Removing Native Oxide from Silicon Substrate for Perovskite Oxide Crystal Growth

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Overview and Objective

Most of modern electronics utilize a device called the Metal-Oxide-Silicon Field-Effect Transistor (MOSFET). The SiO_2 layer in MOSFET is limited to a size of about 40 A due to quantum tunneling. As devices get increasingly smaller the industry runs into complications with this fundamental limit. One solution is to integrate perovskite oxides and utilize its diversity of interesting physical phenomena such as superconductivity, colossal magnetoresistance, and multiferroics. Integration of Silicon (Si) substrates with perovskite oxides is physically and commercially intriguing, allowing for expansion into smaller designs for devices. Si substrates naturally form a native oxide layer (SiO_2) from the Oxygen present in the air. In order for perovskite oxides to grow on Si, the SiO_2 must first be removed. This allows for a good crystalline structure to form as opposed to an amorphous structure like the S

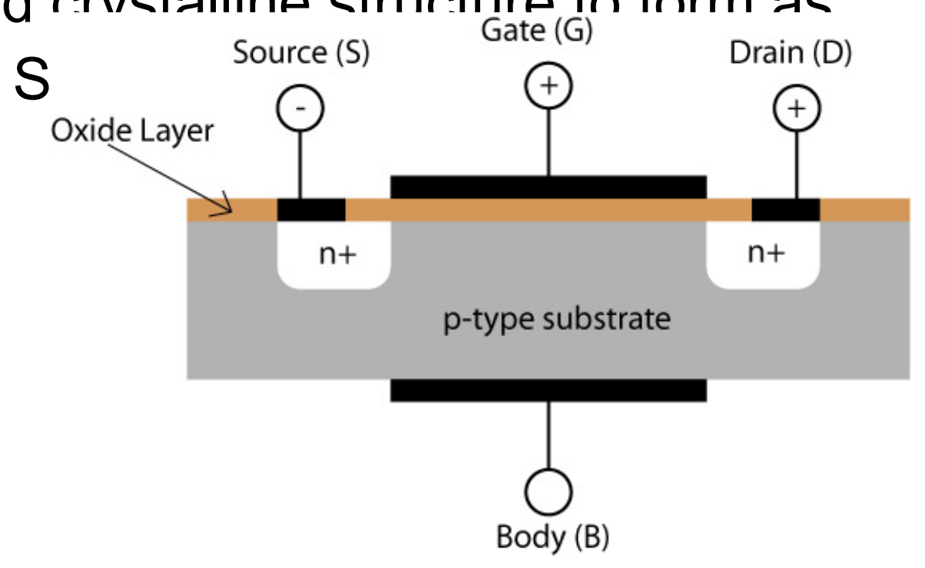


Figure 1

Instrumentation

Reflection High Energy Electron Diffraction (RHEED)

In order to determine if the SiO_2 layer has been removed during molecular beam epitaxial (MBE) growth of perovskite oxides , the use of RHEED must be utilized. In RHEED, a beam of electrons is fired at the substrate and diffracted onto a phosphorus screen. The incident angle of the beam is about 1°, so that the diffracted electrons are only reflected from the top layer of atom. The diffracted pattern can then be used to characterize the surface of the substrate. Figure 2 illustrates how RHEED works

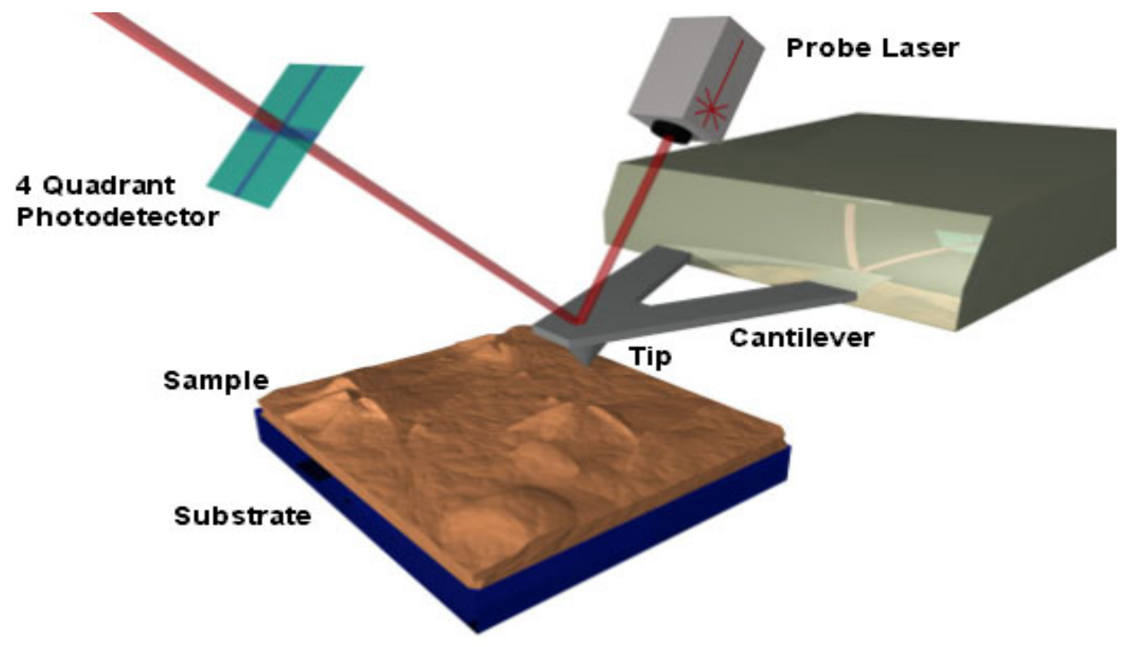


Figure 3

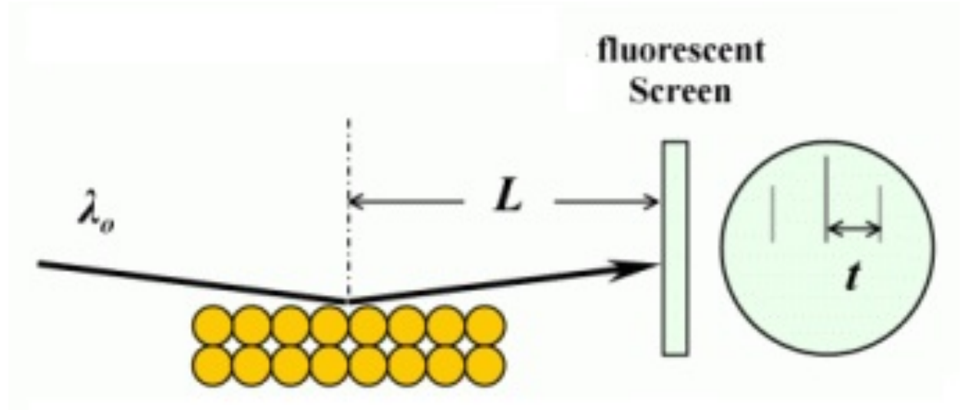


Figure 2

Atomic Force Microscopy (AFM)

AFM is used to create topographical images of objects on the Nano scale. AFM creates topographical images by scanning an extremely small tip across the surface of the sample. A laser is reflected off the back of the tip to a photodetector, which gives feedback of the tips movement. (Figure 3) In AC mode the tip oscillates slightly above its resonance frequency. The van der Waals forces from the surface works to decrease the resonance frequency. The tips adjustment to maintain the resonance frequency correlates with the changes of the surface, allowing a topographical image to be created.

Methods and Experiment

The most efficient way to remove the SiO_2 layer from the Si Substrate in MBE is to heat the substrate to an extremely high temperature (~980°C). Obtaining temperatures this high are not favorable for the MBE chamber used in this experiment. Strontium (Sr) can be used as a catalyst to decrease the temperature necessary to remove the oxide layer. Growing 2 ML of Sr can decrease the temperature needed to about 800°C. Determining if the oxide has been removed will be decided by RHEED images, AFM topographical images, and growth of a perovskite oxide (Strontium Titanate($SrTiO_3$)) on a pure Si surface.

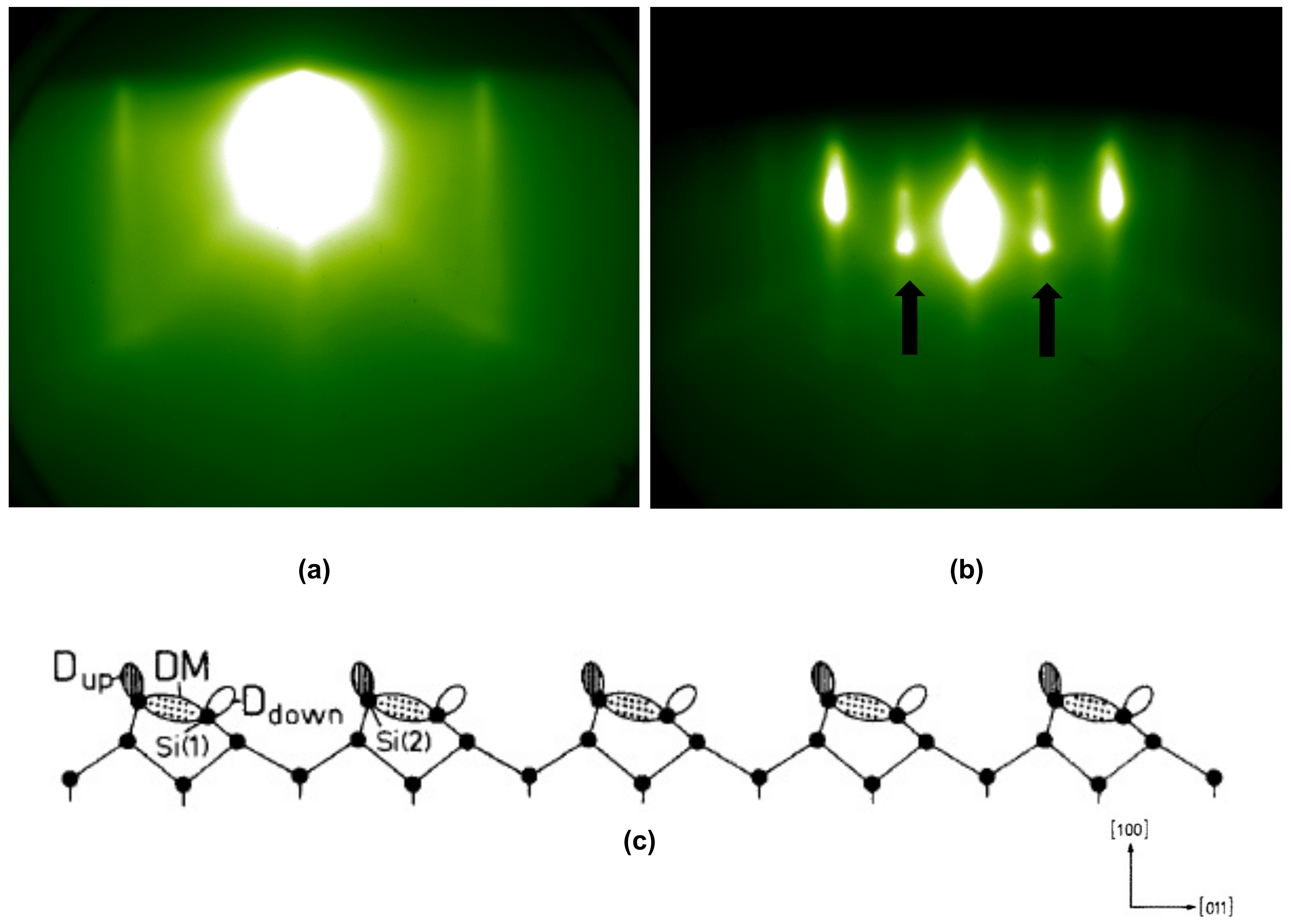
Sr and Titanium (Ti) sources were calibrated using Quartz Crystal Microbalance (QCM) to determine flux and time necessary to deposit individual monolayers (ML). The growth rate was established at 1 ML/min. The Si substrate was purged of organic material using a Ultraviolet Ozone Cleaning System (UVOC[illegible]d into Chamber, and heated to 376˚C. After the pressure has be[illegible]ased, the substrate is heated to 600 ˚C, and 2 ML of Sr are depo[illegible] Si substrate is then heated to 800 ˚C where the SiO_2 layer is re[illegible]fter the native oxide layer is removed the process to grow $SrTiO_3$ can begin.

A presentation created during the 2012 Research Experiences for

Analysis and Data

Both RHEED images displayed below were taken after the Si Substrate was heated to the temperature necessary to remove the SiO_2. Figure 4 (a) displays when the electron beam is along the (1 0 0) direction and Figure 4 (b) is when the electron beam is incident in the (1 1 0) direction. The arrows in Figure 4 (b) indicate a 2x pattern. This pattern is indicative of the SiO_2 layer being removed. Figure 4 (c) displays a side view model of what the reconstructed clean Si surface looks like on the molecular level.

Figure 4

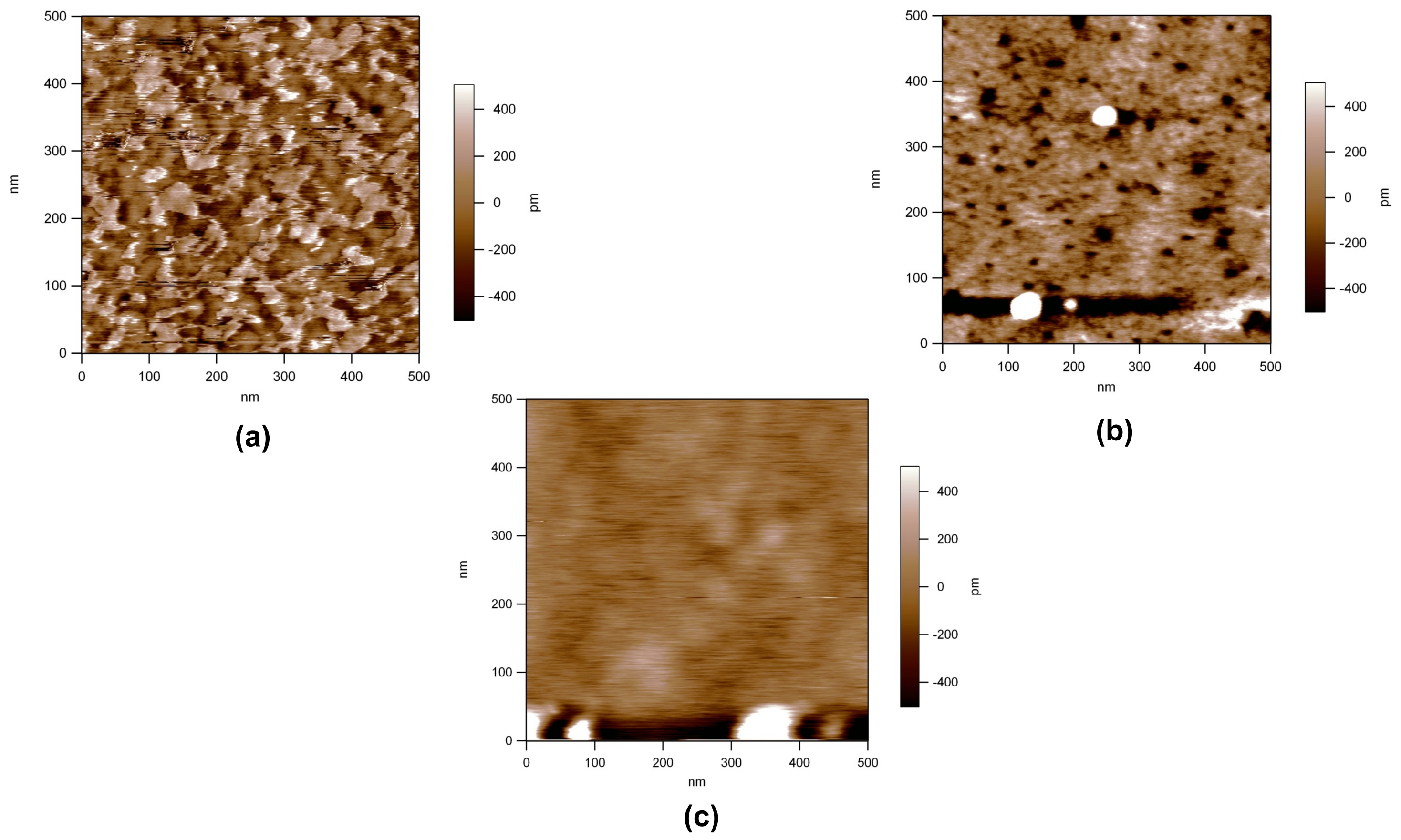


(a)

(b)

(c)

Figure 5



(a)

(b)

(c)

Figure 5 (a) displays an AFM image obtained before the thermal de-oxidation process on a 500 nm scale. Figure 5 (b) displays the same substrate after the thermal de-oxidation process. Air contamination accounted for distortion and bumps on the image, but it is clear that the surface is smoother than before. Figure 5 (c) is an AFM image taken of the $SrTiO_3$ grown on Si. The surface is extremely smooth and similar to the thermally de-oxidized Si surface.

Conclusion

The process of heating the substrate to a very high temperature was effective in removing the SiO_2 layer from the Si Substrate. The RHEEED images obtained indicate that the thermal de-oxidation process was successful during growth. Topographical images taken with AFM were not thorough in proving the SiO_2 layer was removed due to air contamination, but comparison of the images did show a slight change of surface structure. In comparison with the AFM image of the $SrTiO_3$, the smooth surface shows similarity in structures. Samples grown can be used for further study with perovskite oxide's unique properties.

References and Acknowledgements

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