

PRESS RELEASE

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Subject line: Harnessing the rattling motion of oxygen ions to convert T-rays to visible light

(Tokyo, November 29) A team of researchers led by Hideo Hosono at Tokyo Institute of Technology (Tokyo Tech) has shown that terahertz rays can be converted to light visible to the human eye. The finding is a breakthrough for functional materials research and could lead to the development of a new kind of terahertz detector.

Scientists have successfully visualized terahertz radiation, popularly known as T-rays, using a crystal called mayenite ($\text{Ca}_{12}\text{Al}_{14}\text{O}_{33}$). Their method cleverly utilizes the rattling motion caused by the vibration of oxygen ions inside the cage-like structures of the crystal.

In recent years, there has been growing interest in developing practical devices based on terahertz technology. With wavelengths longer than infrared light, T-rays are considered safer than conventional imaging systems. They are already used, for example, at airport security checkpoints, and are starting to be used more widely in areas such as medical screening, food inspection and analysis of artworks. The visualization of terahertz light itself, however, has so far proved challenging.

Now, Hideo Hosono of Materials Research Center for Element Strategy, Tokyo Tech and co-workers in Japan, Ukraine and the US have devised a simple approach to convert T-rays to bright, visible light. Their findings have been published in *ACS Nano*.

First, the study involved beaming T-rays onto the mayenite crystal using a gyrotron¹. This led to the vibration of oxygen anions², which collide with the inside walls of the cages within the crystal. Each cage has an inner diameter of 0.4 nanometers and an outer diameter of 0.7 nanometers (see Figure 1).

“The rattling of oxygen ions within the cages promotes upward energy conversion,” Hosono explains. “Strong and frequent collisions of the oxygen ions induce electron transfer to neighboring empty cages. The excitation of the oxygen ions is key to the emission of visible light.”

Spectroscopy measurements confirmed that the visible light originated from vibrations caused by the free-moving oxygen anions. The researchers took care to rule out the possibility of other sources such as black body radiation and surface polarization as reasons behind the production of visible light.

The study is an example of strategic research on functional materials under the Element Strategy initiative supported by Japan's Ministry of Education, Culture, Sports, Science and Technology (MEXT) and the Japan Science and Technology Agency (JST).

"The crystal in our study is just composed of calcium, aluminium and oxygen, all of which are in the top five of the most abundant elements," says Hosono. "So, it's one of the most inexpensive materials, at around 15 cents per kilogram."

Despite its simplicity, Hosono says that the crystal has many exciting properties due to its nanostructure. Drawing on 20 years of research, his group has already succeeded in demonstrating that the material has excellent catalytic properties for ammonia synthesis and superconductivity.

Best known for his pioneering work on iron-based superconductors, Hosono says that the current study marks a new research direction. "Our group has been concentrating on the cultivation of new functionalities using abundant elements, but it's the first time for me to focus on ionic motion — this is completely new," he says.

The findings could lead to the development of a T-ray detector, as no such conventional detector has yet been designed.

Hosono adds: "Right now, our material is good at detecting strong terahertz radiation. The challenge will be how to adjust the sensitivity."

His group has also reported that the oxygen anions can be substituted with gold or hydrogen anions inside the cages. By making use of these different anions, it may be possible to develop detectors that emit different-colored light in future.

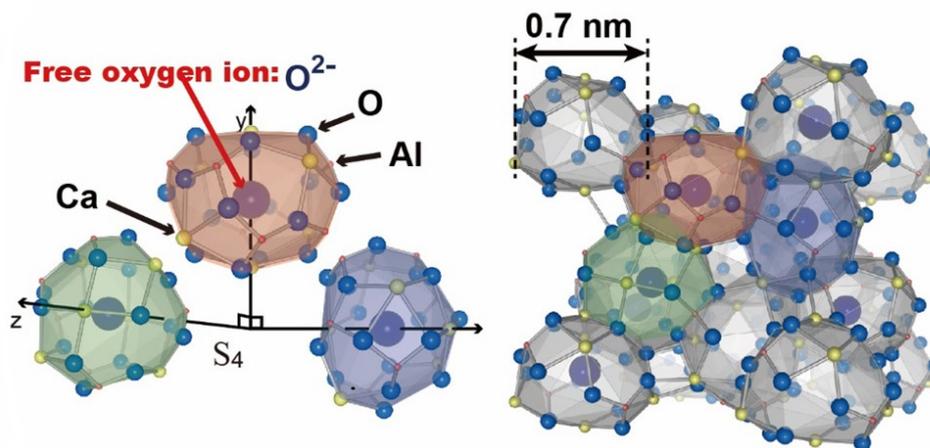


Figure 1. Representation of the crystal structure and visualization of T-rays

Top: A schematic representation of the nanoscale cages. The oxygen anions randomly occupy one sixth of the cages.

Bottom: A photograph of the emission of visible light at a terahertz radiation level of 0.21 and output power of 50 W.

Technical terms

¹Gyrotron: A device capable of generating high-power terahertz radiation. The gyrotron used in this study (called Gyrotron FU CW IV) was developed at the Research Center for Development of Far-Infrared Region, University of Fukui, Japan.

²Anions: Negatively charged ions. Together with their positively charged counterparts (cations), they hold together the structure of ionic crystals.

Reference

Yoshitake Toda[†], Shintaro Ishiyama[‡], Eduard Khutoryan[§], Toshitaka Idehara^{||}, Satoru Matsuishi[†], Peter V. Sushko[⊥], Hideo Hosono[†], Rattling of Oxygen Ions in a Sub-Nanometer Sized Cage Convert Terahertz Radiation to Visible Light, *ACS Nano*, DOI: 10.1021/acsnano.7b06277

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About Tokyo Institute of Technology

Tokyo Institute of Technology stands at the forefront of research and higher education as the leading university for science and technology in Japan. Tokyo Tech researchers excel in a variety of fields, such as material science, biology, computer science and physics. Founded in 1881, Tokyo Tech has grown to host 10,000 undergraduate and graduate students who become principled leaders of their fields and some of the most sought-after scientists and engineers at top companies. Embodying the Japanese philosophy of “monotsukuri,” meaning technical ingenuity and innovation, the Tokyo Tech community strives to make significant contributions to society through high-impact research. www.titech.ac.jp/english/

About University of Fukui

University of Fukui (UF) is a national university in Fukui prefecture located in northwest part of the Chubu region of Japan. At the UF, composed of 4 undergraduate schools: Education, Medical Sciences, Engineering, Global and Community Studies, and 3 graduate schools: Education, Medical Sciences, and Engineering. <https://www.u-fukui.ac.jp/eng/>

The Research Center for Development of Far-Infrared Region at the UF (FIR-UF), collaborates with domestic and overseas institutions in worldwide research activities. The center aims to fulfill its role as a world-class base for research on FIR/THz waves. Our research on high-frequency, high-power radiation sources Gyrotrons and the development of new FIR/THz high-power spectroscopic techniques attracts considerable attention from around the world.

About Hirosaki University

Hirosaki University was established in the former castle town of Hirosaki in 1949.

It is a national university and is located in Aomori prefecture, situated at the northern end of Honshu Island. Hirosaki University is a medium-size university with Faculties of Humanities, Education, Medicine, Science & Technology, and Agriculture & Life Science. These five Faculties cover a broad and comprehensive range of undergraduate academic disciplines.

The university is also home to seven graduate programs, including the independent and interdisciplinary doctoral course in Regional Studies.