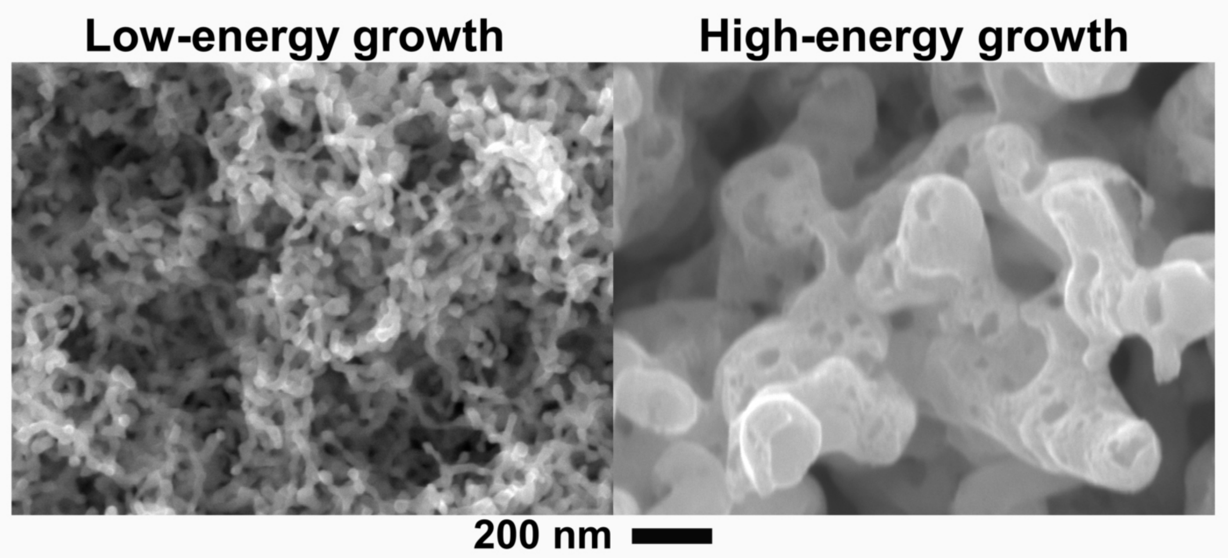
Study examines tungsten in extreme environments to improve fusion materials

March 7 2017



A study led by Oak Ridge National Laboratory subjected tungsten to low energies, akin to normal operations of a fusion reactor (left), and high energies emulating plasma disruptions (right). The study provides new knowledge needed to design robust fusion materials. Credit: Oak Ridge National Laboratory, US Dept. of Energy

A fusion reactor is essentially a magnetic bottle containing the same processes that occur in the sun. Deuterium and tritium fuels fuse to form a vapor of helium ions, neutrons and heat. As this hot, ionized gas—called plasma—burns, that heat is transferred to water to make steam to turn turbines that generate electricity. The superheated plasma poses a constant threat to the reactor wall and the divertor (which removes waste from the operating reactor to keep the plasma hot enough to burn).

"We're trying to determine the fundamental behavior of plasma-facing materials with the goal of better understanding degradation mechanisms so we can engineer robust, new materials," said materials scientist Chad Parish of the Department of Energy's Oak Ridge National Laboratory. He is senior author of a study in the journal *Scientific Reports* that explored degradation of tungsten under reactor-relevant conditions.

Because tungsten has the highest melting point of all metals, it is a candidate for plasma-facing materials. Owing to its brittleness, however, a commercial power plant would more likely be made of a tungsten alloy or composite. Regardless, learning about how energetic atomic bombardment affects tungsten microscopically helps engineers improve nuclear materials.

"Inside a fusion power plant is the most brutal environment engineers have ever been asked to design materials for," Parish said. "It's worse than the interior of a jet engine."

Researchers are studying the interaction of plasma and machine components to make materials that are more than a match for such harsh operating conditions. Materials reliability is a key issue with current and new nuclear technologies that has a significant impact on construction and operating costs of power plants. So it is critical to engineer materials for hardiness over long lifecycles.

For the current study, researchers at the University of California, San Diego, bombarded tungsten with helium plasma at low energy mimicking a fusion reactor under normal conditions. Meanwhile, researchers at ORNL used the Multicharged Ion Research Facility to assault tungsten with high-energy helium ions emulating rare conditions, such as a plasma disruption that might deposit an abnormally large amount of energy.

Using transmission electron microscopy, scanning transmission electron microscopy, scanning electron microscopy and electron nanocrystallography, the scientists characterized the evolution of bubbles in the tungsten crystal and the shape and the growth of structures called "tendrils" under low- and high-energy conditions. They sent the samples to a firm called AppFive for precession electron diffraction, an advanced electron crystallography technique, to infer growth mechanisms under different conditions.

For a few years scientists have known that tungsten responds to plasma by forming crystalline tendrils on the scale of billionths of a meter, or nanometers—a tiny lawn of sorts. The current study discovered that tendrils produced by lower-energy bombardment were slower-growing, finer and smoother—forming a denser carpet of fuzz—than those created by higher-energy assault.

In metals, atoms assume an orderly structural arrangement with defined spaces between them. If an atom is displaced, an empty site, or "vacancy," remains. If radiation, like a billiard ball, knocks an atom off of its site and leaves a vacancy, that atom has to go somewhere. It crams itself between other atoms in the crystal, becoming an interstitial.

Normal fusion-reactor operation exposes the divertor to a high flux of very-low-energy helium atoms. "A helium ion is not hitting hard enough to do the billiard ball collision, so it has to sneak into the lattice to start forming bubbles or other defects," Parish explained.

Theorists like Brian Wirth, a UT-ORNL Governor's Chair, have modeled the system and believe the material that gets displaced from the lattice when bubbles form becomes the building blocks of tendrils. Helium atoms wander around the lattice randomly, Parish said. They bump into other heliums and join forces. Eventually the cluster is big enough to knock a tungsten atom off its site.

"Every time the bubble grows it pushes a couple more tungsten atoms off of their sites, and they have to go somewhere. They're going to be attracted to the surface," Parish said. "That, we believe, is the mechanism by which this nanofuzz forms."

Computational scientists run simulations on supercomputers to study materials at their atomic level, or nanometer size and nanosecond time scales. Engineers explore how materials embrittle, crack, and otherwise behave after long exposure to plasma, on centimeter length and hour time scales. "But there was little science in between," said Parish, whose experiment filled this knowledge gap to study the first signs of material degradation and the early stages of nanotendril growth.

So is fuzz good or bad? "Fuzz is likely to have both detrimental and beneficial properties, but until we know more about it, we can't engineer materials to try to eliminate the bad while accentuating the good," Parish said. On the plus side, fuzzy tungsten might take heat loads that would crack bulk tungsten, and erosion is 10 times less in fuzzy than bulk tungsten. On the minus side, nanotendrils can break off, forming a dust that can cool plasma. The scientists' next goal is to learn how the material evolves and how easy it is to break the nanotendrils away from the surface.

The ORNL partners published recent scanning electron microscopy experiments that illuminate tungsten behavior. One study showed tendril growth did not proceed in any preferred orientation. Another investigation revealed that the response of plasma-facing tungsten to helium atom flux evolved from nanofuzz only (at low flux) to nanofuzz plus bubbles (at high flux).

The title of the current paper is "Morphologies of tungsten nanotendrils grown under helium exposure."

More information: Kun Wang et al, Morphologies of tungsten nanotendrils grown under helium exposure, *Scientific Reports* (2017). DOI: 10.1038/srep42315

Provided by Oak Ridge National Laboratory

Citation: Study examines tungsten in extreme environments to improve fusion materials (2017, March 7) retrieved 26 April 2024 from https://phys.org/news/2017-03-tungsten-extreme-environments-fusion-materials.html