



3D imaging of water ice under high-pressure non-hydrostatic load by time-domain Brillouin scattering

Sathyan Sandeep, Théo Thréard, Elton de Lima Savi, Nikolay Chigarev, Alain Bulou, Vincent Tournat, Andreas Zerr, Vitalyi Gusev, Samuel Raetz

► To cite this version:

Sathyan Sandeep, Théo Thréard, Elton de Lima Savi, Nikolay Chigarev, Alain Bulou, et al.. 3D imaging of water ice under high-pressure non-hydrostatic load by time-domain Brillouin scattering. 21st International Conference on Photoacoustic and Photothermal Phenomena, Mladen Franko (University of Nova Gorica, Slovenia), Jun 2022, Bled, Slovenia. pp.53-54. hal-03862206

HAL Id: hal-03862206

<https://hal.science/hal-03862206>

Submitted on 21 Nov 2022

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

3D imaging of water ice under high-pressure non-hydrostatic load by time-domain Brillouin scattering

Sandeep S⁽¹⁾, Thréard T⁽¹⁾, De Lima Savi E⁽¹⁾, Chigarev N⁽¹⁾, Bulou A⁽²⁾, Tournat V⁽²⁾, Zerr A⁽³⁾, Gusev VE^{(1)*}, Raetz S^{(1)*}

(1) Laboratoire d'Acoustique de l'Université du Mans (LAUM), UMR 6613, Institut d'Acoustique – Graduate School (IA-GS), CNRS, Le Mans Université, Le Mans, France

(2) Institut des Molécules et Matériaux du Mans, UMR 6283 CNRS, Le Mans Université, Le Mans, France

(3) Laboratoire de Sciences des Procédés et des Matériaux (LSPM-CNRS UPR-3407), Université Sorbonne Paris Nord (USPN), Villetaneuse, France

*Corresponding authors' email: vitali.goussev@univ-lemans.fr, samuel.raetz@univ-lemans.fr

Background – Time-domain Brillouin scattering (TDBS) technique is an opto-acousto-optic pump-probe technique [1] that uses ultrashort laser pulses to generate coherent acoustic pulses (CAPs) of picoseconds duration in a solid sample and follow their propagation in order to image inhomogeneities of acoustic, optical and/or photo-elastic parameters of materials transparent to the probe light wavelength [2]. This technique presents an axial resolution deeply sub-optical (to nm-scale), controlled by the CAPs width, and a lateral one down to the optical diffraction limit, controlled by lateral focusing of used laser beams. Detection of propagating CAPs is possible because they scatter time-delayed probe laser pulses heterodyned by the probe-pulse reflections from stationary sample surfaces, giving rise to an oscillating component in a transient reflectivity signal: the so-called Brillouin oscillation (BO).

The instantaneous frequency of the BOs is proportional to the product of local optical refractive index (n) and sound velocity along the beam path (v). Hence, in polycrystalline transparent samples made of anisotropic materials where n and v change from grain to grain, the Brillouin frequency changes with the probe delay give access to the depth arrangement of grains. Two-dimensional lateral scanning of the sample hence allows the TDBS technique to provide 3D-imaging of sample texture. In anisotropic grains, up to three bulk acoustical modes, one longitudinal and two shear, might be monitored. The time-frequency analyzes of frequency contents of the TDBS signals provide then access to shapes, relative coordinates of all grains (if resolved), as well as crystallographic orientation of the identified grains with respect to a common coordinate system [3].

The non-contact feature of the TDBS technique further permits to examine samples located in devices used to reproduce extreme conditions such as diamond anvil cells (DACs) for ultrahigh pressure. We report here on the 3D imaging of water ice under high-pressure non-hydrostatic load by TDBS. The 3D characterization of individual grains of two coexisting high-pressure water ice phases is reported, as well as imaging of a monocrystal fracture induced by non-hydrostatic compression allowing to follow the polycrystallization process occurring upon load increase in a DAC.

Methods – The TDBS experimental set-up (Fig. 1(a)) was based on asynchronous optical sampling, where accumulating time delay between green pump (515 nm, 198 fs duration) and green probe (535 nm, 130 fs duration) laser pulses is due to difference in the repetition rates of these lasers, allowing fast

data acquisition. It was hence possible to obtain 3D images of the Brillouin frequency distribution (of any detected acoustical modes) in a $100 \times 100 \times 10 \mu\text{m}^3$ volume with a lateral resolution of $2.5 \mu\text{m}$ limited by the overlap of pump and probe laser beams. The data collection rate depended on the chosen pump and probe laser powers and the number of averages needed to reach acceptable signal-to-noise ratio.

As depicted in Fig. 1(b), the generation of CAPs propagating in the transparent water ice compressed in the DAC occurred thanks to an absorbing metal layer serving as an optoacoustic transducer (OAT). Pressure inside the DAC was measured using fluorescence spectra of (embedded) ruby grains which R1-line position is calibrated vs. pressure. The optical path for pressure monitoring was included in the set-up (Fig. 1(a)) to allow measurement without removing the DAC from the sample stage, hence facilitating the comparison of 3D images at different pressures and visualizing evolution of crystallite shapes with compression.

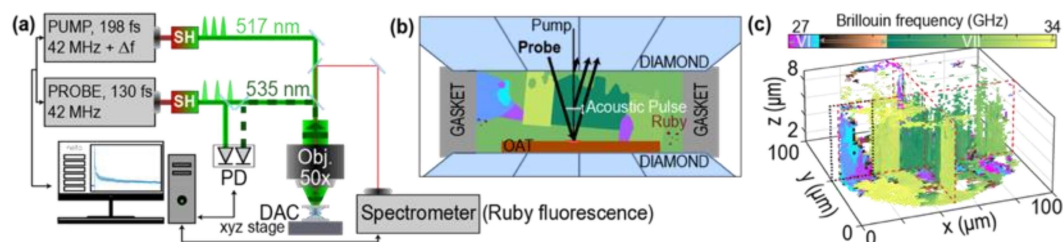


Fig. 1. (a) Experimental set-up and (b) TDBS experiment scheme, where the pump absorbed in OAT launched a CAP in the polycrystalline water ice where it scatters the probe. (c) 3D visualization of polycrystalline water ice microstructure.

Results summary and conclusive remarks – The used TDBS set-up provided a comprehensive, reliable high-resolution *in-situ* 3D visualization of microstructure of a transparent polycrystalline sample of water ice compressed in a DAC to 2.15 GPa where two phases, ice VI and ice VII, coexist (Fig. 1(c)). We observed, for the first time at high pressures in a DAC, TDBS signals containing contribution of quasi-shear CAPs, fruitfully used for grains characterization. Grain boundaries were also localized by identifying specific TDBS signals, caused by CAPs simultaneously propagating in two adjacent grains. Last but not least, the monocrystal fracture induced by non-hydrostatic loading was followed in 3D, further extending the horizons of investigation of solids and their evolution at (changing) extreme conditions.

Acknowledgments – This research is supported by the Agence Nationale de la Recherche (project ANR-18-CE42-I2T2M).

References

- [1] C. Thomsen, H.T. Graham, H.J. Maris, J. Tauc, Picosecond interferometric technique for study of phonons in the Brillouin frequency range. *Opt. Commun.* 60 (1986) 55. [https://doi.org/10.1016/0030-4018\(86\)90116-1](https://doi.org/10.1016/0030-4018(86)90116-1).
- [2] V.E. Gusev, P. Ruello, Advances in applications of time-domain Brillouin scattering for nanoscale imaging. *Appl. Phys. Rev.* 5 (2018) 031101. <https://doi.org/10.1063/1.5017241>.
- [3] S. Sandeep, T. Thr  ard, E. de Lima Savi, N. Chigarev, A. Bulou, V. Tournat, A. Zerr, V.E. Gusev, S. Raetz, 3D characterization of individual grains of coexisting high-pressure H₂O ice phases by time-domain Brillouin scattering. *J. Appl. Phys.* (2021) 130 053104. <https://doi.org/10.1063/5.0056814>.
- [4] A. Bandari, 3D-imaging of polycrystal texture, boundaries using time-domain Brillouin scattering, *AIP Scilight* (2021). <https://doi.org/10.1063/10.0005895>.

June 19 - 24, 2022
Bled, Slovenia



BOOK OF ABSTRACTS



<https://indico.ung.si/event/5/>

ORGANIZERS:

- UNIVERSITY OF NOVA GORICA
- UNIVERSITY OF LJUBLJANA
- JOŽEF STEFAN INSTITUTE



University of Ljubljana



Jožef Stefan Institute

Abstracts of the ICPPP21 Conference 2022

ICPPP21

19 – 24 June 2022, Bled, Slovenia

Organizing and Programme Committee

Chair:

Mladen Franko (University of Nova Gorica, Slovenia)

Vice-Chairs:

Dorota Korte (University of Nova Gorica, Slovenia)

Boris Majaron (Jožef Stefan Institute; University of Ljubljana, Slovenia)

Rok Petkovšek (University of Ljubljana, Slovenia)

Members:

Hanna Budasheva (University of Nova Gorica, Slovenia)

Humberto Cabrera (The Abdus Salam International Centre for Theoretical Physics, Italy)

Aljaž Čujec (University of Nova Gorica, Slovenia)

Petra Makorič (University of Nova Gorica, Slovenia)

Claudia D'ercole (University of Nova Gorica, Slovenia)

Petra Makorič (University of Nova Gorica, Slovenia)

Griša Močnik (University of Nova Gorica, Slovenia)

Nives Štefančič (University of Nova Gorica, Slovenia)

Iain R. White (University of Nova Gorica, Slovenia)

Nadja Lovec Santaniello (University of Nova Gorica, Slovenia)

Neža Golmajer Zima (Jožef Stefan Institute, Slovenia)

Martina Bergant Marušič (University of Nova Gorica, Slovenia)

Maria Chiara Magnano (University of Nova Gorica, Slovenia)

Martina Bergant Marušič (University of Nova Gorica, Slovenia)

Swapna Nair Sindhu (University of Nova Gorica, Slovenia)

International Scientific Committee:

Juan José Alvarado-Gil (Mexico)

Nelson Astrath (Brazil)

Bertrand Audoin (France)

Mauro L. Baesso (Brazil)

Jerzy Bodzenta (Poland)

Peter Burgholzer (Austria)

Mihai Chirtoc (France)

Nicu D. Dadarlat (Romania)

Gerald Diebold (USA)

Stanislav Emelianov (USA)

Mladen Franko (Slovenia)

Christ Glorieux (Belgium)

Xinxin Guo (Canada)

Vitaliy Gusev (France)

Daniel Lanzillotti Kimura (France)

Bincheng Li (China)

International Steering and Advisory Board:

Walter Arnold (Germany)

Stephen E. Bialkowski (USA)

Gabriel Bilmes (Argentina)

Paolo G. Bison (Italy)

Silvia Braslavsky (Germany)

Edson Corrêa da Silva (Brazil)

Danièle Fournier (France)

Yuri Gurevich (Mexico)

Frans J.M. Harren (Holland)

Peter Hess (Germany)

Alexander A. Kolomenskii (USA)

Jean-Claude Kraepz (France)

Junyan Liu (China)

John F. McClelland (USA)

Humphrey Maris (USA)

Fulvio Mercuri (Italy)

Roberto Li Voti (Italy)
Christiane Maierhofer (Germany)
Boris Majaron (Slovenia)
Xavier Maldague (Canada)
Andreas Mandelis (Canada)
Antonio Mansanares (Brazil)
Ernesto Marin (Mexico)
Alexei Maznev (USA)
Arantza Mendioroz (Spain)
Todd Murray (USA)
Matt O'Donnell (USA)
Alberto Oleaga (Spain)
Alexander Oraevsky (USA)
Keith A. Nelson (USA)
Mikhail Proskurnin (Russia)
Pascal Ruello (France)
Agustin Salazar (Spain)
Masahide Terazima (Japan)
Dragan Todorović (Serbia)
Chinhua Wang (China)
Oliver Wright (Japan)
Perry Xiao (United Kingdom)
Jacek Zakrzewski (Poland)
Ugo Zammit (Italy)
Vladimir Zharov (USA)

Jose Ordonez-Miranda (France)
Jean-Pierre Monchalin (Canada)
Udo Netzelmann (Germany)
C. Kumar N. Patel (USA)
Ivan Pelivanov (USA)
Joseph Pelzl (Germany)
Bernard Perrin (France)
Jun Shen (Canada)
Tomasz Starecki (Poland)
Jan Thoen (Belgium)
Helion Vargas (Brazil)
Mayo Villagrán-Muniz (Mexico)
Sebastian Volz (France)
Lihong Wang (USA)