Microscopic investigation of a metal-superconductor proximity bilayer

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The local properties of superconductors (S) are modified when they are in good electrical contact with a normal metal (N). The reciprocal influence of the two metals is characterized by appearance of superconductivity and Cooper pairing in N as well as a weakening of the superconductivity in S (proximity effect) [1].

The underlying spatial variations in the condensation amplitude and order parameter are an essential aspect of the proximity effect but until now it has not been possible to investigate this directly. With low energy muons we have performed depth resolved investigations of the magnetic response of Al(90nm)/Nb(400nm) bilayers as a function of temperature and applied magnetic field (field parallel to the surface, Meissner geometry). For $T_{cAl} << T < T_{cNS}$ (T_{cAl} critical temperature of Al, T_{cNS} critical temperature of the NS bilayer $\sim$ 9 K) the local magnetic field $B(z)$ in Al linearly decreases from the surface and shows a pronounced diamagnetic shift with respect to the external field. This response is a direct manifestation of the presence of induced Cooper pairs in normal state Al and shows that the pair density is constant over the entire thickness of 90 nm. The linear dependence of $B(z)$ in Al qualitatively corresponds to the prediction of the clean limit theory based on the Eilenberger equations [2], although in the investigated samples only Nb is clearly in the clean limit. From the data we determine the temperature dependence of the induced superfluid density reflecting the presence of low lying electronic excitations in the proximated Al layer.

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