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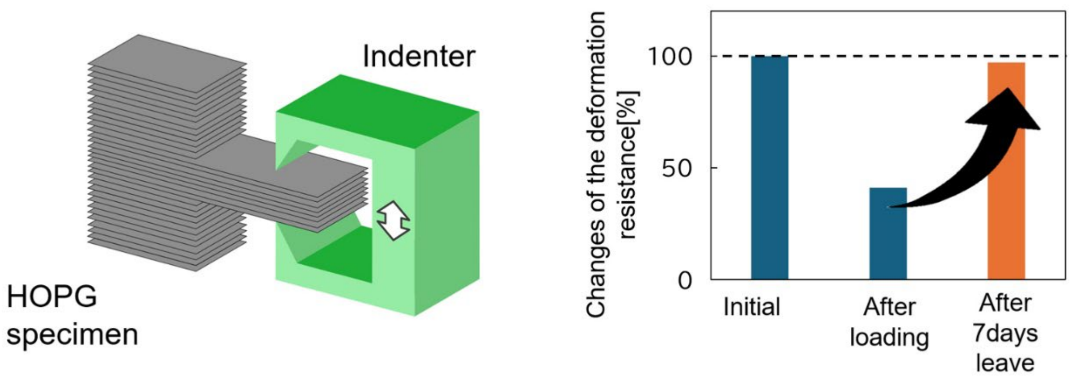
Mitsubishi Electric Confirms World's First Self-recovery Property of Highly Oriented Pyrolytic Graphite

Enhanced vibration resistance expected to extend operational lifetime of MEMS devices



Test method and confirmed self-recovery characteristics

TOKYO, January 27, 2026 – Mitsubishi Electric Corporation (TOKYO: 6503) announced today that it has confirmed the world's first[1] self-recovery property of highly oriented pyrolytic graphite (HOPG),[2] a van der Waals (vdW)-layered material,[3] in joint research with the Solid Mechanics Laboratory (Hirakata Laboratory) of Kyoto University's Graduate School of Engineering. This achievement is expected to extend the operational lifetime of micro electro mechanical systems (MEMS)[4] by utilizing vdW-layered materials, thereby contributing to the reliability of devices equipped with MEMS.

The demand for MEMS including accelerometers and pressure sensors is rapidly expanding, driven by the advancement of smartphone functionality, the increasing sophistication of autonomous driving and safety controls in automotive systems, and the widespread adoption of wearable devices. There is a growing need to achieve weight reduction while ensuring durability capable of withstanding prolonged vibration and shock. Against this backdrop, the application of vdW-layered materials—lightweight, flexible, and possessing high strength—to MEMS has been regarded as promising. However, producing micro-scale test specimens of vdW-

[1] According to Mitsubishi Electric research as of January 27, 2026.
[2] Highly pure and well-oriented graphite in which the orientation of individual graphite crystallites matches.
[3] A material that uses the weak attraction between molecules to form a structure.
[4] A micron-level device that integrates mechanical components, sensors, actuators, and electronic circuitry on a single substrate.

layered materials is technically challenging, and testing methods have not yet been established. As a result, their medium- to long-term reliability, particularly fatigue properties under repeated loading, has remained unexplored until now.

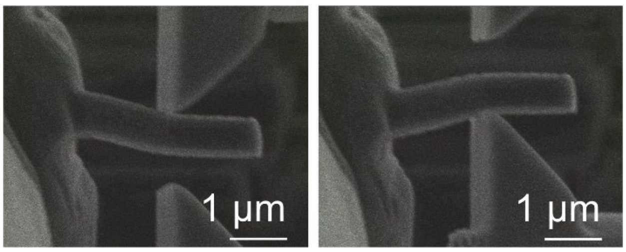
Mitsubishi Electric, in collaboration with Kyoto University, has succeeded in fabricating micro-scale test specimens of HOPG and has further established a new testing method in which the specimens are subjected to repeated bending loads to induce shear deformation. Analysis of the test results has been ongoing, and now, for the first time in the world,[1] the company has confirmed that HOPG specimens exhibit a self-recovery property, whereby they soften as the number of load cycles increases, and then, over time, their mechanical properties, including hardness, recover. This discovery suggests the potential to utilize HOPG, which inherently dissipates vibrational energy due to its layered structure, as a vibration absorption mechanism[5] equipped with the ability to recover from vibration-induced fatigue. Applying such a mechanism is expected to contribute to the development of highly reliable devices that are resistant to damage even in continuous vibration environments. Going forward, this fatigue testing method will be applied to other vdW-layered materials, advancing research aimed at extending the operational lifetime of MEMS.

The results of this research were selected for publication in the international journal *Diamond and Related Materials*.[6]

Features

World's first technology to confirm self-recovery property of HOPG, demonstrating recovery of deformation resistance from 41% to 97% in seven days

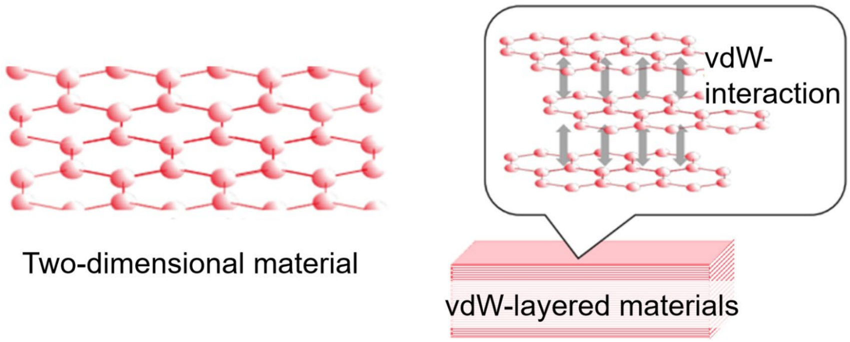
- A test involving repeated bending loads was conducted on micro-scale specimens of HOPG. It was confirmed for the first time in the world that, although the specimens soften with an increasing number of load cycles, they exhibit a self-recovery property in which their mechanical properties, including hardness, gradually return to their original states over time.
- In tests involving deformation of specimens in both directions, it was confirmed that the specimens softened to 41% of their original deformation resistance after 1,000 load cycles. However, after leaving the specimens for seven days, the deformation resistance recovered to 97%. This self-recovery behavior is expected to contribute to the extension of the operational lifetime of MEMS made from HOPG.



Electron microscope image taken during test

[5] By absorbing and dispersing vibration energy applied from the outside, the vibration and impact of the object are reduced, and damage and fatigue are suppressed.
[6] https://www.sciencedirect.com/journal/diamond-and-related-materials

Metals commonly used in everyday products deteriorate and eventually fail when subjected to repeated bending or loading due to metal fatigue. This occurs because repeated application of force leads to the initiation and propagation of cracks. In contrast, vdW-layered materials such as graphite have a unique structure in which thin sheets with strong atomic bonds (graphene layers) are stacked in multiple layers held together by very weak vdW forces. Owing to this structure, the layers can slip relative to each other (interlayer slip) when bent, allowing the material to flexibly absorb large deformations without breaking.

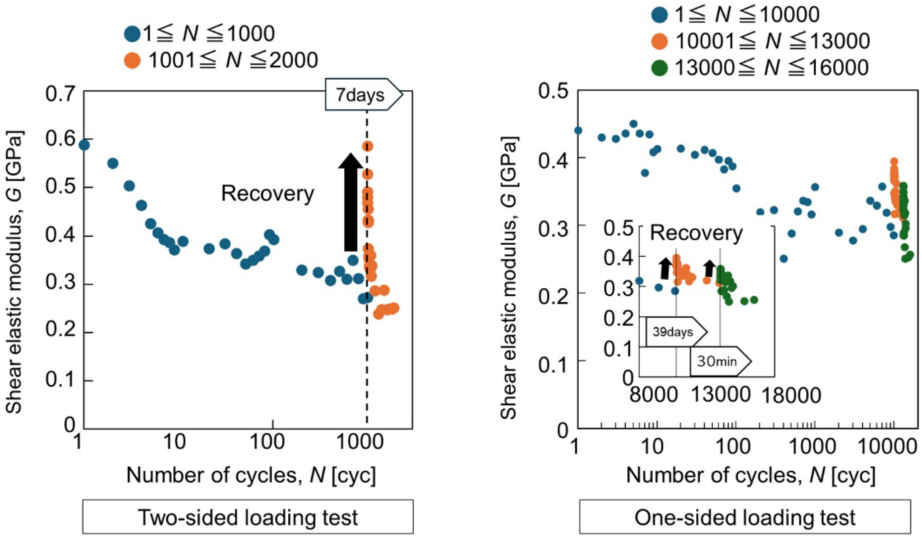


Configuration of vdW laminate

In this study, tests in which repeated loads were applied to extremely small HOPG specimens were conducted inside an electron microscope. Two loading methods were used: one in which deformation was applied in only one direction (one-sided loading) and another in which deformation was applied in both directions (two-sided loading). In the one-sided loading test, the specimen was subjected to 10,000 load cycles, then left to rest for 38 days. This was followed by 3,000 load cycles with a slightly increased load, a 30-minute rest period, and then another 3,000 load cycles with a further increased load, for a total of 16,000 cycles. In the two-sided loading test, the specimen was subjected to 1,000 load cycles, left to rest for 7 days, and then subjected to another 1,000 load cycles with an increased load, for a total of 2,000 cycles.

As a result, in both tests it was found that increasing the number of load cycles led to softening of the specimens (a decrease in deformation resistance). In the one-sided loading test, deformation resistance dropped to 66% of its initial value after 10,000 cycles, and in the two-sided loading test, it dropped to 41% after 1,000 cycles. Furthermore, for the first time in the world, it was confirmed that this softened state recovers over time—a property referred to as self-recovery. In the one-sided loading test, deformation resistance recovered to 91% when the specimen was allowed to rest for 38 days following 10,000 load cycles. In the two-sided loading test, it recovered almost completely to 97% after 7 days of rest following 1,000 load cycles. In the one-sided test, even after a short rest period of 30 minutes between the 13,000th and 13,001st cycles, deformation resistance increased from 70% to 82%. This self-recovery property observed in HOPG is attributed to two factors: the high strength and flexibility of graphene, which is the two-dimensional material forming the vdW-layered structure, and the characteristic of vdW interactions between graphene layers reforming after being temporarily broken due to interlayer slip.

These results indicate that MEMS made from HOPG achieve extended lifespans and thereby longer-term reliability. Additionally, the results are expected to support the realization of increased reliability across various devices equipped with MEMS, enhancing overall performance and durability.



Relationship between shear modulus and number of cycles in tests

Roles

Organization	Responsibilities
Mitsubishi Electric	Fatigue characterization of HOPG and analysis of results
Kyoto University	Basic research on physical properties of nanostructures

Future Development

The self-recovery property confirmed this time will be applied to vibration absorption mechanisms in MEMS, with the goal of developing highly reliable and long-lifetime vibration-damping systems. Additionally, research on self-recovery characteristics will be expanded to other vdW-layered materials, and efforts will be made to apply these materials to systems where deformation induces electrical potential. This approach seeks to enable MEMS that can efficiently convert deformation energy into electrical energy continuously, advancing the development of energy-harvesting MEMS.

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About Mitsubishi Electric Corporation

With more than 100 years of experience in providing reliable, high-quality products, Mitsubishi Electric Corporation (TOKYO: 6503) is a recognized world leader in the manufacture, marketing and sales of electrical and electronic equipment used in information processing and communications, space development and satellite communications, consumer electronics, industrial technology, energy, transportation and building equipment. Mitsubishi Electric enriches society with technology in the spirit of its "Changes for the Better." The company recorded a revenue of 5,521.7 billion yen (U.S.$ 36.8 billion*) in the fiscal year ended March 31, 2025. For more information, please visit www.MitsubishiElectric.com

*U.S. dollar amounts are translated from yen at the rate of ¥150=U.S.$1, the approximate rate on the Tokyo Foreign Exchange Market on March 31, 2025