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Tailoring of Two-dimensional Electron Gas Density in Thin Film Oxide Heterostructure via Atomic Layer Deposition

Seong Hwan Kim, Hye Ju Kim, and Sang Woon Lee
Department of Energy Systems Research and Department of Physics, Ajou University
Suwon 16499, Republic of Korea
pucksae77@ajou.ac.kr; ajuphysics@ajou.ac.kr; slee01@ajou.ac.kr

Extended Abstract

Recently, oxide heterostructure-based two-dimensional electron gas (2DEG) has received intensive attentions owing to their interesting properties. The model system is epitaxial $LaAlO_3$ (LAO) grown on single crystalline $SrTiO_3$ (STO) substrate.[1] Electrons with a density of 10^{13}~10^{14}/cm^2 were observed which moves freely along in-plane direction while they are confined within ~2 nm (out-of-plane direction). Unfortunately, the adjustment of electron density was not available for the epitaxial LAO/STO heterostructure. In addition, the growth of epitaxial LAO film requires a high-temperature process (700 ~ 800°C) using pulsed laser deposition technique.

Here, we demonstrated a creation and control of 2DEG at the interface of non-epitaxial Al_2O_3/TiO_2 thin film heterostructure using atomic layer deposition (ALD). The electron density can be tailored from ~ 10^{11}/cm^2 to ~ 10^{14}/cm^2 by the control of ALD process temperature because the electrons are coming from oxygen vacancies at the interface of Al_2O_3/TiO_2 heterostructure of which oxygen vacancy density is governed by kinetics during the ALD process. Electron density up to ~10^{14}/cm^2 was achieved at the interface of the Al_2O_3/TiO_2 heterostructure which is 100 times higher than that of the conventional semiconductor heterojunction such as AlGaAs/GaAs.

The 2DEG at Al_2O_3/TiO_2 heterostructure can be applied for the development hydrogen (H_2) gas sensor. A high-performance, transparent, and extremely thin (<15 nm) hydrogen gas sensor was fabricated using 2DEG at the interface of Al_2O_3/TiO_2 heterostructure grown by ALD. [2] Palladium nanoparticles (≈2 nm in thickness) are used on the surface of the Al_2O_3/TiO_2 thin film heterostructure to detect H_2. Both oxides with a wide bandgap (>3.2 eV) have transmittance of 83% in the visible spectrum, which allows for a transparent sensor. The $Pd/Al_2O_3/TiO_2$ gas senor detects H_2 gas quickly with a short response time of <30 s even at room temperature which outperforms conventional H_2 gas sensors. This sensor responds to a wide range of H_2 concentration, especially from ~5 ppm to 1%, implying a promising candidate for a general H_2 sensor. Interestingly, the $Pd/Al_2O_3/TiO_2$ gas senor showed an optimal electron density for H_2 detection owing to the tailoring ability of 2DEG at the Al_2O_3/TiO_2 heterostructure. Particularly, a sensitivity was as low as 3% for a 2DEG density of 5.6×10^{13} cm^{-2} while the sensitivity was improved from 6% to 43% as the electron density decreased from 5.6×10^{13} cm^{-2} to 4.1×10^{11} cm^{-2}. Besides the sensor application, other application of 2DEG will be introduced in the presentation.

References

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