

High Resolution Study of Photo-induced Effects in CMR Materials

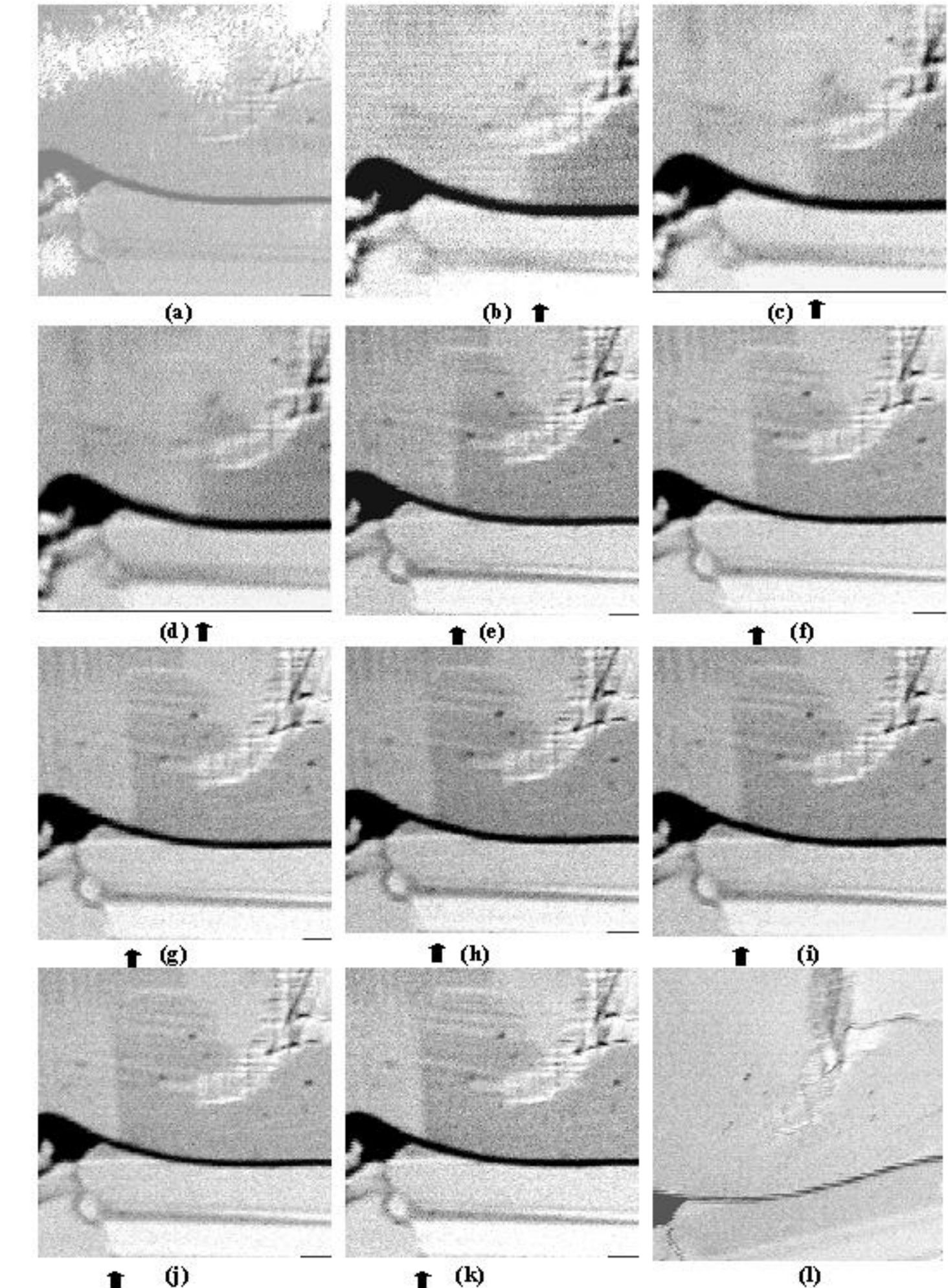
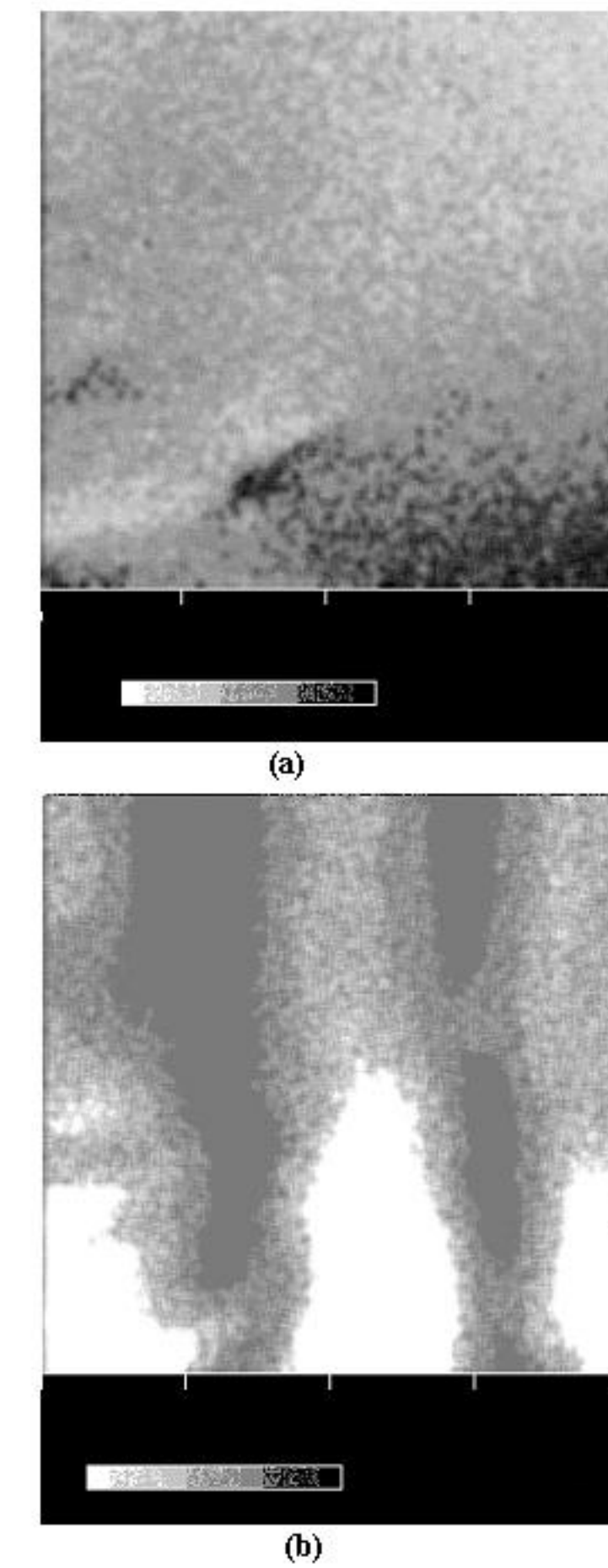
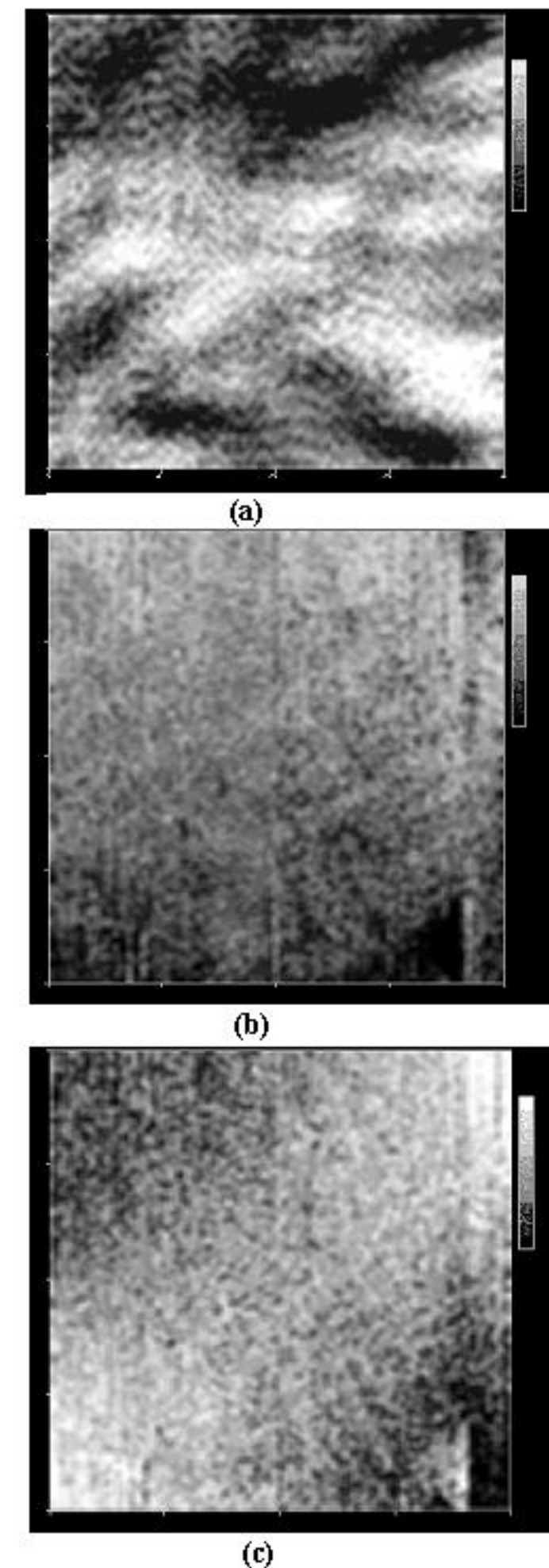
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We report near-field and far-field optical microscopic studies of photoinduced effects in charge-ordered $\text{Bi}_{0.3}\text{Ca}_{0.7}\text{MnO}_3$. Unlike previously reported transient photoinduced effects in manganites, we have observed permanent reflectivity changes following local sample illumination with 488 nm light. High-resolution images of exposed regions reveal optical contrast on a submicrometer scale. This observation indicates that switchable photonic band-gap structures may be created using holographic recording in manganites.

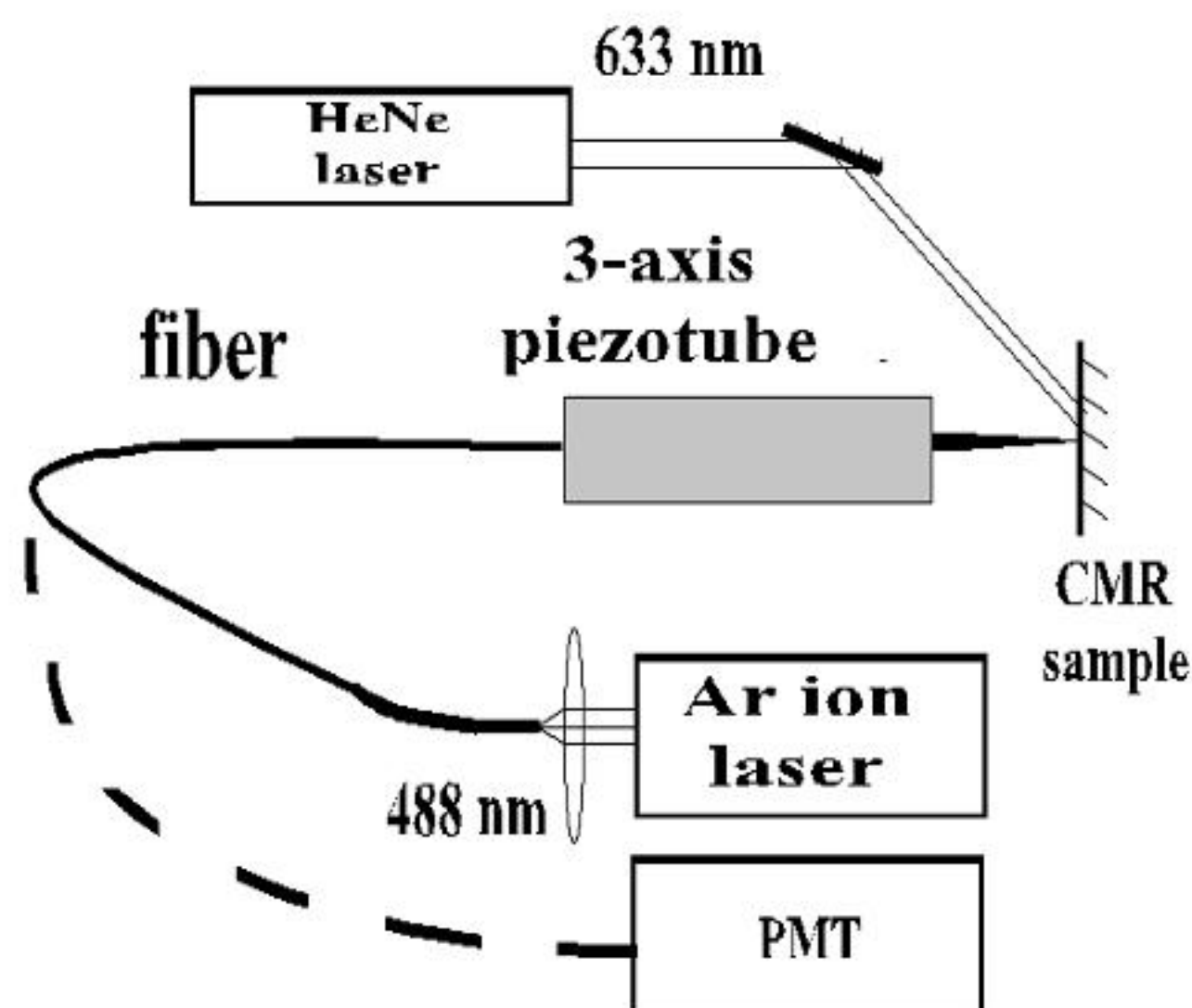
The perovskite-type manganese oxides $\text{R}_{1-x}\text{A}_x\text{MnO}_3$ (where R and A are trivalent rare- and divalent alkaline-earth ions, respectively) exhibit a rich variety of magnetic and electronic phenomena, such as colossal magnetoresistance (CMR), charge and orbital ordering, etc., associated with strong coupling of lattice, charge, spin, and orbital degrees of freedom. Application of modest external fields may drastically modify the state of such materials, e.g., induce an insulator to metal transition. This can be done with application of an external magnetic field as in the CMR effect, or with optical illumination, as was recently demonstrated in our work. Thus, a variety of new physics effects, as well as novel optoelectronic device concepts are being constantly discovered.

A photoinduced insulator to metal transition is especially interesting from the point of view of creating photonic band-gap materials. Inside a photonic band-gap region, optical modes, spontaneous emission, and zero point fluctuations are all absent, which makes such materials exhibit very unusual optical properties. A photonic band-gap may appear in a three-dimensional photonic crystal (a material with periodic modulation of refractive index with a period on the order of the wavelength of light). The necessary condition for the photonic band gap to appear is high refractive index contrast (more than 2 to 1) within the photonic crystal. Creation of a photonic band-gap material is a very difficult task. A three-dimensional hologram recorded in a photosensitive material (such as doped BaTiO_3 or LiNbO_3 perovskite-type oxides that exhibit very prominent photorefractive effect) would be a very good solution, but normally the holograms have very small refractive index contrast. Manganites may be very promising in this respect since small photoinduced variation of their properties could be "developed" by the applied magnetic field or by cooling down to low temperatures where the insulating and metallic states differ greatly in resistance and, hence, refractive index.

We report the first (to our knowledge) near-field optical microscopic studies of photoinduced effects in charge-ordered manganites. In our study we have used single crystals of $\text{Bi}_{0.3}\text{Ca}_{0.7}\text{MnO}_3$, which have a rather high temperature of charge ordering transition $T_{co}=307\text{K}$. Unlike previously reported transient photoinduced effects in other manganites, we have observed permanent reflectivity changes following local sample illumination with 488 nm light. High-resolution images of the exposed regions reveal fine optical contrast on a submicrometer scale. This observation opens up an exciting possibility of creating photonic band-gap structures using holographic recording in $\text{Bi}_{0.3}\text{Ca}_{0.7}\text{MnO}_3$. Such a development would lead to a material with a photonic band gap extremely sensitive to the external magnetic field and temperature.



Schematic view of our near-field optical microscope experimental setup



4 by 4 micrometers near-field optical microscope images of the sample topography (c) and reflectivity at 633 nm before (b) and after (a) sample exposure to 488 nm light through the tip of the microscope. A substantial increase in the local optical reflectivity after illumination is evident from the comparison of the optical images. The vertical scale in the topographical image (c) is 61 nm.

4 by 4 micrometer near-field optical microscope images of the sample topography (a) and reflectivity at 633 nm (b) after sample exposure to 488 nm light through a combination of a diffraction grating and a microscope objective.

A series of frames captured from the movie showing photoinduced charge-order domain creation, domain wall motion and pinning by a surface defect, and melting of the charge order by heating the sample from room temperature to just above $T_{co}=307\text{K}$. The position of the photoinduced domain wall (seen as a vertical boundary of lighter and darker areas) is indicated by an arrow in each frame. The movie was shot at 5 frames per second. The size of each frame is 50 by 50 micrometers. The order numbers of the frames are 35 (a), 39 (b), 43 (c), 45 (d), 49 (e), 52 (f), 56 (g), 59 (h), 65 (i), 70 (j), and 93 (k). Frame (l) was taken after heating the sample above T_{co}