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Nonlocal Four-Terminal Method for Electrical Measurements

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The four-terminal measurement technique is a foundational and widely utilized method for determining the electrical conducting characteristics of materials, especially thin films, bulk crystals, semiconductors, and complex nanostructures. By employing four separate electrical contacts - two for current injection and two for voltage measurements - on top of a sample, this methodology effectively eliminates the influence of contact and lead resistance, which can otherwise introduce significant errors in resistance and conductivity measurements. Here, we introduce a through-sample nonlocal four-terminal method based on the Landauer-Büttiker approach relating the electrical resistance to scattering properties of a mesoscopic conductor. The new methodology has been tested on all-metallic hybrid sandwiches composed of two 80 nm thick NbN films and a 50 nm thick core made of three archetypal ferromagnetic materials, F = Co, Ni, or NiCu alloy. Using a simple equivalent circuit model with six resistances connecting the four probes, we have explained some unexpected findings in the normal state and the temperature range corresponding to the normal-to-superconducting transition. Notably, it relates apparent negative resistances of some trilayers above the NbN critical temperature. By comparing NbN and NbN/F/NbN trilayers, we demonstrate that the inclusion of an F interlayer leads to a significant shift in the onset of the superconducting transition, particularly in the near-surface region, and increases the overall transition width. This work provides insights into the delicate interplay between superconductivity and magnetism and opens pathways for engineering interface-sensitive superconducting spintronic devices.

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