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Transistor Using Two-dimensional Electron Gas in Thin Film Oxide Heterostructure via Atomic Layer Deposition

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Extended Abstract

Two-dimensional electron gas (2DEG) at an epitaxial interface of $LaAlO_3/SrTiO_3$ (LAO/STO) heterostructures has received considerable attentions because of their unique physical properties.[1] Electrons at the interface of LAO/STO heterostructure move freely along in-plane direction while they are confined in 1~2 nm range of out-of-plane direction. The electron density of 2DEG at LAO/STO heterostructure is 10^{13}~10^{14}/cm^2 which is 100 times higher than those of the conventional semiconductor heterojunction such as AlGaAs/GaAs. The high density of electrons enables a fabrication of high-performance transistor. Unfortunately, the growth of LAO epitaxial layer on single crystalline STO substrate is necessary for 2DEG generation via polar catastrophe mechanism which impeded a practical use of the oxide heterostructure.

Here, we demonstrated a creation of 2DEG at the non-epitaxial interface of Al_2O_3/TiO_2 (<15 nm) thin film heterostructure via atomic layer deposition (ALD), without using single crystalline STO substrate for the first time.[2] By implementing ALD, the mature thin film process can facilitate mass production as well as three-dimensional integration of the devices. The electrical properties of thin film Al_2O_3/TiO_2 heterostructure are similar with those of the epitaxial LAO/STO heterostructures. It was observed that high density electrons up to (10^{13}~10^{14}/cm^2) were confined within ~2.2 nm of the interface of the Al_2O_3/TiO_2 heterostructure. Interestingly, the electron density can be adjusted from ~ 10^{11}/cm^2 to ~ 10^{14}/cm^2 by the control of ALD process temperature because the free electrons are created by the formation of oxygen vacancies at the interface of Al_2O_3/TiO_2 heterostructure of which kinetics is governed by the ALD process temperature. Those oxides (Al_2O_3 and TiO_2) are transparent insulators with wide bandgaps (>3.2 eV) which implies a possible application of transparent devices.

With the Al_2O_3/TiO_2 thin film heterostructure, a transparent thin film transistor (TFT) was fabricated which outperforms conventional TFTs. A high on-current (I_{on}, > 12 μA/μm), high on/off current ratio (I_{on}/I_{off} > ~10^8), low off-current (I_{off}, ~10^{-8} μA/μm), and low sub-threshold swing (*SS*, ~100 mV/dec.) are achieved. Besides the TFT application, a high-performance transparent hydrogen (H_2) gas sensor was developed using the 2DEG at Al_2O_3/TiO_2 thin film heterostructure which shows a sensitive detection of H_2 gas even at room temperature.[3] It exhibited a reliable detection with a fast response speed (<30 s) for H_2 concentration as low as 5 ppm which outperforms conventional H_2 gas sensors operating at room temperature, indicating that heating modules are not required for the rapid detection of H_2. The gas sensor can detect H_2 gas across a wide range of concentrations, from 5 ppm to 1%, implying that it is a promising candidate for a general H_2 sensor. The H_2 gas sensor using 2DEG was fabricated on a polyimide substrate which enabled a fabrication of flexible gar sensor. The H_2 sensing performance was maintained even after bending cycles of 500 with a bending radius of 10 mm.

After all, the creation and control of 2DEG at thin film oxide heterostructure using ALD, and their applications will be addressed in the presentation.

References

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