

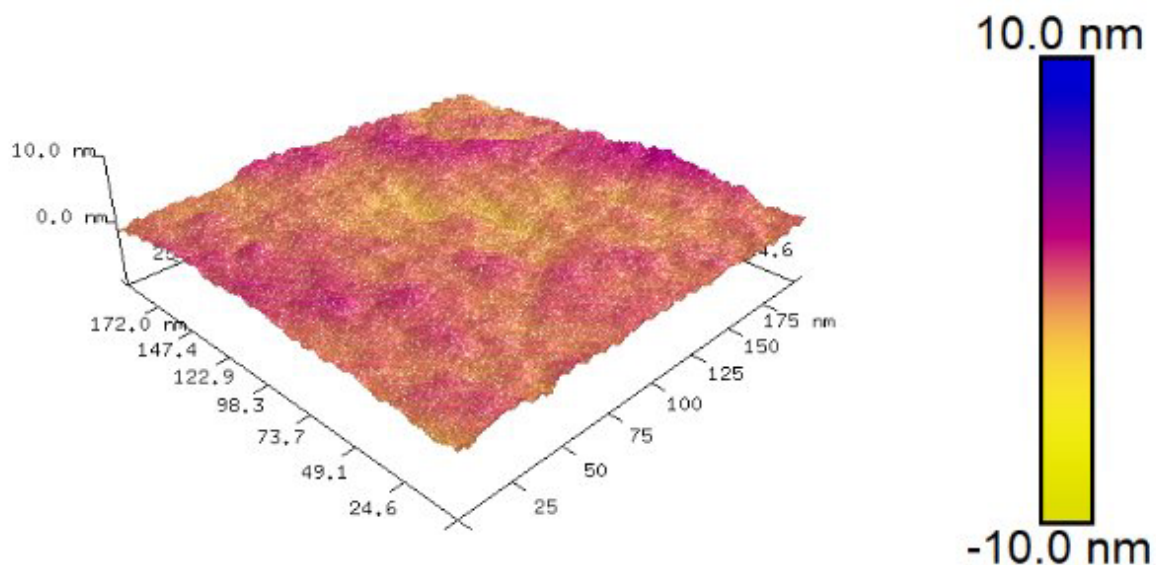


Commercial Micro-Manufacturing – April 2026 Articles

Recent Research into Structural and Electrical Changes in Vanadium Oxide Thin Films Critical for Microbolometric Device Performance

by Jim McMahon

The Nanomaterials Lab at the University of North Texas – a research group which strives to better understand the unique properties of nanoscale materials – has been experimenting with annealing driven phase changes in vanadium oxide thin films and their impact on bolometric characteristics. The lab's recent research, assisted by Negative-Stiffness vibration isolation, demonstrate that stress relaxation, crystallite formation, changes in resistivity and noise, which influence the film's electrical properties, are governed by specific annealing conditions. Vanadium oxide thin films are critical nanomaterials necessary for uncooled microbolometers used in applications including military, aerospace, gas analysis, security systems and medical imaging.



Topographic map of a vanadium oxide (VOx) thin film after annealing driven phase changes, viewed with an atomic force microscope (AFM), provides a good indicator of internal stress in the film which is a direct indicator of surface roughness. (Image courtesy University of North Texas)

Bolometric sensors are widely used in devices that detect heat or electromagnetic radiation by measuring temperature-induced changes in electrical resistance. Bolometers are primarily categorized by their sensing materials, operating temperatures, and the physical mechanisms they use to detect thermal energy, with two categories being prevalent in use:

- a) Cooled bolometers – which operate at cryogenic temperatures (e.g. liquid helium ~ 4.2 K or liquid nitrogen ~ 77 K), to achieve high sensitivity and low noise. They are essential for astronomical observations and high-end scientific experiments.
- b) Uncooled (room temperature) bolometers – usually designed as microbolometers, operate without cryogenic cooling, and are widely used in commercial thermal imaging, security, and automotive safety.

This paper focuses on recent research developments regarding structural and electrical changes within microbolometers.

Microbolometers

A microbolometer is a highly sensitive instrument that detects radiant energy by measuring the change in electrical resistance of a conductor as its temperature changes. Leveraging MEMS (Micro-Electro-Mechanical Systems) technology for mass production and uncooled operation, they work by absorbing infrared energy, which heats a thermistor element, changing its electrical resistance, and mapping this change into a visible thermal image.

A thermistor element is a semiconductor device made from metallic oxide thin films, such as vanadium oxide (VOx), that changes its electrical resistance dramatically with temperature, allowing it to function as a highly accurate temperature sensor or controller in electronics.

The important figures of merit for a thermal sensing membrane are the material's temperature coefficient of resistivity (TCR), and electrical noise. TCR quantifies how much a material's electrical resistance changes per degree of temperature change, crucial for electronics design.

Highly resistive films typically exhibit high TCR values and high signal-to noise ratios, factors that influence their performance in bolometer applications.

VOx Thin Films

VOx constitutes a class of materials characterized by significant physical and chemical properties. They exhibit intriguing solid-state physics, centered around phase transitions, in particular metal/insulator transitions as a function of temperature, which display peculiar structural, electronic, and magnetic behavior.

VOx thin films are the materials of choice for uncooled infrared microbolometers used in thermal radiation sensing. Ranging from a single atom to a few micrometers thick, thin films are used to modify surfaces for various technology applications, such as solar cells and integrated circuits, created by depositing material to control electrical or optical functions, or provide protective properties.

VOx thin films exhibit complex phase changes, primarily driven by temperature, oxygen content, and fabrication methods. These changes are attributed to stress relaxation and microstructural composition fluctuations, which today still pose questions concerning their description.

Annealing-Driven Phase Changes in VOx Thin Films Influence Bolometric Characteristics

Such questions are being researched by the Nanomaterials Lab at the University of North Texas, a research group which strives to better understand the unique properties of nanoscale materials.

The lab has been considering the effect of low-temperature annealing in various ambient atmospheres on not just the macroscopic electrical properties, but also changes to the low-frequency noise signal and the conduction mechanisms. The changes to the film properties are explained in terms of the impact of annealing on surface quality and microstructure evolution.

“We have been experimenting with annealing-driven phase changes in VOx thin films and their impact on bolometric characteristics,” said Alia Naciri, Graduate Research Assistant, Nanomaterials Lab, Department of Physics, University of North Texas. “Our recent studies highlight several competing mechanisms, such as stress relaxation and crystallite formation of various sizes, that influence the film's electrical properties. Changes in resistivity, TCR, and low-frequency noise are governed by the dominant mechanism under specific annealing conditions.”

“A major challenge in the growth of VOx films is its different oxidation states, resulting in several stable and unstable phases,” added Naciri. “The thin films we researched were annealed at 100 °C, 200 °C, and 250 °C in vacuum, oxygen, or argon for 15 or 30 min. At 100 °C, the film property changes are primarily attributed to stress relaxation, leading to reduced surface roughness. In contrast, high-temperature anneals promote film oxidation and formation of large microcrystals, resulting in substantial modifications to the resistivity, TCR, and low-frequency noise.”

The lab's research demonstrates that low-temperature thermal treatments on VOx thin films improve stress relaxation, crystallite formation, resistivity, and low-frequency noise, which influence the film's electrical properties increasing their bolometric potential. It is, therefore, critical to assess changes to the film microstructure and to its bolometric properties during these low-temperature thermal processes.

Need for Vibration Isolation

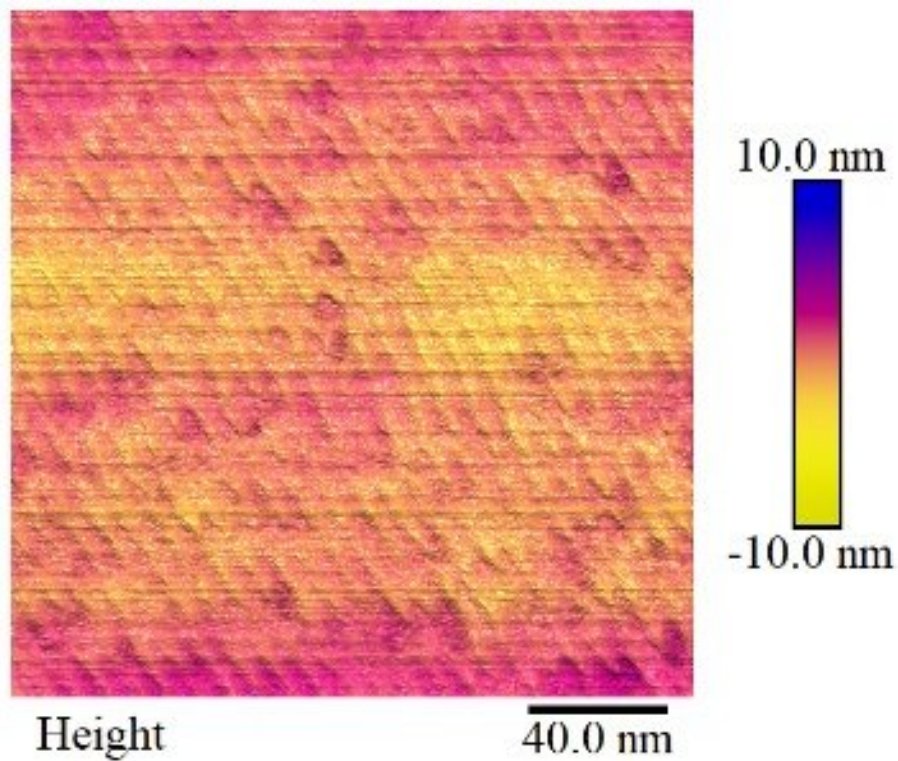
Because the films are so thin, however, it is difficult to characterize them before and after annealing to determine what has physically changed. Using an atomic force microscope (AFM), researchers at the lab can obtain topographic maps that provide a good indicator of how much internal stress is in the film, which is a direct indicator of surface roughness.

“Our ability to obtain clear results with the AFM, however, has been impeded by ambient vibrations coming from the building where our lab is located,” explained Naciri. “We have an optical table, but it is insufficient for isolating these low-frequency vibrations. The lab is on the third floor of a building on campus, where the vibrations necessitated us to use an AFM at a remote location off campus.”

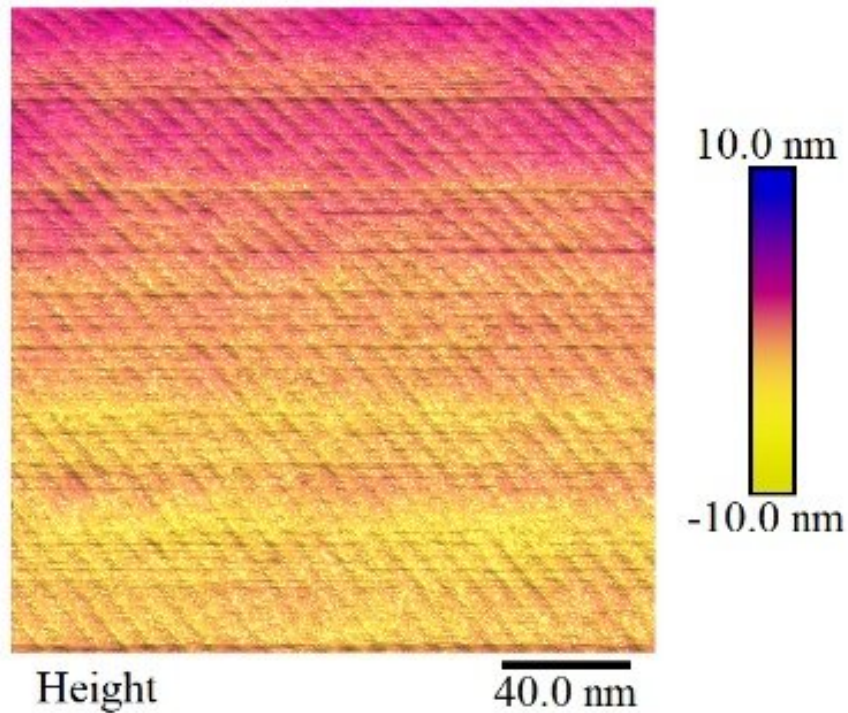
“Recently, our lab was awarded a complimentary Negative-Stiffness vibration isolation platform from Minus K Technology.” Explained Naciri. “With the isolator we are now able to achieve clean measurements without artifacts from the AFM location in our third-floor laboratory.”



AFM positioned on top of the Minus K Negative-Stiffness isolator at the Nanomaterials Lab at the University of North Texas. (Image courtesy University of North Texas)



AFM 2D image of VOx thin film after annealing driven phase changes, using an optical table for vibration isolation showing surface roughness. (Image courtesy University of North Texas)



AFM 2D image of VO_x thin film after annealing driven phase changes, using Negative-Stiffness vibration isolation showing reduced surface roughness. (Image courtesy University of North Texas)

Every year Minus K Technology awards a limited number of college and university labs with a Negative-Stiffness isolator. Minus K Technology's Educational Giveaway has provided over \$100,000 of their patented mechanical passive vibration isolators to colleges and universities in the U.S. over the last 10 years.

Introduced in the mid-1990s by Minus K Technology, Negative-Stiffness vibration isolation has been widely accepted for vibration-critical applications, largely because of its ability to effectively isolate lower frequencies, both vertically and horizontally. The company's isolators are used by more than 300 universities and government laboratories in 53 countries.

Negative-Stiffness isolators are unique in that they operate purely in a passive mechanical mode. They do not require electricity or compressed air. There are no motors, pumps or chambers, and no maintenance because there is nothing to wear out.

"Vertical-motion isolation is provided by a stiff spring that supports a weight load, combined with a Negative-Stiffness mechanism," said Erik Runge, Vice President of Engineering at Minus K. "The net vertical stiffness is made very low without affecting the static load-supporting capability of the spring. Beam-columns connected in series with the vertical-motion isolator provide horizontal-motion isolation. A beam-column behaves as a spring combined with a Negative-Stiffness mechanism. The result is a compact passive isolator capable of very low vertical and horizontal natural frequencies and high internal structural frequencies."

Negative-Stiffness isolators achieve a high level of isolation in multiple directions, with the flexibility of custom-tailoring resonant frequencies to 0.5 Hz vertically and horizontally (with some versions at 1.5 Hz horizontally)*. When adjusted to 0.5 Hz, the isolators achieve approximately 93 percent isolation efficiency at 2 Hz, 99 percent at 5 Hz, and 99.7 percent at 10 Hz.

(*Note that for an isolation system with a 0.5 Hz natural frequency, isolation begins at 0.7 Hz and improves with increase in the vibration frequency. The natural frequency is more commonly used to describe the system performance.)

About Nanomaterials Lab, University of North Texas

The Nanomaterials Lab at the University of North Texas is an interdisciplinary research group, which strives to understand the unique properties of nanoscale materials. At the same time, finding ways in which these materials can be used for innovation to enhance applications is also a core focus of the lab's research efforts.

The lab's research is broadly categorized into three general areas: (a) materials synthesis using bottom-up assembly and top-down nanofabrication techniques; (b) materials property characterization which includes electronic, opto-electronic, mechanical and strain-dependent properties; and (c) device characterization for platforms such as low-power, energy-efficient electronics, opto-electronics, sensors, solar cells, flexible and printed electronics, and devices for biosensing and implantable applications.

About Minus K Technology, Inc.

Minus K® Technology, Inc. was founded in 1993 to develop, manufacture and market state-of-the-art vibration isolation products based on the company's patented Negative-Stiffness technology. Minus K products are used in a broad spectrum of applications including microscopy, nanotechnology, biological sciences, semiconductors, materials research, quantum research/computing, zero-g simulation of spacecraft, and high-end audio. The company is an OEM supplier to leading manufacturers of scanning probe microscopes, micro-hardness testers and other vibration-sensitive instruments and equipment. Minus K customers include private companies and more