Muon Spin Rotation in Overdoped $Tl_2Ba_2CuO_{6+\delta}$

A recent Letter [1] has suggested that the suppression in T_c observed with overdoping in $Tl_2Ba_2CuO_{6+\delta}$ can be attributed to a decrease of the superconducting condensate density n_s regardless of the increasing normal-state carrier density n. This conclusion was based on an effective penetration depth in the presence of pair breaking, given generally by $\lambda^2 = \lambda_L^2(1+\xi_0/l_b)$, where λ_L is the London penetration depth, ξ_0 the coherence length, and l_b a pair-breaking distance. Fitting their muon data with a linearized limiting form, the authors present the result "$l_b \sim 60.0$ Å which is entirely reasonable." The authors neglect to mention, however, that their second fit using the general expression and full range of data yields a much smaller value: Upon duplicating their fit, we find $l_b \leq 4$ Å for an effective mass ratio $m^*/m_e \gtrsim 5$. The inconsistency arises because these values of l_b imply opposite limits of both weak and strong pair breaking in the same data. The full-range fit implies strong pair breaking (even though it should not apply for optimum T_c), since $l_b < \xi_0$, where $\xi_0 \approx 15$ Å at optimum T_c. But, since the linearized form is valid only for strong pair breaking, the larger l_b obtained is also self-contradictory, given that $l_b > \xi_0$ over most of the range and implies weak pair breaking.

Although numerous other experiments were touched upon in the Letter, an obvious opportunity for error lies with the approach stated in the abstract, "In the framework of the clean-limit London model, $\sigma(0) \sim \lambda^{-2} \sim n_s/m^*, \ldots$." The "$\sim$" symbol is indeed a caveat for an ill-defined relationship between muon depolarization rates, $\sigma(0)$, and λ, since n_s/m^* is found only by assuming that $\lambda^2\sigma(0)$ is a constant. Experimentally, however, this product can vary by $\sim 60\%$ (e.g., see Fig. 1, Ref. [1]).

The approach of the subject Letter assumes a perfect three-dimensional vortex lattice. In reality, mechanisms such as fluxon pinning (Gaussian and random fluctuations) [2], longitudinal disordering [3], fluxon motion [4], finite fluxon core size [2], and stoichiometric inhomogeneities [5,6] induce significant deviations in vortex lattices which are reflected in the temperature dependence and magnitude of $\sigma(T)$. For example, it is shown that $\sigma(0)$ obtained by fitting $\sigma(T)$ with a power law is larger for a $T_c \sim 66$ K sample than for a $T_c \sim 84$ K sample. The authors attribute this to an unknown doping variation of the 84 K sample. But extrapolations of the lowest temperature points yield nearly the same value. In any case, the data could simply indicate that nonoptimum doping produces depressed T_c and enhanced fluxon pinning. In addition, $\sigma(T)$ shows strong departure from the s-wave pairing form with increased overdoping and becomes nearly linear with temperature for the lowest-T_c (~ 13 K) sample. Although the authors invoke pair breaking, such effects can also arise from thermal fluxon motion, granularity, and stoichiometric inhomogeneity. The reduced specific heat jumps ($\Delta C_p/T_c$), the enhanced low-temperature C_p/T values, low Meissner fractions, and anomalous temperature dependences in $\sigma(T)$ in the overdoped samples suggest departures from optimization in high-T_c superconductors [6,7], where $\Delta C_p/T_c \propto m^*$ in two dimensions.

The conclusions in the Letter concerning n_s/m^* are based on a formula "$\sigma \sim \lambda^{-2}$" that is generally qualitative, owing to the undetermined extrinsic fluxon interactions; a rigorous treatment was shown earlier to be amenable to the optimized compounds, where extrinsic effects are minimized [6] or included [2–5]. Contrary to the authors' claims, their data do not provide unambiguous and general information on n_s/m^*: One cannot discern from the data whether the depression of T_c in the overdoped regime is associated with a decrease in condensate density or even if strong pair breaking is involved at all. In fact, a quantitative reexamination of their analysis leads to the result, $n_s/n > 1$ and constant, after correcting for ξ_0/l_b. This is unphysical and in conflict with the stated conclusions of the subject Letter.

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