Material synthesis, Energy, Cutting edge sciences

High performance high-power lasers and high energy density materials

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Abstract

Our research is to study structures and properties of materials in extreme conditions, such as ultrahigh pressures generated by high-power lasers. Understanding the changes in the structure and state of matter and the resulting changes in physical properties and chemical reactions is crucial for designing and synthesizing new materials. We believe that we can contribute to the developments of advanced laser machining and processing by combining real-time observation data with informatics technology. Our project will produce new knowledge through collaborative research using state-of-the-art facilities and equipment such as X-ray free electron lasers and supercomputers.

Background & Results

High-power laser-driven dynamic compression enables us to study materials under ultrahigh pressures over 10 million atmospheres (three times the pressure of the Earth's core), which is impossible to achieve with other techniques. In other words, the laser technique is an excellent approach to discovering the hidden structures and properties of matter. For example, carbon is one of the most important materials with various polymorphs. It has a unique phase that can exist as a solid (diamond) even under ultra-high pressure and temperature. Nano-polycrystalline diamond, consisting of nano-sized diamond grains packed without gaps, has believed to exhibit much higher strength than single-crystal diamond. In our research project, the strength of nano-polycrystalline diamond was quantitatively determined for the first time using the laser-driven ultrahigh pressure technique. Moreover, materials' deformation and state change under such extreme conditions can now be directly investigated using a highly bright, ultra-short pulsed light source called an X-ray free electron laser. We can even visualize how high-strength diamond is deformed and loses its strength by measuring the X-ray diffraction on such an X-ray free electron laser facility. In our research project, we plan to investigate how such high strength and high hardness materials melt. As the first step, we have succeeded in directly investigating the structure of tantalum, which is one of the hardest elemental metals with a very high melting point. The "breaking" of the high-temperature tantalum liquid was revealed by comparing the experimental results with first-principles quantum mechanics calculations.

Significance of the research and Future perspective

The discovery of new materials and new structures in extreme conditions extends the possibility of materials. Many questions exist in fast structural transitions, state changes like melting and metallization, and chemical reaction kinetics under extreme pressures and temperatures. The understanding of structural changes in terrestrial and planetary materials can lead to the elucidation of the internal structure and formation process of planets. A cross-disciplinary science in which Japan has an advantage, called high-energy density science, is progressing, and further developments are expected.

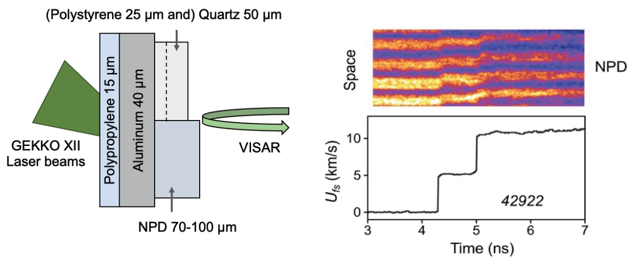


Fig. 1

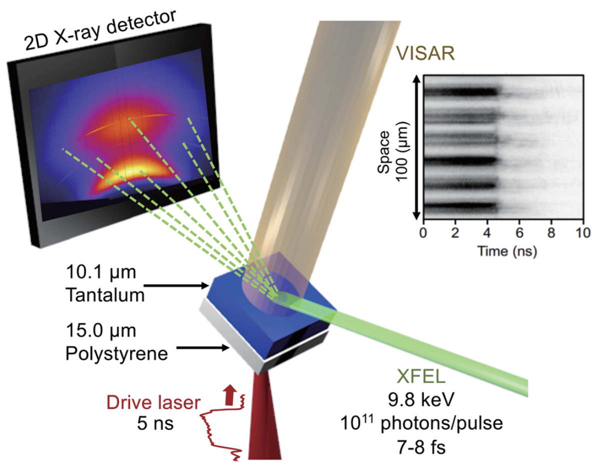
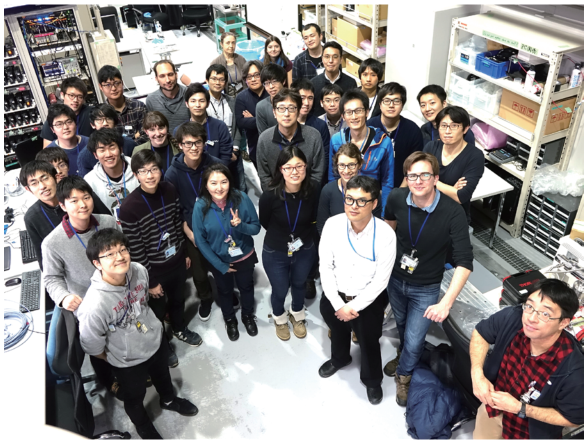


Fig. 2



Patent	Japanese Unexamined Patent Publication No.2020-098330, WO2019098330
Treatise	Katagiri, Kento; Ozaki, Norimasa; Umeda, Yuhei et al. Shock Response of Full Density Nanopolycrystalline Diamond. Physical Review Letters. 2020;125: 185701. doi: 10.1103/PhysRevLett.125.185701 Katagiri, Kento; Ozaki, Norimasa; Ohmura, Satoshi et al. Liquid Structure of Tantalum under Internal Negative Pressure. Physical Review Letters. 2021; 126:175503. doi: 10.1103/PhysRevLett.126.175503
URL	https://resou.osaka-u.ac.jp/ja/research/2020/20201028_1 https://resou.osaka-u.ac.jp/ja/research/2021/20210521_2 https://www.asahi.com/articles/ASN767L0BN6TPLBJ004.html?iref=pc_photo_gallery_bottom https://www.ile.osaka-u.ac.jp/ja/blog/2019/08/21/post-4073/index.html
Keyword	high-power laser, new material, extreme conditions, X-ray free electron laser, laser machining