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Atomic-layer superconductors

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One or two atomic layers on crystal surfaces, or one-crystal unit layer of ultrathin films are recently found to be superconducting: a monolayer of Pb, two atomic layers of In and Ga [1], and a monolayer of Tl+Pb alloy [2] on Si(111) surface, a single unit layer of FeSe [3] film, Ca-intercalated double-layer graphene [4], and so on. Interesting points of these 'atomic-layer superconductors' may be three fold; (1) Two-dimensionality, (2) Influence of substrates, and (3) symmetry breaking.

(1) Two dimensionality (2D): According to Mermin-Wagner Theorem, 2D lattices do not have phase transitions due to large fluctuation. This means no superconductivity in monatomic layers. But in reality, even monatomic layers are not strictly 2D, but 'quasi-2D' having a finite thickness due to spread of electron wavefunction in surface-normal direction, which results in atomic-layer superconductivity. In addition, we can expect Berezinskii-Kosterlitz-Thouless (BKT) transitions in the atomic-layer superconductivity, in which unusual low-temperature phases are expected having exponentially decaying correlation with distance. We have experimentally observed the large fluctuation and BKT transition at atomic-layer superconductors [1,2].

(2) Influence of substrate: The superconducting transition temperatures TC of most of the known atomic-layer superconductors are lower than those of the bulk materials. This is believed to be due to the interaction with the substrates. One exception is the single unit-layer FeSe film which shows TC higher than 100 K while that of the bulk FeSe crystal is a few K [3]. One explanation for this is interface phonons which are effective for Cooper pairing. This example indicates possibility to enhance TC by making materials as thin as monolayer thick on suitable substrates.

(3) Symmetry breaking: Since the material surfaces are in a situation of break-down of space-inversion symmetry, spin degeneracy in electronic states can be lifted (Rashba effect) [2]. Superconductivity at such surfaces and monolayers are then novel because singlet- and triplet- Coopers can be mixed (parity-broken superconductivity).
In my talk I will show some experimental data of transport at some atomic-layer superconductors, revealed by in situ four-point probe measurements in ultrahigh vacuum, and discuss the future.

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