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High-density 2D electron system induced by oxygen vacancies in ZnO

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1 Introduction

The transparent semiconductor ZnO stands out for its numerous applications, notably due to its optoelectronic properties, which are also determined by electron density and dimensionality [1, 2]. The realization of a highly doped 2D electron system (2DES) in ZnO would be highly desirable for, e.g., high-power applications, as ZnO is cheaper, easier to process, and non-toxic compared to other transparent semiconductors such as In_2O_3. However, so far, only moderate electron densities of $2x10^{13}$ cm^2 had been achieved in ZnO, while the contribution of oxygen vacancies to its n-type conductivity remained controversial. This work reports the creation of a high-density 2DES in ZnO.

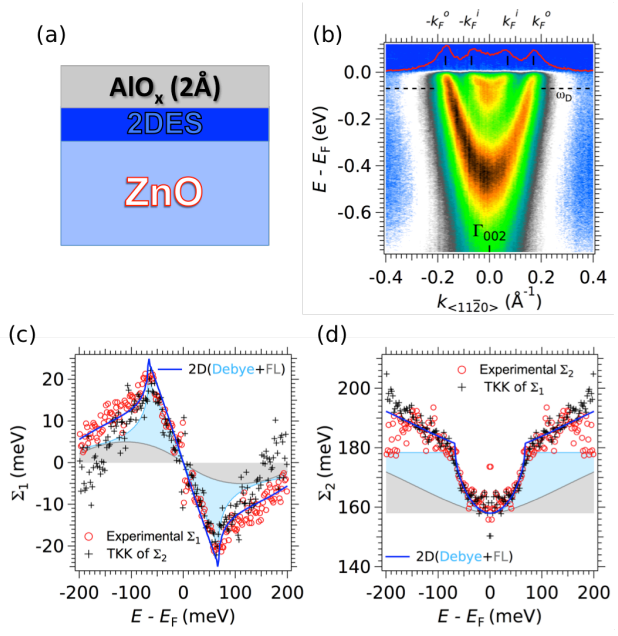

Fig. 1: (a) Fabrication of a highly doped 2DES in ZnO. Pure Al is evaporated at the surface of ZnO. The redox reaction produces a 2DES at the AlO_x/ZnO interface. (b) ARPES energy-momentum map of the 2DES. The red curve is the momentum distribution curve at E_F. The black vertical bars show the Fermi momenta k_F^i and k_F^o of the inner and outer subbands, respectively. Bands are coupled to phonons with a Debye energy ω_D shown by the dashed black line. (c, d) Experimental real and imaginary parts of the electron self-energy (red circles), and their Kramers–Kronig transforms (black crosses), for the outer subband of the 2DES. The dark blue curves are simultaneous fits to Σ_1 and Σ_2 using a model of a 2D Fermi-liquid (filled gray) dressed by Debye phonons (filled light blue). Adapted from Ref. [3].

2 Experiment

ARPES experiments were performed at BL-2A of KEK-PF and at synchrotron SOLEIL (France). The AlO_x/ZnO interface was obtained by in situ surface preparation as described in Ref. [3]. The sample temperature during measurements was 20 K. Variation of the photon energy in the range 30-110 eV revealed no changes in the energy-momentum dispersion, demonstrating the 2D character of the band structure. The pressure was below 10^{-11} mbar during measurements, and no degradation of the spectra quality was observed.

3 Results and Discussion

We observed (Fig. 1a) that the evaporation in ultra-high vacuum of an atomic layer of aluminum on ZnO creates a 2DES with electron densities up to 100 times higher than in previous studies. The 2DES results from oxidation of the Al layer and concomitant doping with oxygen vacancies of the underlying ZnO surface. The 2DES is composed of two subbands (Fig. 1b) with different effective masses. The self-energy of the 2DES (Figs. 1c-d) can be accurately described using a 2D Fermi liquid coupled to a Debye distribution of phonons. Thus, the inner band is wholly renormalized due to the proximity of its bottom with the phonon cutoff energy, whereas the outer band, dispersing deeper in energy, shows only a kink due to electron-phonon interaction.

References

[1] C. F. Klingshirn *et al.*, *Zinc Oxide: From Fundamental Properties Towards Novel Applications*, Springer Series in Materials Science **120**, Springer-Verlag (2010).
[2] H. Morko and Ü. Özgür, *Zinc Oxide: Fundamentals, Materials and Device Technology*, Wiley-VCH Verlag GmbH & Co. KGaA (2009).
[3] T. C. Rödel *et al.*, *Phys. Rev. Materials* **2**, 051601(R) (2018).

Research Achievements

1. Our paper [3] was selected as an "Editors' Suggestion" in Phys. Rev. Materials.

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