Manipulation and imaging of coexisting ordered phases

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Outline

1- I will describe the textures in complex oxides
2- I will describe the experimental approach.

We have investigated:

a simple copper perovskite showing oxygen ordering and we have used space resolved synchrotron x-ray diffraction, as a function of temperature and photon flux

3- The results show that it is possible to control the self-organized textures and to manipulate them by x-ray illumination

Different nanoscale domains formed by oxygen self-organization can be locally "written/read" by a calibrated dose of x-ray illumination and controlled in situ by synchrotron x-ray scattering
La$_2$CuO$_{4+y}$

We have studied the simple cuprate perovskite La$_2$CuO$_4$ formed by bcc CuO$_2$ monolayers intercalated by fcc rocksalt LaO bilayers with a periodicity of 1.3 nanometers.

Structure of La$_2$CuO$_{4+y}$

- Interstitial oxygen
- LaO planes
- CuO$_2$ plane

006 peak in the diffraction pattern

$q2 = 0.090(3) \ a^* + 0.250(2) \ b^* + 0.500(5) \ c^*$
$q3 = 0.030(3) \ a^* + 0.210(2) \ b^* + 0.290(5) \ c^*$
Method to detect and to manipulate the textures

space-resolved X-ray diffraction based upon a beam size of ~ 100µm, at Elettra and ~ 7 µm, at ESRF, high precision mechanical movement of the sample and high dynamic range cooled CCD camera to detect the superstructure peaks in the diffraction patterns.

At Elettra we have used high/low flux of X-ray photons E=12KeV (λ=0.1 nm)

The dose of x-ray irradiation can be carefully controlled in the range $10^{16}$-$10^{18}$ photons/cm² equivalent to an energy dose of $10^{20}$-$10^{22}$ eV/cm²
Mapping of oxygen ordering on microscopic scale

**T=300K**

- Reading with low flux
- 100 μm

**T=380K**

Increasing the thermally activated mobility of the interstitial oxygen
The q2 superstructure disappears at $T_{02} \sim 334K$, that shows order to disorder phase transition of interstitial oxygen
(while the q3 superstructure is constant between 300 and 380 K.)
Pumping and probe at 300 K with x rays

After a rapid quenching from 380K-300K the interstitial oxygen are frozen in a glassy phase.

We observe the increase of the q2 with x-ray illumination dose.

The disorder to order transition is stimulated by x-ray.

The photo-induced ordering process shows a threshold characteristic of cooperative phenomena.

By making a scan with a low flux below threshold.

This process is determined by the size of the x-ray beam.
The size of the oxygen ordered domain formed by the x-ray illumination is determined by the beam size. Beam size = 7 micron.
Photo-induced ordering process at different temperatures.

- We have fitted the data with an exponential and we obtain the value for $t_s$ and $t_o$.

- The time threshold changes with temperature:

  $t_s$ is: $130 \pm 20$ sec, $160 \pm 25$ sec, $336 \pm 32$ and $420 \pm 30$ sec at different temperature $T=300K$, $285K$, $250K$ and $220K$ respectively.
Effects of X-ray illumination on Q3 phase:

- The q3 increases under x-ray illumination below 250 K. We illuminated three different areas with a high flux beam size of 100 microns. We observed no threshold showing a different process.
Reading

Reading with low flux x-ray beam

the intensity of the q3 peaks is enhanced just in the illuminated area.

Before the illumination

After the illumination
**Temperature dependence of the Photo Induced effects**

X-ray illumination at 100K increases the ordering of Q3

Q3 returns to its initial value with increasing temperature, under continuous x-ray illumination, at $T \sim 230$ K
Microdiffraction at ESRF ID 13

3D mapping of Q2 and Q3 with a beam size of 7 micron

• T = 95K
HISTOGRAM of the intensity of q2 and q3

- T=95K
- Beam size = 7 micron
- Region 10*2.25

T=380K

Intensity (arb.unit)
we have shown that the synthesis of photo-stimulated superstructures in the $\text{La}_2\text{CuO}_{4+y}$ can be controlled by setting:

- Dose of synchrotron x-ray illumination
- Temperature
- Incident beam size
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