Experiment 1094

β-NQR Study of the Phase Transition in $SrTiO_3$ and Related Compounds

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All phase transitions in condensed matter (except Bose-Einstein Condensation) arise because of interactions between the basic constituents of the system in question, e.g. spins, ions, electrons etc. Near any surface or interface the symmetry of those interactions is broken and thus, in general, the phase transition (order parameter, transition temperature, etc.) must be altered to some extent. Unfortunately few experimental methods are able to probe local properties in a depth resolved manner. Recently we have developed the technique of depth resolved β-detected NMR and NQR for investigating local electronic, magnetic and structural properties on a nanometre scale.

In this experiment we investigate the surface effect on a well known phase transition in the ionic insulator Strontium Titanate, $SrTiO_3$ (STO). STO has a number of interesting and useful properties, and is perhaps best known for its use as a substrate for growing thin films. There is a second order structural phase transition at 105K in the bulk, the high temperature phase is cubic whereas the low temperature phase is characterized by a small tetragonal distortion. The phase transition has been the subject of intense experimental investigation, and its bulk properties are well understood. However, much less is known about the behavior close to a free surface or interface. Optical SHG has demonstrated that an enhancement of the transition temperature is present at the surface, with a change in the surface lattice geometry observed at approximately 150K, but it is not clear how this temperature enhancement varies as a function of depth.

We have demonstrated that zero field spin relaxation and β-NQR of ^{8}Li can be used as a probe of this near surface transition behavior [1]. The quadrupole moment of the ^{8}Li nucleus couples to electric field gradients within the crystal lattice, and since these gradients are sensitive to the lattice geometry this makes the implanted ^{8}Li a sensitive probe of the phase transition. Specifically, the ^{8}Li occupies three equivalent sites in the cubic phase, and in the tetragonal phase two of these sites are oriented such that field gradients cause fast precession of the ^{8}Li nuclear spin. The signal from lithium stopping in either of these sites is therefore averaged to zero in the tetragonal phase, resulting in a decrease of the initial β-decay asymmetry to 1/3 of its value above the transition. The time dependence of the asymmetry at several temperatures is shown in figure 1, demonstrating a clear decrease in the initial asymmetry with decreasing temperature. This initial asymmetry is shown as a function of temperature in figure 2. As expected, the asymmetry is decreased to 1/3 of its high temperature value below the phase transition. It is also clear that the loss of asymmetry begins around 150K, indicating that the tetragonal axis lattice constant begins to increase in some lattice sites at this temperature.

The ^{8}Li nuclei are implanted into the sample by directing the particle beam onto the sample surface. As a result, there is a distribution of penetration depths of the ^{8}Li into the sample. The data shown in figures 1 and 2 were taken using a 28keV ^{8}Li beam, and the stopping distribution for such a beam is shown in the inset of figure 2. Nearly all the ^{8}Li occupy lattice sites within 400nm of the sample surface, with a large fraction stopping within the first 200nm. Thus the ^{8}Li are sensitive to surface effects.

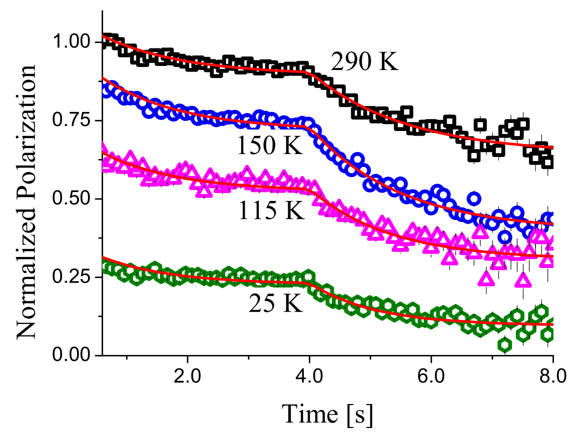

Fig. 1. Time dependence of the asymmetry at several temperatures. The solid lines are fits to a double exponential relaxation function.

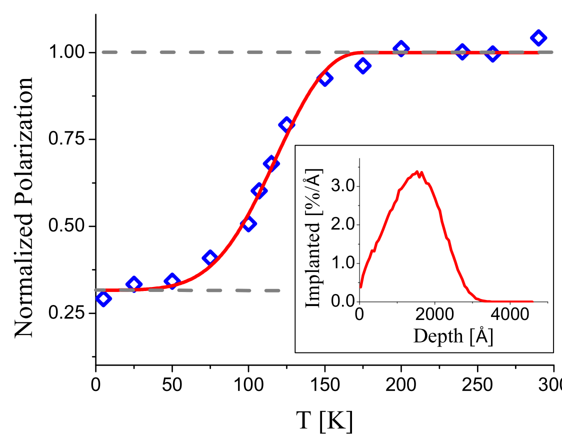

Fig. 2. Temperature dependence of the initial asymmetry. The solid line is a guide to the eye. The inset is the implantation profile of the 28keV ^{8}Li beam.

In conclusion, we have demonstrated that the small quadrupole moment of ^{8}Li can be used as a sensitive probe of the local crystal symmetry. We have also confirmed that the structural phase transition near the surface of STO is shifted higher by about 50K compared to the bulk. This establishes β-NMR and β-NQR developed here at TRIUMF as powerful tools to probe phase transitions near a surface. We suspect many other phase transitions will also be altered near a surface or interface, and intend to continue this study both on STO and related materials. Additionally, the upcoming completion of the beam deceleration platform on the β-NQR spectrometer will provide us with the ability to vary the beam implantation energy, thus allowing us to study these transitions as a function of depth.

Publications:

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