The thinnest high-temperature superconductor

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Superconductivity is one of the most important topics in physics and materials science. The superconducting transition temperature \( T_C \) of a quasi-2D superconductor, a superconductor with one dimension smaller than the coherence length of Cooper pairs, is normally descending with decreasing sample thickness since thermal and quantum fluctuations are expected to destroy the superconducting phase coherence even at low temperatures. The question of how thin a superconductor can be is not only crucial for understanding superconductivity in low-dimensional systems but also important for technological application in low-dissipation quantum devices.

Nowadays, with the development of molecular beam epitaxy (MBE) technique, the fabrication of high-quality crystalline metallic films with thickness down to one unit-cell (1-UC) on semiconducting or insulating substrates becomes reality and makes it possible for the study of superconductivity at 2D limit. Different from traditional theoretical understanding of 2D superconductivity for free-standing films, in such film/substrate heterostructures the interface may dramatically affect the superconductivity and even possibly enhance \( T_C \) compared with thicker film or bulk case. Recently, a research team led by Professor Qi-Kun Xue successfully grew 1-UC-thick FeSe films on SrTiO\(_3\) (STO) substrate by MBE, where a superconducting-like gap was discovered by \textit{in situ} scanning tunneling microscopy/spectroscopy (STM/STS) study \[1\]. Surprisingly, the detected gap is 20 meV and almost 10 times larger than the gap of bulk FeSe. Soon after that, angle resolved photoemission spectroscopy experiments further revealed a nearly isotropic gap of above 15 meV, which closes at a temperature of around 65 K \[2,3\]. However, the question is whether the observed gap is a superconducting gap. Direct evidence of superconductivity in 1-UC FeSe films, such as zero resistance and Meissner effect, is highly desired.

Very recently, for the first time Professor Jian Wang and Professor Qi-Kun Xue’s collaboration team demonstrated that the 1-UC-thick FeSe films grown on STO substrates are high \( T_C \) superconductors by direct transport and magnetic measurements \[4,5\], with an onset transition temperature \( T_C \) above 40 K and a critical current density \( J_C \sim 1.7 \times 10^6 \) A/cm\(^2\) at 2 K (Fig. 1), which are much higher than \( T_C \sim 8 \) K and \( J_C \sim 10^4 \) A/cm\(^2\) for bulk FeSe. The significantly enhanced superconductivity with high \( T_C \), \( H_C \), and \( J_C \) makes the 1-UC FeSe thin films on high-dielectric STO substrate attractive for potential applications in...
A milestone in methane conversion

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Direct conversion of methane, the dominating component of natural and shale gases, into key chemical feedstock and liquid fuels has long been a big challenge in chemistry and chemical engineering [1, 2]. The industrial processes for methane-resourced higher hydrocarbons (e.g. olefin and gasoline) are based on indirect methane conversion integrating several catalytic reaction technologies. The production of syngas (a mixture of H₂ and CO) by catalytic methane steam reforming over a supported Ni catalyst is always the first technology. The second is methanol synthesis from syngas using a supported Cu–ZnO catalyst. The third technology in the integration is methanol-to-olefin or methanol-to-gasoline, employing zeolite-based catalysts. The syngas production is energy intensive and capital costing; the breaking of C–H bonds in methane has to be substantially reversed in the subsequent processes to produce olefins and fuels [3]. When the syngas conversion is devised instead to produce higher hydrocarbons, inevitable loss of carbon as CO₂ would happen, leading to methane utilization efficiency no higher than 50%.

As the smallest hydrocarbon molecule in tetrahedron symmetry, methane holds the strongest C–H bond (434 kJ/mol) and the lowest polarizability. Suitable catalysts and oxidants (such as oxygen, halogens and water) are always desirable for the initiation (activation) and product selectivity control of its reaction [1–3]. Summarized in Fig. 1A are the presently known possibilities of direct methane conversion. Catalysts are the keys to these possibilities except the long-known energy-intensive high-temperature non-catalytic methane pyrolysis process for acetylene production (a). The discovery in the early 1980s of ethylene formation via oxidative coupling of methane over redox oxide catalyst (c) [4] had been very encouraging since it ignited the hope for formation of a carbon–carbon bond and higher hydrocarbons from methane. Another important avenue to direct methane conversion was discovered in early of the 1990s by Wang et al. at Dalian Institute of Chemical Physics (DICP), Chinese Academy of Sciences, which showed that bifunctional Mo-loaded zeolites can catalyze the dehydro-aromatization of methane for selective formation of benzene and naphthalene at above 600°C (f) [5]. Unfortunately, the yield of aromatics remained low and catalyst deactivation was fast due to surface coking.

Bao at DICP has been devoting a part of his group to searching for better catalysts for more efficient non-oxidative methane activation since the late 1990s. Their work has now advanced to a report in Science of 9 May [6], which uncovers that lattice-confined single iron sites embedded in silica matrix enable direct methane conversion exclusively to ethylene, benzene, naphthalene and hydrogen. Ethylene selectivity at the maximized methane conversion at 1363 K (48.1%) reached as high as 48.4% by carbon balance and the total selectivity to ethylene, benzene and naphthalene exceeded 99%, demonstrating an atom-economic process of direct methane conversion. The catalyst also exhibits a remarkable stability; no sign of deactivation was detected during a 60-hour reaction test (Fig. 1B). High-resolution high-angle annular dark-field scanning transmission electron microscopy and in situ X-ray absorption near edge spectroscopy/extended X-ray absorption fine structure spectroscopy measurements of the iron species, as well as theoretical calculations, suggest that the catalytic active sites would be SiO₂-embedded isolated Fe atoms that are coordinated with one silicon and two carbon atoms (inset of Fig. 1B). The