Novel phenomena in oxide two-dimensional electron systems

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Abstract: I will present results about oxide two-dimensional electron systems (2DES) characterized by functional properties engineered by epitaxy. I will show that 2DES with multiple coexisting order parameters can be designed and realized using this approach.

Multiferroics are compounds in which at least two ferroic orders coexist – typically (anti)ferromagnetism and ferroelectricity [1]– and whose investigation has been a major area of materials science during the last two decades. While magnetic order can arise in both insulating and metallic compounds, ferroelectricity is in principle only allowed in insulators, although ferroelectric metals were proposed over 60 years ago [2]. Recently, several two-dimensional (semi)metals have been reported to behave as ferroelectric [3-5]. Yet, the combination with magnetic order remains elusive. Here we show that a metallic and multiferroic system can be created in an oxide-based two-dimensional electron gas (2DEG) by heterostructure engineering.

A ferromagnetic and a ferroelectric 2DEG has been theoretically modeled and experimentally realized by introducing two-unit cells of the antiferromagnetic insulator $EuTiO_3$ between $LaAlO_3$ band insulator and ferroelectric (FE) 1%Ca-doped $SrTiO_3$.

By using total electron yield Ti-$L_{3,2}$ edge x-ray linear dichroism we show that the 2DEG orbital splitting and related Ti-O polar displacements are tuned in a non-volatile manner by the FE polarization direction, switched *in-situ*. Eu $M_{4,5}$ edge and Ti-$L_{3,2}$ edge x-ray magnetic circular dichroism show that Eu and Ti- cations order ferromagnetically with an in-plane easy-axis.

Transport data and FE-polarization vs. gate voltage loop show an electric field-induced hysteresis of the sheet resistance correlated to the FE-polarization and an anomaly of the R_{sheet} vs T dependence at the FE Tc. Furthermore, the 2DEG displays an anomalous Hall effect and a magnetoresistance that can both be modulated and cycled by switching the remnant polarization, demonstrating a magnetoelectric coupling.

Our findings provide new opportunities in quantum matter stemming from the interplay between ferroelectricity, ferromagnetism, and Rashba spin-orbit coupling in an oxide 2DEG.

References

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