Controlling atomic scale epitaxial crystallization by an interfacial conductivity of the insulating oxides under an electron beam

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Device structures have become miniaturized with a recent rapid progress in nanotechnology, and the demand for fabricating and manipulating nanostructures has dramatically increased. An e-beam lithography (EBL) is one of the most promising for nanoscale patterning owing to its excellent resolution and maskless patterning among the several other techniques utilizing various sources including light, X-ray and ion-beam sources.

Meanwhile, researches on the perovskite-structured oxide materials are rapidly increasing recently and interesting physical properties of perovskite material have observed [1]. For instance, interfacial conductivity between two insulating oxides, that is two-dimensional electron gas (2DEG), shows a number of intriguing properties such as on/off switching with external electric fields, nanoscale electronic devices and tunable conductivity. A formation of the conductive interface has been reported in crystalline (c)- as well as amorphous (a)-LaAlO3/SrTiO3 heterostructures, and the interfacial conductivity can be degraded by annealing in high oxygen pressure [2].

Here, we demonstrate an e-beam-controlled crystallization of an a-$LaAlO_3$ thin film grown epitaxially at the a-LaAlO3/SrTiO3-substrate interface. Also, we report the effect of the interfacial conductivity on the kinetic behavior of epitaxial crystallization. The observation on the crystallization behavior of a-LaAlO3 under the e-beam irradiation was performed in aberration-corrected STEM (Titan S80-300; FEI) operated at 300 kV. The irradiation current was conducted from 0.16 nA to 0.67 nA.

When a convergent e-beam positioned at a-LaAlO3 overlayer, in most cases, local crystallization occurs with a random crystal orientation due to knock-on energy of electron accelerated as 300 keV. However, epitaxial crystallization from the interface occurs when the e-beam is located within a critical distance from the interface. The 2DEG acting as a current path delays the crystallization kinetic, thus delicate control of the crystallized pattern shape and size was available. Schematics showing the distribution of electrons around the incident e-beam in the a-LAO overlayer is shown in the figure below.

As a result, successful pattern writing with a width of about 5 nm was performed as shown in the figure [3]. This work provides useful guidelines for coherent atomic scale e-beam patterning considering critical distance of the e-beam from the interface for the epitaxial growth, e-beam dose rate effect on the growth rate and the heterostructure interfacial conductivity.

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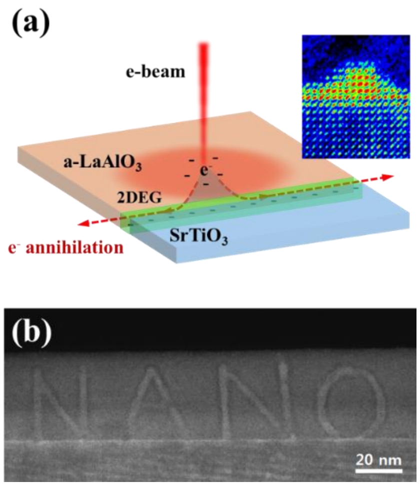

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