PRESS RELEASE

Toyama, July 30, 2026

Just 50°C Decides Whether an Ultrathin Magnetic Film Stays Flat or Falls Apart

A two-step heating process produces highly ordered 5-nm-thick FePd films for low-power magnetic random-access memory and high-density magnetic storage

Ultrathin magnetic films for next-generation memory devices face a trade-off between atomic ordering and surface flatness. Researchers from the University of Toyama addressed this using a two-step heating method to grow highly ordered 5-nm-thick FePd films. The process involves low-temperature deposition for smooth layer-by-layer growth, followed by an annealing step to promote atomic ordering. The findings provide a simple strategy for developing energy-efficient magnetic random-access memory and high-density magnetic storage technologies.

Magnetic storage technologies, which store information in magnetization direction, play an essential role in modern data storage. Hard disk drives (HDDs) are widely used for long-term storage, while non-volatile magnetic random-access memory (MRAM) is emerging as a promising alternative to flash memory. These devices rely on epitaxial ultrathin magnetic alloy films in which two atomic species are arranged in alternating layers along a single crystallographic direction. This structure creates a large magnetocrystalline anisotropy energy (MAE), making the magnetic state more stable and preventing stored bits from accidentally flipping. The more perfectly ordered the atomic arrangement—measured by the degree of $L1_0$ ordering—the greater the MAE and the thermal stability of each magnetic bit.

However, producing films with both a high degree of $L1_0$ ordering and an atomically flat surface has remained a major challenge. High-temperature heating improves atomic ordering but also makes the film rougher as grains grow larger.

In a study made available online in the *Journal of Alloys and Compounds* on July 26, 2026, researchers from the University of Toyama, Japan, investigated how ultrathin 5-nm-thick $L1_0$-FePd films evolve during a two-step heating process. The study was led by Professor Hiroshi Naganuma from the University of Toyama.

$L1_0$-FePd films are particularly promising for MRAM because their low magnetic damping allows their magnetization to be switched using very little energy. Unlike conventional methods, the two-step heating process avoids exposing the film to high temperatures throughout its growth. Critically, the team also investigated the role of a nanoscale phenomenon known as solid-state dewetting (SSD), where atoms diffuse across ultrathin films during heating, causing the continuous film to break into holes or isolated islands if its surface free energy is much higher than that of the underlying substrate.

"Although SSD is more promoted in thin films, there have been no reports on the influence of SSD on the two-step heating process for $L1_0$-FePd alloy epitaxial films below a thickness of 5 nm," says Prof. Naganuma.

The researchers fabricated the films using radio-frequency magnetron sputtering. They first deposited Fe and Pd atoms onto a strontium titanate substrate at a relatively low temperature. Under these conditions, the atoms remain close to where they first land, allowing the film to grow layer by layer smoothly. After cooling the sample to room temperature, the researchers heated it to 600°C. This second heating step provides enough energy for the Fe and Pd atoms to rearrange into the highly ordered $L1_0$ crystal structure.

The researchers found that changing the first heating temperature by just 50°C strongly influences how the film evolves during the second annealing step. At 150°C, the film remained smooth and continuous, growing layer by layer in what is known as the Frank–van der Merwe growth mode. At 200°C, atomic diffusion becomes sufficient to initiate SSD, allowing the film to achieve nearly perfect $L1_0$ ordering while forming square holes that penetrate into the substrate. At 300°C, the film evolves into a rough, island-like morphology.

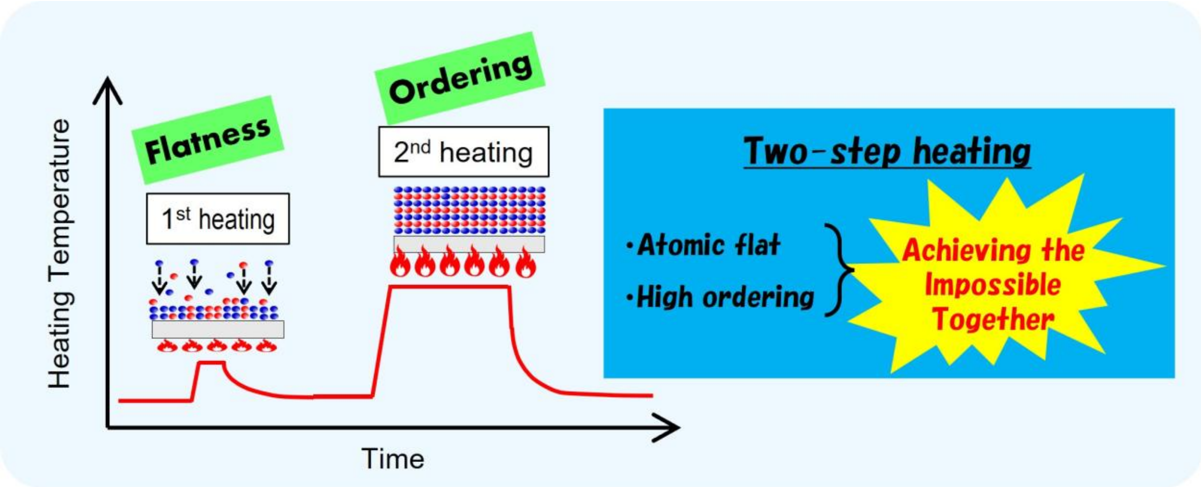
First-principles calculations revealed that SSD is driven by the surface free-energy difference between the film and substrate but only begins when defects formed during the first heating step trigger the process.

The findings show that controlling the first heating temperature provides a simple way to tune the structure and magnetic properties of ultrathin FePd films. For instance, the researchers state that films grown at 150°C are best suited for MRAM due to their flat surface and strong perpendicular magnetic anisotropy. In contrast, the controlled SSD observed at 200°C could enable self-organized magnetic structures for next-generation high-density storage devices.

This strategy could help develop ultra-low-power magnetic recording materials for future HDDs and MRAM, helping increase storage density while reducing energy consumption.

"These findings offer a strategic blueprint for leveraging nanoscale thermodynamic instabilities based on the two-step heating process to offer new routes to engineer magnetic anisotropy and nanostructures in spintronic devices," says Prof. Naganuma.

Image



Title: Two-step heating method delivers flat, highly ordered ultrathin magnetic films

Caption: The researchers fabricated 5-nm-thick $L1_0$-FePd films using a two-step heating process: low-temperature deposition for smooth layer-by-layer growth, followed by 600°C annealing to promote atomic ordering.

Credit: Professor Hiroshi Naganuma from the University of Toyama, Japan

License type: Original content

Usage restrictions: Cannot be reused without permission

Reference

Title of original paper:	Harnessing Two-Step Heating and Solid-State Dewetting for Highly Ordered $L1_0$-FePd Alloy Epitaxial Films
Journal:	*Journal of Alloys and Compounds*
DOI:	10.1016/j.jallcom.2026.189751

Additional information for EurekAlert

Latest Article Publication Date:	26 July 2026
Method of Research:	Experimental study
Subject of Research:	Not Applicable
Conflicts of Interest Statement:	The authors declare the following financial interests/personal relationships which may be considered as potential competing interests. Hiroshi Naganuma reports financial support was provided by Nagoya University. Hiroshi Naganuma reports a relationship with Nagoya University that includes: employment. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

About University of Toyama, Japan
University of Toyama is a leading national university located in Toyama Prefecture, Japan, with campuses in Toyama City and Takaoka City. Formed in 2005 through the integration of three former national institutions, the university brings together a broad spectrum of disciplines across its 9 undergraduate schools, 8 graduate schools, and a range of specialized institutes. With more than 9,000 students, including a growing international cohort, the university is dedicated to high-quality education, cutting-edge research, and meaningful social contribution. Guided by the mission to cultivate individuals with creativity, ethical awareness, and a strong sense of purpose, the University of Toyama fosters learning that integrates the humanities, social sciences, natural sciences, and life sciences. The university emphasizes a global standard of education while remaining deeply engaged with the local community.

Website: https://www.u-toyama.ac.jp/en/

About Professor Hiroshi Naganuma from the University of Toyama, Japan
Professor Hiroshi Naganuma is a Professor in the Academic Assembly Faculty of Engineering at the University of Toyama, Japan, where he specializes in spintronics, magnetic materials, thin films, electronic materials, and non-volatile memory devices. His research focuses on developing advanced magnetic materials for next-generation data storage technologies, including magnetic random-access memory, magnetic tunnel junctions, and epitaxial thin films. He has authored more than 260 peer-reviewed publications and contributed to six books on magnetic materials, ferroelectrics, and multiferroics. His work combines materials science, nanotechnology, and electronic engineering to develop energy-efficient spintronic devices and magnetic memory technologies.

Funding information
This work was partly supported by the JSPS Core-to-Core Program (No. JPJSCCA20230005), KAKENHI (Nos. 23H03803, 24K01346, and JP21H05016), the Collaborative Research Project of the Materials and Structures Laboratory at the Institute of Science Tokyo, the Design & Engineering by Joint Inverse Innovation for Materials Architecture program of MEXT, the Nagoya University Program for Research Enhancement, the Israel Science Foundation (Grant No. 2973/21), and the NSF–BSF Civil, Mechanical and Manufacturing Innovation (CMMI) program (Grant No. 2022600).

Media contact: Yumiko Kato
E-mail: ykato@ctg.u-toyama.ac.jp