Exploring tiny structures with big consequences
Probing the rapid mass transport mechanisms of tin whiskers.

Even when not shaving, Edmund B. Webb III and Yibo Wang worry about whiskers – tin whiskers, to be specific, that cause significant material destruction.

Webb, associate professor of mechanical engineering and mechanics, and Wang, a graduate student, study tin thin films, which are used in electronic circuits as coatings on contacts and solders for joining components. The films are found in everything from cell phones to satellites.

It’s widely known that the films grow “whiskers,” or thin crystalline structures, about 1/100th the thickness of human hair and long enough, sometimes, to form circuits between contacts and cause damage and loss.

NASA reports tin whiskers have caused system failures on Earth and in space. In a handful of incidents, whiskers have caused complete loss of satellite functionality. Typically, says Webb, whiskers are not a problem for products like cell phones or computers, which most people upgrade every few years. But they can become a concern in components and systems that sit idle for years and then must be restarted.

Lead has been used to solve this problem for more than 50 years, but its use today is precluded by health concerns. Webb and Wang are collaborating with Sandia National Laboratories to fabricate membranes for improving separation devices that monitor HIV infection as well as molecular separations of high-value chemicals produced by biorefineries.

Webb, Gilchrist and others are trying to learn how minute particles deposit similar — “the coffee ring effect” — examples of self-assembly. Something similar — “the coffee ring effect” — occurs when a drop of coffee dries into a ring instead of a spot.

Gilchrist observes these effects at the nanoscale where arrays of nanoparticles self-assemble. He and Prof. Nelson Tansu of electrical and computer engineering are trying to learn how minute particles deposit themselves into optical coatings. Their work has led to development of LEDs that are three times brighter.

Gilchrist also collaborates with Profs. Xuanhong Cheng of materials science and engineering and Mark Snyder of chemical engineering to fabricate membranes for improving separation devices that monitor HIV infection as well as molecular separations of high-value chemicals produced by biorefineries.

Snyder and Gilchrist have formed a company to develop nanoscale coatings and dye-support anodes to enhance dye-sensitized solar cells (DSSCs). Reversing the engineering of the LED project (engineers want to get light out of LEDs but into solar cells), they are flipping the microlens array inside the solar cell device and using dye molecules instead of silicon to absorb light. Solar cells with internal microlenses have proven to be 30 percent more efficient.

A $1.1 million NSF grant is helping Gilchrist and his colleagues develop two processes that enable commercial scale-up of these products. Both utilize roll-to-roll technology, similar to high-speed newspaper printing, to produce monolayer particle coatings that self-assemble into well-ordered arrays as they are being deposited.

With Snyder and Prof. Jeetain Mittal of chemical engineering, Gilchrist is studying fundamental deposition and developing numerical models, respectively. Process development is done with Versatilis, a Vermont company that manufactures advanced electronics for solar, lighting, display and related markets.

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“Most metal films are composed of microscopic crystallites, or grains, that grow together and merge during the formation process,” says Webb. “Regions where grains merge are called grain boundaries, and we suspect these regions control the formation of whiskers. We are studying the influence of atomic transport along grain boundaries to determine where on a surface a whisker will form. We also want to understand how stress in a thin film – known to play a role in driving whisker formation – influences grain boundary transport.”

Their models are revealing for the first time that anomalously rapid atomic transport for some boundaries directly determines where a whisker forms. If this is true, then preventing whiskers requires preventing the formation of the anomalous boundaries.

This phenomenon may explain why adding lead mitigates whisker formation since lead atoms are expected to reside in grain boundaries. The next step will be to use models to suggest non-lead-based processing strategies for achieving this same effect.

Gilchrist studies applications in LEDs and solar cells for particle self-assembly at the nanoscale.