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Microstructural Characterization of Sputter Deposited $BaTiO_3$/Ni/$BaTiO_3$/Ni/$BaTiO_3$ Multi-layer Thin Films on SiO_2/Si wafers

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Perovskite structures are widely used in various electronic, electro-optical, and electro-mechanical applications. Barium titanate is a lead-free, environment-friendly ferroelectric material with a high dielectric constant, low dielectric loss, and large dielectric tenability [1]. Typical applications of $BaTiO_3$-based capacitors include dynamic random access memory, tunable microwave devices, and discreet capacitors [2, 3]. With the increasing demand of smaller and lighter devices, deposition of homogeneous nano-scale $BaTiO_3$ thin films is critical to the fabrication of high-end, nano-scale ceramic capacitors, and sputter deposition is a viable fabrication method. While Pt is often used as electrode, Ni is a promising alternative material.

Interfacial and defect studies of the multi-layer thin films are of great importance for understanding the interplay of processing, structure, and electronic transport. Therefore, transmission electron microscope (TEM) is needed for atomic scale structural characterization and compositional analysis. To avoid diffusion effect and phase transformation due to heating associated with traditional TEM specimen preparation, i.e. slicing, polishing, dimpling and ion-milling, a FEI Helios 600 focused ion beam (FIB) dual beam instrument was used to prepare cross-sectional TEM specimens. A 300 kV Philips EM430 TEM equipped with an x-ray energy dispersive spectroscopy (EDS) system was used for electron diffraction and high resolution TEM imaging.

Three layers of 100 nm thick $BaTiO_3$ and two layers of Ni electrodes approximately 5-10 nm in thickness were sputter deposited on SiO_2/Si wafers, as shown in Figure 1 (a). Composition analysis showed that no measurable amounts of impurities were contained in either of the $BaTiO_3$ films and the Ni electrodes. A high resolution TEM image in Figure 1 (b) taken at the interface between the $BaTiO_3$ and one of the Ni electrodes showed that the Ni electrodes were composed of nanocrystalline while the $BaTiO_3$ dielectric layer was amorphous. The inset in Figure 1 (b) is a Fast Fourier transform (FFT) pattern from lattice fringes in the Ni layer. The scattered FFT spots confirmed the nanocrystalline phase. A broadened, continuous electron diffraction ring with selected area only from the $BaTiO_3$ layer, not shown here, confirmed that $BaTiO_3$ layer was an amorphous phase with only short range order. Figure 1 (c) is a high resolution TEM image taken at the $BaTiO_3$/SiO_2 interface, showing the SiO_2 layer was also an amorphous phase. Measured dielectric permittivities between approximately 280 and 1000 with corresponding losses between 0.02 and 0.09 and resistivities greater than 8.7×10^{10} Ω·cm in devices deposited at temperatures below 573 K shows promise for the development of nano-scale capacitors.

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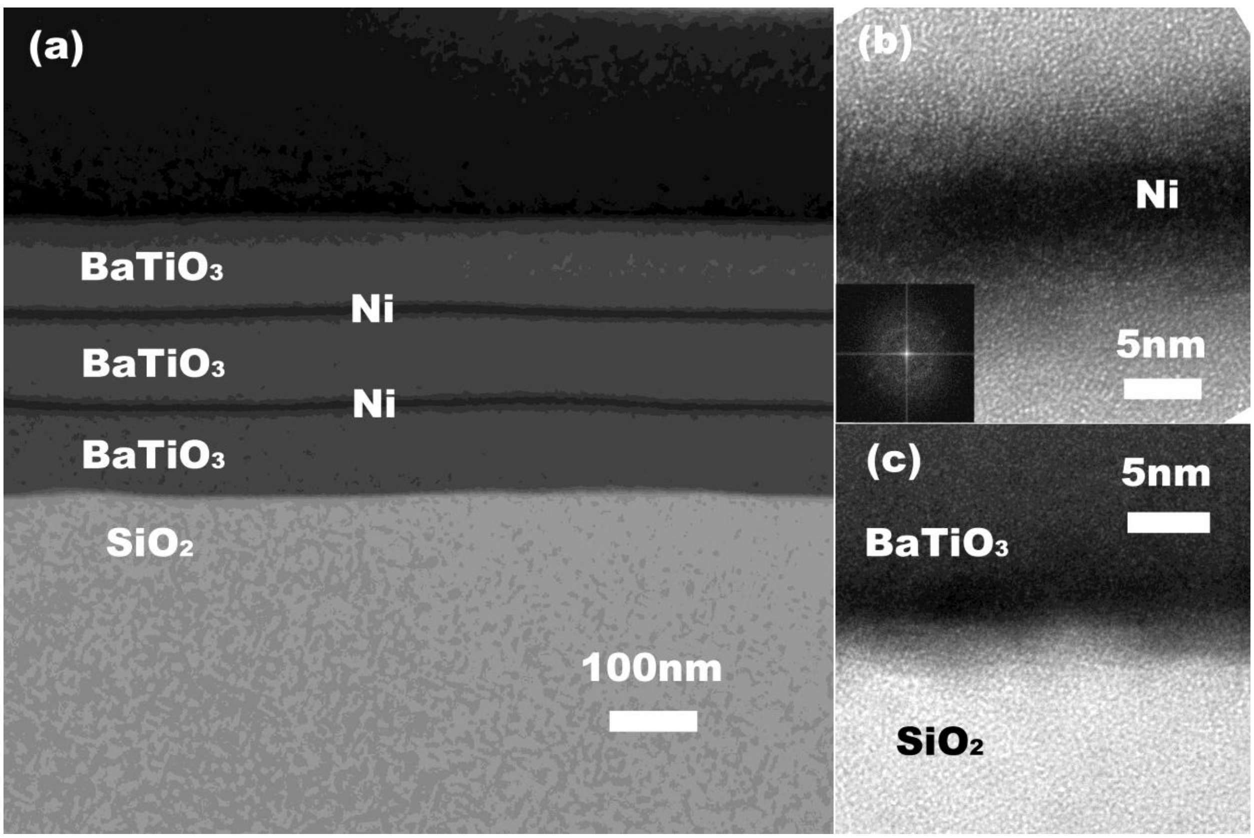

Figure 1. (a) Cross-section TEM image of $BaTiO_3$/Ni multi-layers grown on SiO2/Si substrate; (b) High resolution TEM image showing lattice fringes of nanocrystalline Ni and amorphous $BaTiO_3$ layers. The inset is a Fast Fourier Transform (FFT) pattern from a selected area only from the Ni layer. The scattered spots indicate that Ni layer is composed of nanocrystalline grains. (c) High resolution TEM image showing SiO_2 layer is also an amorphous phase.