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Model for anomalous transverse voltages in inhomogeneous high-T_c superconductors.

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The anomalous peaks in the transverse resistivity which are observed in many high-T_c systems in the transition from the normal to the superconducting state are thought to be at least partly caused by the inhomogeneity of the material. We model an inhomogeneous sample by using a two-dimensional random resistor network. Each resistor is characterized by a highly non-linear current-voltage relation which incorporates flux-creep and flux-flow. Values for T_c or the vortex pinning energy U_0 are assigned randomly to each resistor. Depending on the type of inhomogeneity various kinds of anomalies can be reproduced, e.g. resistive peaks which increase or decrease with increasing magnetic field.

In many high-T_c samples the *transverse* resistivity shows peaks near the transition from the normal to the superconducting state, even in the absence of a magnetic field. So far, this anomalous behaviour was assumed to be an intrinsic property related to the vortex motion [1]. However, recently two other anomalies were reported: i) peaks also in the *longitudinal* resistivity [2] and ii) a rather unpredictable change of the transverse resistivity anomalies when the oxygen content is varied by sequential oxygen anneals. This suggests that the observed anomalies are at least partly caused by the inhomogeneity of the samples.

In high-T_c materials, even in high-quality single crystals, the oxygen impurity concentration is inhomogeneous. This inhomogeneity leads to spatial fluctuations in the charge carrier density hence to fluctuations in the critical temperature T_c. Both fluctuations in the charge carrier density and in T_c cause pinning of vortices [3]. Since the local value of T_c depends on the long-range average of the charge carrier density and the vortex pinning energy U_0 depends on the fluctuations in the charge carrier density (and T_c), it is justified to assume that T_c and U_0 can fluctuate *independently* over a sample.

To model an inhomogeneous high-T_c superconductor we use a square two-dimensional random resistor network, see fig. 1. The resistors represent homogeneous superconducting domains, which are perfectly connected to each other.

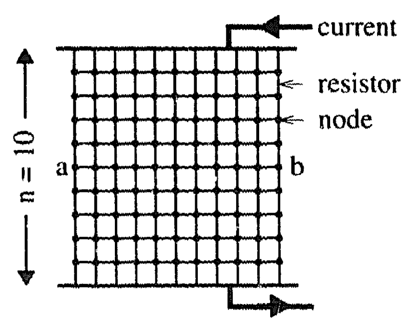

Figure 1. *Random Resistor Network. The top and bottom rows of resistors are connected to equipotential bars through which the current is fed. The connections for the transverse voltage are marked* a *and* b.

In each superconducting domain the vortex motion causes dissipation. For currents below the critical current density j_c the vortices are pinned but can hop from pinning site to pinning site because of thermal activation. Since the transport current leads to a Lorentz force on the vortices, the average direction of the vortex motion will be in the direction of the Lorentz force. For currents above j_c the vortices are not pinned but are only slowed down by a viscous drag force. For the overall current-voltage relation for one domain we adopt the combined flux-flow/flux-creep model of

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Griessen [4]:

$$E(j) = \left[S \exp\left(\frac{U_0}{kT}\right) / \sinh\left(\frac{Aj}{kT}\right) + \frac{1}{\rho_{flow} j} \right]^{-1} \quad (1)$$

where E is the voltage over a domain and j the passing current. For the magnetic field and temperature dependence of U_0 we take [5,6]:

$$U_0(B,T) = U^* \, (1 - T/T_c)^{3/2} / B \quad (2)$$

Since we expect no thermally activated vortex motion near the transition from the superconducting to the normal normal state the first term in eq. 1 should vanish at $B = B_{c2}(T)$ where B_{c2} is the upper critical magnetic field. Thus we set:

$$S(B,T) = S_0 \, [B_{c2}(T)/B - 1] \quad (3)$$

Inhomogeneity is brought into the model in two distinct ways: either i) U^* is lognormally distributed [7] and T_c is constant or ii) U^* is constant and T_c is Gaussian distributed. Once each domain is assigned values for U^* and T_c for given T and B for each domain the I-V relation is fully determined. By solving for a given applied voltage over the two current bars for each network node Kirchhoff's current law, we obtain the potential of each node and thus the current through each domain. In this paper we focus on the behaviour of the transverse resistivity, which we define as

$$\rho_{xy} = [E_a - E_b] / j_{tot} \quad (4)$$

where $E_a - E_b$ is the voltage between the nodes marked a and b in fig. 1 and j_{tot} is the total current passing through the network. All results presented in the following were obtained at a constant current density of $10^6 Am^{-2}$ and with a network with size n equal to 10.

Figure 2 shows anomalous peaks in the transverse resistivity for a network with random U^*. The height of the peak *increases* with increasing magnetic field. In the case of a random T_c the anomalous peak *decreases* with increasing magnetic field, see fig. 3. We see that our model on a qualitative level nicely explains various observed anomalies. Comparison with experiments can lead to insight in the kind of inhomogeneity of samples.

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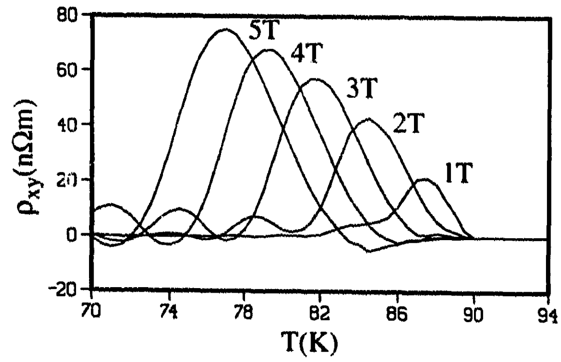

Figure 2. *Transverse resistivity as a function of temperature for different magnetic fields, with U^* lognormally distributed with $U_0^* = 2 \cdot 10^{-19} JT$ and $\gamma = 1.4$ and T_c, constant, equal to $90K$.*

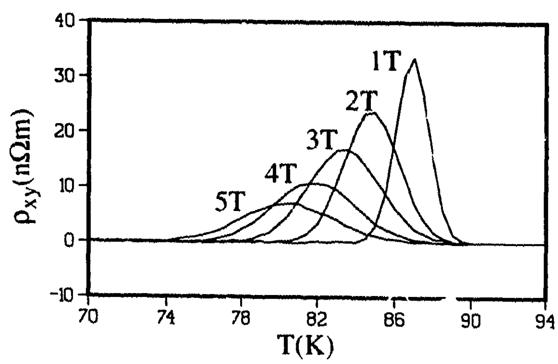

Figure 3. *Transverse resistivity as a function of temperature for different magnetic fields, with U^*, constant, equal to $5 \cdot 10^{-19} JT$ and T_c Gaussian distributed around $89K$ with $\sigma_{T_c} = 1K$.*

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