Electromigration in the dissipative state of high-temperature superconducting bridges

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Commonly, superconducting nanocircuits are not concerned by atomic migration problems chiefly because in the non-dissipative superconducting state, there is no net momentum transfer between the carriers (Cooper pairs) and the atomic lattice. Furthermore, in low critical temperature superconductors, the critical current density J_c lies well below the current density J_{EM} needed to start displacing atoms.

Interestingly, this scenario may no longer hold for cuprate superconductors. The reason is twofold; on the one hand, the atomic diffusion barrier can be relatively weak for certain atoms like oxygen in $YBa_2Cu_3O_{7-d}$, consequently reducing J_{EM}. On the other hand, these compounds exhibit high superconducting critical current densities. Under these circumstances, when the dissipative state is accessed by applying a current density $J > J_c$, the component of the current carried by the quasiparticles can surpass J_{EM} and produce irreversible damage to the material even at local temperatures substantially lower than the melting point of the compound. This phenomenon has been largely oversighted so far.

In this work, the current stimulated atomic diffusion in $YBa_2Cu_3O_{7-d}$ superconducting bridges is investigated. A superconductor to insulator transition can be induced by the current controlled electromigration process, whereas the partial recovery of the superconducting state can be achieved by inverting the polarity of the bias. Interestingly, the temperature dependence of the current density $J_{EM}(T)$, above which atomic migration takes place, intersects the critical current density $J_c(T)$ at certain temperature T^*. Therefore, for $T<T^*$, the current-induced dissipative state cannot be accessed without leading to irreversible modifications of the material properties [1]. This phenomenon could also lead to the local deterioration of high critical temperature superconducting films abruptly penetrated by thermomagnetic instabilities.

References

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