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High Curie temperature ferromagnetism and high hole mobility in tensile strained Mn-doped SiGe thin films

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Up to now, substantial work has been carried out on different materials-based diluted magnetic semiconductors, and great achievements have been made on increasing Curie temperature of these materials. However, the carrier mobility of the magnetic semiconductors is still low due to various scatterings, and rare studies have been performed to effectively enhance the carrier mobility. As we know, both high Curie-temperature ferromagnetism and high carrier mobility are important characteristics for ideal magnetic semiconductors, which are essential for spin polarized current generation and transport in real spintronic semiconducting devices.

Recently, the research team led by Prof. Gang Xiang from Sichuan University, China has demonstrated a way for enhancing both ferromagnetism and carrier mobility in group-IV thin films compatible with current silicon technology. Specifically, Mn-doped SiGe thin films were first fabricated on Ge substrates by radio frequency magnetron sputtering and then crystallized by rapid thermal annealing. After annealing, the samples became ferromagnetic, in which the Curie temperature increases with increasing Mn doping concentration and reaches 280 K with 5% Mn concentration. The data suggest that the ferromagnetism comes from the hole-mediated process and is enhanced by the tensile strain in the SiGe crystals. In addition, the Hall effect measurement up to 33 T to eliminate the influence of anomalous Hall effect reveals that the hole mobility of the annealed samples is greatly enhanced and the maximal value is ~1000 $cm^2 \cdot V^{-1} \cdot s^{-1}$, 1–2 orders of magnitude bigger than other magnetic semiconductors, owing to the tensile strain-induced separation of heavy holes and light holes on the valence band top. As a result, the tensile-strained Mn-doped SiGe thin films exhibit both high Curie-temperature ferromagnetism and high hole mobility, which is one piece of few exciting news since the outbreak of COVID-19 epidemic, especially for the community of semiconductor spintronics.

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2D MAGNETIC SEMICONDUCTORS

A crystal graph multilayer descriptor

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2D ferromagnetic (FM) materials are crucial for next-generation spintronic devices owing to their atomic thickness and controllable electron/spin degree of freedom. However, due to the diversity of 2D structures and the complexity of magnetism, massive search for 2D FM materials is still a tough task. Recent development of machine learning technique has shown great potential in rapid searching for material with target property in large chemical space. Nevertheless, due to the lack of material data and proper descriptor, searching for 2D FM materials remains a challenge.

Recently, the research team led by Prof. Jinlan Wang from School of Physics, Southeast University, China has reported 89 intrinsic ferromagnetic 2D materials through rapid screening framework powered by advanced machine learning techniques and high-throughput calculations. Some of the selected FM materials have considerable high Curie temperature, for example, the Curie temperature of $CrCuTe_2$ monolayer is predicted to be 898 K. Additionally, a sizeable database of 2D magnetic materials, including 542 FM and 917 antiferromagnetic materials, has been built for further research. Specifically, a new descriptor named CGMD (crystal graph multilayer descriptor) is developed to describe complex 2D structures and various properties by combining crystal graph and elemental properties in form of multiple feature layers. CGMD shows good performance (over 90% accuracy) on predicting thermodynamic stability, magnetic ground state and bandgap of 2D materials even with a small-scale training dataset. The comprehensive data-driven framework with flexible descriptor might pave a feasible route for machine learning based rapid screening of diverse structures and/or complex properties.

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