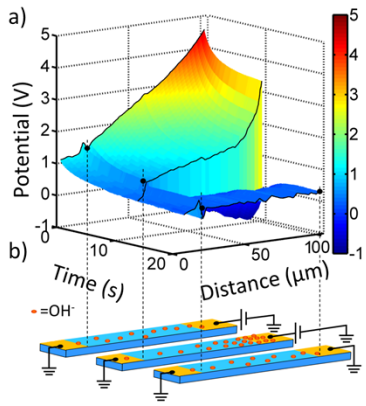
CNMS Staff Science Highlight

Space- and Time-Resolved Mapping of Ion Dynamics



a) Spatial and temporal distribution of surface potential of a Ca-doped $BiFeO_3$ film.
b) Schematics of ionic charge distribution on sample's surface at beginning, intermediate, and late times from graph (a).

Work was performed at the Center for Nanophase Materials Sciences, ORNL

Scientific Achievement

A new scanning probe microscopy technique was used to selectively distinguish surface vs. bulk ion dynamics in Ca-doped $BiFeO_3$.

Significance and Impact

Electronic and ionic transport enables operation of numerous electrochemical devices including fuel cells, batteries, separators, and gas sensors. Time-resolved Kelvin Probe Force Microscopy (tr-KPFM) maps the surface potential in both space and time domains, displaying electronic and ionic charge dynamics and separating underlying processes based on their time responses.

Research Details

- Tr-KPFM was used to probe the surface potential of a Ca-$BiFeO_3$ device with space and time resolution between 23-125 °C.
- At low temperature and polarizing bias adsorbed ions dominate the potential distribution; at high temperature and bias oxygen vacancy motion is activated.
- Activation energy and mobility of the surface species indicates that they are protons.

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The operation of numerous electrochemical devices, such as batteries, fuel cells, gas sensors, memristors, etc., relies on the electronic and ionic transport, which is often controlled by the nanoscale features of the device's material. For this reason, in order to understand the underlying physical mechanisms, it is crucial to probe the electronic and ionic transport through the grain boundaries, interfaces, memristor conductive filaments and other microstructural elements of the corresponding devices. The currently available scanning probe microscopy techniques (e.g. KPFM and ESM) allow measuring only the *total* electronic and ionic potential distribution in devices, without distinguishing between the different mechanisms driving the changes in the potential distribution. However, the characteristic times of various transport mechanisms are different due to differences in the effective masses and mobilities of the corresponding charge species (electrons, electronic holes, surface or bulk ions, etc.). Thus, separation of the contributions of different transport mechanisms should be possible in the time domain. Our time-resolved Kelvin Probe Force Microscopy Technique endeavors to solve this problem by tracking the temporal evolution of the interelectrode potential profile on the nanoscale. With its help we were able to demonstrate separation of the surface ionic dynamics from the bulk oxygen vacancy motion in CaBFO, which would be impossible without entering the time domain.

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