EUROPEAN SYNCHROTRON RADIATION FACILITY

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ESRF

Experiment Report Form

The double page inside this form is to be filled in by all users or groups of users who have had access to beam time for measurements at the ESRF.

Once completed, the report should be submitted electronically to the User Office via the User Portal: *https://wwws.esrf.fr/misapps/SMISWebClient/protected/welcome.do*

Deadlines for submission of Experimental Reports

Experimental reports must be submitted within the period of 3 months after the end of the experiment.

Experiment Report supporting a new proposal ("relevant report")

If you are submitting a proposal for a new project, or to continue a project for which you have previously been allocated beam time, you must submit a report on each of your previous measurement(s):

- even on those carried out close to the proposal submission deadline (it can be a *"preliminary report")*,
- even for experiments whose scientific area is different from the scientific area of the new proposal,
- carried out on CRG beamlines.

You must then register the report(s) as "relevant report(s)" in the new application form for beam time.

Deadlines for submitting a report supporting a new proposal

- 1st March Proposal Round **- 5th March**
- 10th September Proposal Round **- 13th September**

The Review Committees reserve the right to reject new proposals from groups who have not reported on the use of beam time allocated previously.

Reports on experiments relating to long term projects

Proposers awarded beam time for a long term project are required to submit an interim report at the end of each year, irrespective of the number of shifts of beam time they have used.

Published papers

All users must give proper credit to ESRF staff members and proper mention to ESRF facilities which were essential for the results described in any ensuing publication. Further, they are obliged to send to the Joint ESRF/ ILL library the complete reference and the abstract of all papers appearing in print and resulting from the use of the ESRF.

Should you wish to make more general comments on the experiment, please note them on the User Evaluation Form, and send both the Report and the Evaluation Form to the User Office.

Instructions for preparing your Report

- fill in a separate form for each project or series of measurements.
- type your report in English.
- include the experiment number to which the report refers.
- make sure that the text, tables, and figures fit into the space available.
- if your work is published or is in the press, you may prefer to paste it in the abstract and add full reference details. If the abstract is in a language other than English, please include an English translation.

ESRF	**Experiment title:** Full strain determination in photostriction of $PbTiO_3$	**Experiment number**: HC-4561
Beamline: BM 32	**Date of experiment**: from: 23/09/2021 to: 28/09/2021	**Date of report**: 28/02/2021
Shifts: 15	**Local contact(s)**: Odile Robach (email: odile.robach@cea.fr) Jean-sebastien Micha (email: micha@esrf.fr)	*Received at ESRF:*

Names and affiliations of applicants (* indicates experimentalists):

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Report:

Light-induced nonthermal strain, known as the photostrictive effect, offers a potential application in remote control optomechanical devices. However, the mechanisms behind photostriction remain unsatisfactorily known. One of the reasons for the lack of complete understanding of the mechanism is due to the method used for the measurement; most of them measure strain along one particular direction(B. Kundys)[1]. Here, for the first time, we used rainbow-filtered Laue Micro-diffraction to access the complete strain tensor caused by external laser illumination. An optical setup was implemented on BM32 as shown in Figure 1. Along with the hutch interlock, the lasers were operated with a separate interlock at all times. The safety goggles correspond to the class and wavelength of the laser were used. A computer-controlled laser beam shutter was used for extra safety as shown in Fig 1 b.

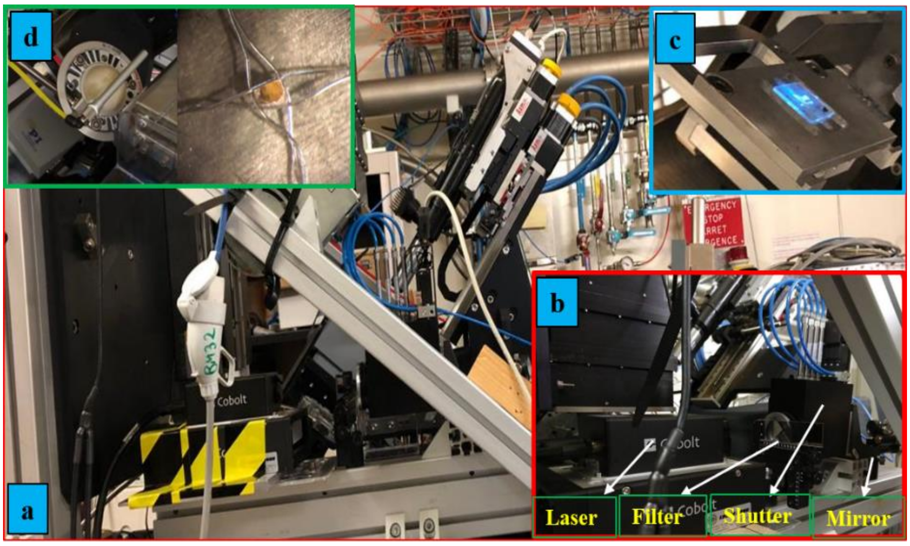

Fig. 1: (a) Optical setup overview at BM32. (b) Close-up of the optical components used for external illumination for photo-striction measurement. (c) 355 nm laser-illuminated on $PbTiO_3$ crystal. (d) Anton-Paar oven mounted on the Laue diffractometer and $PbTiO_3$ crystal held between four intertwined Ta wires for temperature-dependent measurements.

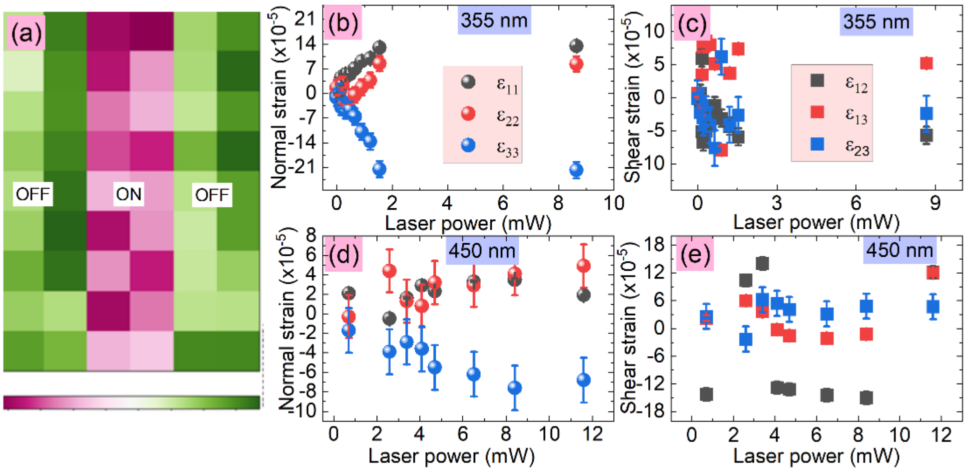

Fig. 2: (a) Time series mapping of peak positions for laser On/Off. (b), (c), and (d), (e) are deviatoric strain components for 355 nm and 405 nm lasers, respectively.

We investigated systematically the prototypical perovskite $PbTiO_3$ single crystal, chosen as a model system, for several excitation wavelengths, laser power, and temperature in order to understand the mechanism behind photostriction in ferroelectrics. The measurements were done for 3 selected wavelengths: 355 nm, 450 nm, and 808 nm. About 12 shifts were used to complete the room temperature photostrictriction measurements. The last 3 shifts were utilized to set up the oven and perform some temperature-dependent Laue diffraction.

As an initial test, we performed a time-series mapping of peak positions with and without light illumination to make sure that the light does induce some effect in the $PbTiO_3$ crystal. The position of one of the peaks (far away from the center) is displayed in Fig. 2 (a). A clear shift in peak position can be noticed when the laser is illuminated on the sample, which was the first validation of our approach.

To quantify the magnitude of strain and access the full strain tensor, we performed rainbow-filtered Laue diffraction. Fig. 2 (b), (c) and (d), (e) show deviatoric strain components calculated from the Laue pattern fitting for 355 nm and 450 nm laser illuminations, respectively. For 355 nm illumination, it can be observed that there is contraction along the polar axis (*c*-axis), whereas, the axes perpendicular to the polar axes expands with an increase in laser power up to 1.55 mW. Though the data between 1.55 mW and 8.65 mW are not available, the strain seems to saturate beyond 1.55 mW. The strain variation with respect to laser power for 450 nm illumination follows a similar trend but is not as pronounced as 355 nm. For 808 nm laser illumination, we did not observe any changes, even for 100 mW (not shown here). It is fairly clear that the closer the energy of incident light to the bandgap energy of $PbTiO_3$ (3.87 eV), the higher the strain is. The non-diagonal elements obtained from the Laue pattern fitting are probably due to the measurement uncertainties arising from uncertainty in Bragg angle and the energy of Laue spots, which otherwise would be zero for tetragonal symmetry. Nevertheless, it is important to note that the non-diagonal elements are more or less constant irrespective of laser power.

Data analysis is still ongoing at the time of the writing, but the results analyzed so far and presented above are very promising. The calculated strain results are very much in line with experimental reports (D. Darancinag *et al.*)[2] and consistent with the theoretical prediction as well (Paillard *et al.*).[3] Details of the interpretation are currently under discussion with the main author of the latter C. Paillard who will also join follow-up proposals. Future steps are (i) calculation of the hydrostatic strain components in order to obtain the true strains from the deviatoric components, (ii) analysis of the temperature-dependent experiment to separate any thermal effect from photostriction.

In summary, this experiment has fully validated our approach to photostriction studies and provided us for the first time with the full strain tensor under laser illumination. This gives us perspective for good quality publications and follow-up measurements.

REFERENCES:

1. B. Kundys, *Appl. Phys. Rev*. **2**, 011301 (2015).
2. C. Paillard *et al*., *Phys. Rev. B* **96**, 045205 (2017).
3. D. Daranciang *et al*., *Phys. Rev. Lett*. **108**, 087601 (2012).