Correlated Electron Optics in Quantum Confined Mott Insulators

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1. 研究のねらい

A diverse range of physical properties can be found in perovskite oxides closely latticed-matched to one another. Our general research interest is to develop these materials as a new heteroepitaxial family with new physical phenomena and devices, focusing on atomic scale control and design. When we consider basic artificial structures used in semiconductor devices, such as heterojunctions and quantum wells, we find two important issues arise when incorporating perovskites: 1) The atomic composition of the interface. For abrupt perovskite interfaces in the (001) orientation, there are two different interface terminations which can be grown with often vastly different electronic properties. 2) Incorporating strongly correlated electrons. A key feature for poorly screened electrons is that the electronic structure evolves with electron density, quite different from filling electrons into a rigid single particle band. The aim this project is to develop the materials ingredients and optical probes for using band bending and quantum confinement with correlated electrons in perovskite oxide heterostructures.

2. 研究成果と考察

Manipulating Interface States Using Polar Discontinuities

The electronic structure of perovskite interfaces can be dramatically tuned at the atomic level. We examined the (001) interface between two insulators, $SrTiO_3$ (composed of charge neutral layers) and $LaAlO_3$ (composed of alternatively charged layers). This 'polar discontinuity' creates a diverging potential, which forces an *electronic reconstruction* for n-type interfaces, and an *atomic reconstruction* for p-type interfaces. The n-type interface forms an artificial high-mobility metallic state at the interface between two insulators.

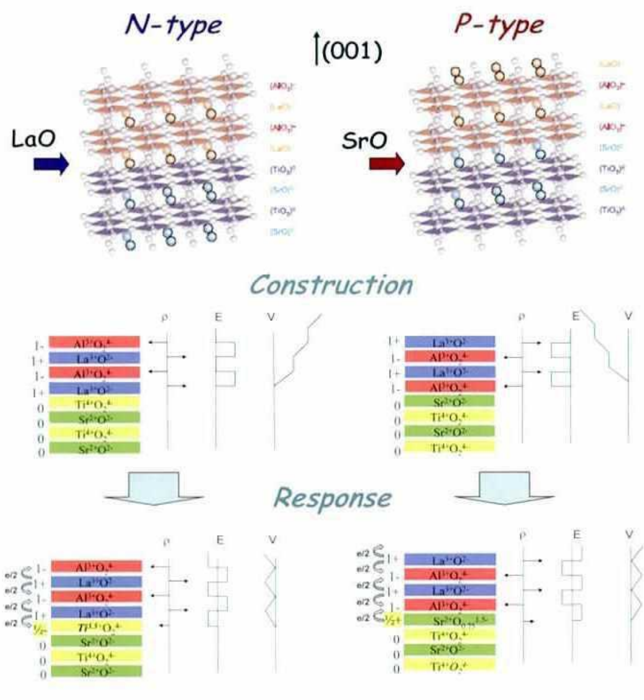

Fig. 1. The two (001) interfaces between $LaAlO_3$ and $SrTiO_3$. The unreconstructed interface has a polar discontinuity, leading to a potential divergence. This is resolved by an electronic reconstruction in the n-type case (induced Ti^{3+}), and an atomic reconstruction in the p-type case (induced oxygen vacancies).

Artificial Structures Incorporating the Mott Insulator $LaVO_3$

A central focus of this project has been to develop $LaVO_3$ as a perovskite component in thin film heteroepitaxial structures. $LaVO_3$ is a prototypical Mott insulator showing a large correlation gap (>1 eV), with a spin and orbital ordered ground state. The thin film growth phase diagram evolves between $LaV^{3+}O_3$ and $LaV^{5+}O_4$ with varying thermodynamic conditions. Between these phases lies an extended region of phase coexistence, since $LaV^{4+}O_x$ cannot form in bulk. In this regime we have examined abrupt interfaces between $LaV^{3+}O_3$ and $LaV^{5+}O_4$, and we find the vanadium valence smoothly varies from V^{3+} to V^{5+}, inducing a nanometer wide region of V^{4+} at the interface. This is a striking example of the strong electronic reconstructions which can occur at transition metal oxide interfaces. For optimized conditions, atomically flat $LaVO_3$ films can be grown in the layer-by-layer growth mode, and we have successfully fabricated superlattices of $LaVO_3/SrTiO_3$

and $LaVO_3/LaAlO_3$ down to single unit cell layers. In the latter case, we have examined the electronic structure of the $LaVO_3$ Mott quantum wells using x-ray photoemission spectroscopy. We have found that the well can be systematically doped by charge transfer from the polar $LaAlO_3$ surface. Studies of the optical properties of these quantum wells are in progress, and preliminary results indicate that for ultra-thin wells, the reduced dimensionality increases the bandgap and reduces the bandwidth of the upper Hubbard band.

Magnetically Tunable Interface Barrier in Manganite/Titanate Heterojunctions

We have studied rectifying Schottky junctions using ferromagnetic manganite electrodes. At low temperatures we have found that the junctions can exhibit exponential-enhanced magnetoresistance as well as large magnetocapacitance. To probe the origin of this effect, we have developed a probe to use internal photoemission spectroscopy under magnetic field. This technique can directly measure the Schottky barrier height by monitoring the photocurrent across the junction while illuminated by tunable monochromatic light. We find that the barrier height can be significantly reduced by magnetic field, consistent with the electric properties. This result, opposite of what would be expected from purely Zeeman effects, may indicate an interface metal-insulator transition driven by magnetic field.

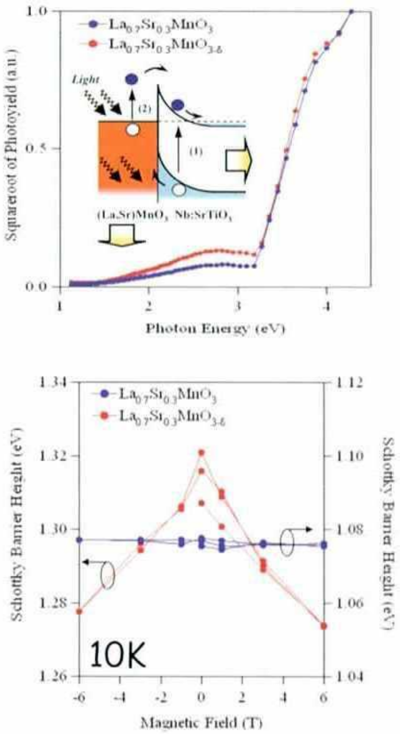

Fig. 2. The top panel shows the photocurrent yield as a function of photon energy. The two principle features observed are the SrTiO3 bandgap and the Schottky barrier height. The bottom panel shows the evolution of the barrier height with applied magnetic field. Only the magnetically active $La_{0.7}Sr_{0.3}MnO_{3-\delta}$ junction exhibits field dependence.

3. 謝辞

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4. 主な論文

1. L. Fitting, Y. Hotta, T. Susaki, H. Y. Hwang, and D. A. Muller, "Nanometer Scale Electronic Reconstruction at the Interface between $LaVO_3$ and $LaVO_4$," *Physics Review Letters*, submitted.
2. Y. Hotta, H. Wadati, A. Fujimori, T. Susaki, and H. Y. Hwang, "Electronic Structure of the Mott Insulator $LaVO_3$ in a Quantum-Well Geometry," *Applied Physics Letters*, submitted.
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4. N. Nakagawa, M. Asai, Y. Mukunoki, T. Susaki, and H. Y. Hwang, "Magnetocapacitance and Exponential Magnetoresistance in Manganite-Titanate Heterojunctions," *Applied Physics Letters* **86**, 082504 (2005).
5. A. Ohtomo and H. Y. Hwang, "A High-Mobility Electron Gas at the $LaAlO_3/SrTiO_3$ Heterointerface," *Nature* **427**, 423 (2004).

5. その他

1. 2006-2007 Visiting Associate Professor, Institute for Chemical Research, Kyoto University.
2. 2005 Materials Research Society Outstanding Young Investigator Award.
3. Two patents filed with JST for this project.