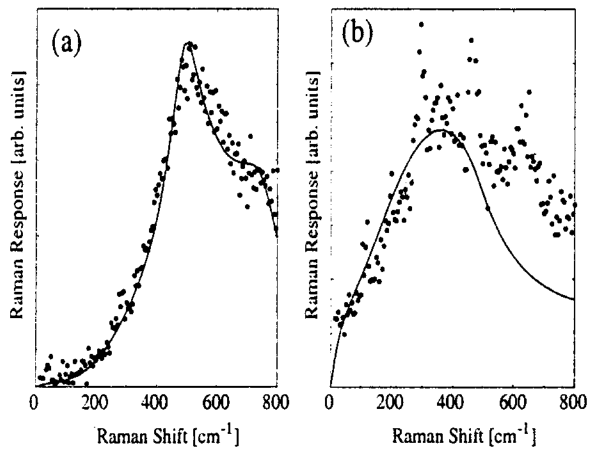

Figure 1. Fits to the B_{1g} (a) and B_{2g} (b) low temperature spectra on Bi-2212 (T_c=86K) taken by R. Hackl *et al.* in [1].

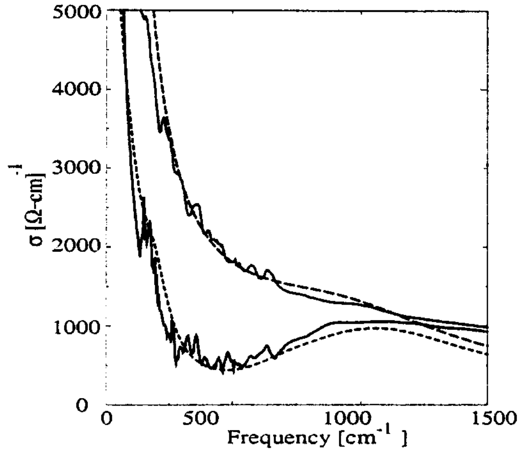

Figure 2. Fits to the normal and superconducting IR on Bi-2212 (T_c=93K) taken by N. L. Wang *et al.* [5].

tionally well with the measured spectra especially at low frequencies where the effects of impurities are dominant.

Assuming a Drude model for $\rho(T{=}0)$ ($\approx 10\mu\Omega$-cm) and a plasma frequency ω_{pl}=1.2 eV [6] implies a scattering rate $1/\tau_{imp} = 15\text{cm}^{-1}$, while the penetration depth T to T^2 crossover [7] measured in the same sample [8] as the Raman data gives 12 cm^{-1}. Previous Raman fits using isotropic impurity scattering only and a Fermi surface restricted approach required $1/\tau_{imp} = 2\Gamma = 72$ cm^{-1}[4]. Our calculation for $\alpha = 0.5$ yields $1/\tau_{imp}^{ave} = 23$ and 20 cm^{-1} for the FS averaged impurity scattering rate for t = 81 and 69 meV, respectively. Given the uncertainty in estimating $\rho(T{=}0)$ and ω_{pl}, this is in favorable agreement with existing measurements.

In summary we have shown how the inclusion of electron correlations in both inelastic and elastic scattering potentials lead to a consistent description of the channel dependent Raman and IR response and lead to better fits than previously achieved. The overall intensity of the IR can be accounted for and the effect of extended impurities on the low frequency behavior of the Raman response can resolve the discrepancy between large impurity scattering rates needed previously for IR and Raman fits and the small rates needed for transport.

We thank R. Hackl and N. L. Wang for sharing the data presented in Figs. 1 and 2, respectively.

REFERENCES

1. D. Einzel and R. Hackl, J. Raman Spect. **27**, 307 (1996).
2. A. P. Kampf and T. P. Devereaux, Phys. Rev. B **56**, 2360 (1997).
3. T. P. Devereaux and A. P. Kampf, to appear in Phys. Rev. B, Jan. 2000.
4. T. P. Devereaux and A. P. Kampf, Int. J. Mod. Phys. B **11**, 2093 (1997).
5. N. L. Wang *et al.*, Phys. Rev. B **59**, 576 (1999).
6. L. Forró *et al.*, Phys. Rev. Lett. **65**, 1941 (1990).
7. P. J. Hirschfeld and N. Goldenfeld, Phys. Rev. B **48**, 4219 (1993).
8. O. Waldmann *et al.*, Phys. Rev. B **53**, 11825 (1996).