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Two-dimensional electron gas at the atomically smooth $LaAlO_3/SrTiO_3$ (111) interface

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The two-dimensional electron gas (2DEG) at the $LaAlO_3/SrTiO_3$ (001) heterointerface has been widely investigated due to its diverse functionalities such as conductivity, ferromagnetism, and superconductivity. In this orientation, the $SrTiO_3$ is nonpolar, with charge-neutral AO and BO_2 planes, while +e of charge is transferred between AO and BO_2 planes in the $LaAlO_3$ layer. The (111) orientation is, however, qualitatively different in that the AO_3 and B lattice planes in both materials exhibit charge transfer between layers, and both have in principle a polar character. We have found that $LaAlO_3$ deposited on the (111) $SrTiO_3$ polar surface also supports an interfacial 2DEG. An atomically smooth step and terrace structure of (111) $SrTiO_3$ surface was prepared by buffered-HF and heat treatment. The step height of the treated (111) $SrTiO_3$ is $\sim$2.25Å, which is 1/3 of the diagonal of the cubic $SrTiO_3$ lattice along the [111] direction, consistent with the thickness of one AO_3/B (111) bilayer. $LaAlO_3$ was grown epitaxially in a layer-by-layer growth mode, with one oscillation of the reflection-high energy electron diffraction (RHEED) specular spot corresponding to this single step height. The (111) interfacial 2DEG shows a higher carrier concentration than LAO/STO (001) at room temperature. We find a $LaAlO_3$ critical thickness between 11.3 and 16 Å, with the transition between insulating and conducting regimes broader than that of LAO/STO (001). Surface X-ray diffraction with COherent Bragg Rod Analysis (COBRA) has been carried out to explore the possible structural reconstruction of (111) $SrTiO_3$. We will discuss the origin of 2DEG at this polar-polar interface. This work has been done in collaboration with S. Ryu, C. W. Bark, T. Hernandez, M. S. Rzchowski, H. Zhou and D. D. Fong, T. R. Paudel and E.Y. Tsymbal.