MATERIAL WITNESS

YET MORE LAYERS

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The award of the 1987 Nobel Prize in Physics to Georg Bednorz and Alex Müller for their discovery of high-temperature superconductivity in cuprate materials looks today more deserved than ever — but perhaps not quite for the reasons first imagined. Although applications of these new superconductors have been more limited than initial breathless predictions anticipated, the real value of the work is proving to be the disclosure of the wealth of exotic electronic properties to be had from such perovskite-type transition-metal oxide materials, of which superconductivity might prove ultimately to be not the most useful after all.

Quite apart from the applications, the physics of these materials is extraordinarily rich — a result of the potential for new kinds of coupling between the electrons' degrees of freedom, particularly their electronic and magnetic properties. These interactions fuel interest in linking semiconducting behaviour with ferromagnetism, with consequent possibilities for spintronics, and new memory and magnetoresistive technologies.

One of the most promising systems to emerge recently for exploring these phenomena is the interface of insulating lanthanum aluminium oxide ($LaAlO_3$; LAO) and strontium titanium oxide ($SrTiO_3$; STO). Here the interfacial electrons can behave as a two-dimensional electron gas[1], which can apparently form a charge-ordered state with ferromagnetic spin alignment[2], even though the bulk oxides are non-magnetic. At temperatures below about 0.2 K this electron gas can undergo pairing to form a superconducting state[3], and in fact — most unusually — the superconducting and magnetic behaviour can coexist due to nanoscale phase separation[4,5].

Although these observations, hinting at a long-suspected interplay between superconductivity, magnetism and spin–orbit coupling, have stimulated an avalanche of studies, there is still some debate about the nature of the magnetic ordering. Some studies have suggested that it is strongly dependent on the thickness of the LAO layer[6], or have even failed to find evidence for it at all[7]. It is with these ambiguities in mind that Bi *et al.* have set out to explore the ferromagnetism of the LAO/STO interface using magnetic force microscopy[8].

The magnetic behaviour is predicted to be dependent on the carrier density in the interfacial electron gas — a quantity that can be conveniently varied with a gate electrode applied to a LAO/STO heterostructure. In this way, Bi *et al.* find a rich variety of magnetic behaviours at room temperature. At low carrier density (or equivalently, small LAO layer thickness), there is no magnetism, and the interface is insulating. Above a threshold density a ferromagnetic phase is formed, which persists, for an increasingly narrow range of densities, even above 300 K. For still greater carrier density the magnetism vanishes and the interface undergoes a transition from insulating to metallic; but then above another threshold there exists a second magnetic phase that, at low temperature, coexists with superconductivity.

In other words, this system seems to be even richer than suspected, with two distinct kinds of magnetism. This observation places still more demands on a theoretical framework for comprehending the heterostructure — but it might also enhance the possibilities for creating spintronic and quantum devices. ❐

References

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