Ultrafast laser induced microexplosion: A new strategy to synthesise super-dense nanomaterials

Saulius Juodkazis[1], Hiroaki Misawa[1], Eugene G. Gamaly[2], Andrei V. Rode[2]*

[1]*Research Institute for Electronic Science, Hokkaido University, Sapporo, Japan*

[2]*Laser Physics Centre, Research School of Physics and Engineering, Australian National University, Canberra ACT 0200, Australia*

**e-mail: avr111@rsphysse.anu.edu.au*

We demonstrate the ability to compress materials to high density/temperature using femtosecond laser pulses from a standard table-top laser tightly focused inside transparent dielectrics such as glass, quartz, or sapphire. Extremely high pressure (~10 TPa) and temperature (5×10^5K) have been produced using a single ~200 fs laser pulse focused inside transparent dielectrics. The laser pulse of intensity over 0.1 PW/cm^2 converts a material within the absorption volume of ~0.15 mm^3 into plasma in a few femtoseconds. A pressure of ~10 TPa, far exceeding the strength of any material, builds up to the end of the pulse. The pressure generates strong shock and rarefaction waves. Finally, this results in the formation of a nano-void surrounded by a shell of shock-compressed material [1]. In sapphire, the size of the compressed shell revealed that it has a density 1.14 times of the initial sapphire density. The unique conditions, namely, the extreme pressure and temperature at record high heating and cooling rates become available in a well-controlled laboratory environment.

Analysis of the size of the void and the shock affected zone as a function of the deposited energy shows that the experimental results can be explicitly understood on the basis of conservation laws and thus can be modelled by plasma hydrodynamics. The average density of compressed shell can be deduced from measured void size and size of shock-affected zone on the basis of the laws of mass and energy conservation [1].

The compressed material close to the boundary between the crystalline and the amorphous sapphire was investigated under the high-resolution transmission microscope (HRTEM). Fast Fourier Transform (FFT) analysis of the images revealed the existence of new spatial period of 1.6 Å absent from the known crystalline structure of sapphire (Fig.1,2). This period was observed in many spatial areas at distance of 50 nm along the amorphous-crystalline boundary in different samples, indicating the reproducibility of the results. We associate the presence of this new spatial period with the high-pressure induced crystal transformation to a dense phase.

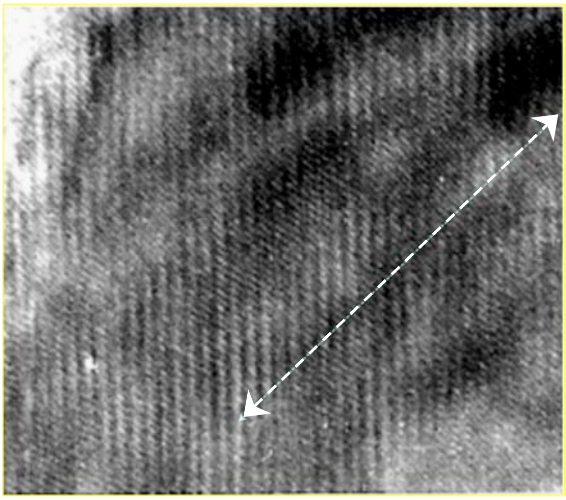

Fig.1. TEM image of the region analysed in Fig.2. The arrow marks the direction of the 0.16 nm periodicity.

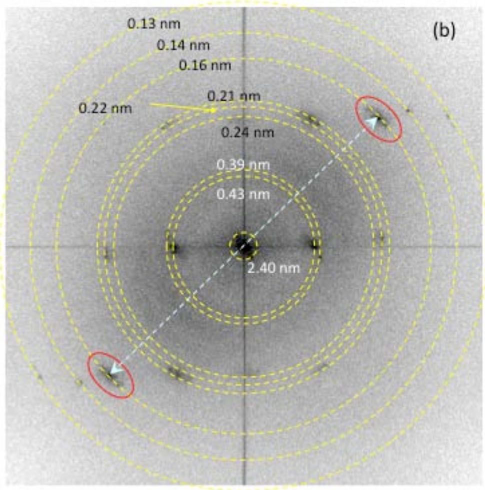

Fig.2. Fast Fourier Transform (FFT) of a region marked in Fig.1.

The new approach will have applications in the creation of new high-pressure phases of common crystals, and synthesis of a large variety of new materials with exotic properties, which are theoretically predicted but has not experimentally confirmed yet.

References

[1] S. Juodkazis, K. Nishimura, S. Tanaka, H. Misawa, E.G. Gamaly, B. Luther-Davies, L. Hallo, P. Nicolai, V.T. Tikhonchuk, "Laser-Induced Microexplosion in the Bulk of a sapphire Crystal: Evidence of Multimegabar Pressures", Phys. Rev. Lett. **96**, 166101 (2006).

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