Nanospirals that form as molten metals solidify could be key to new materials—and invisibility

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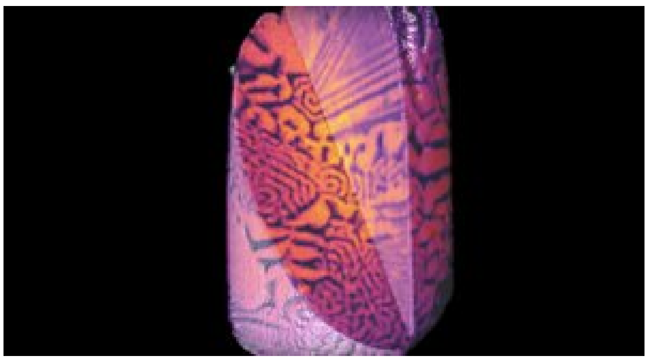

Nanospirals captured by Prof. Shahani's research. Credit: University of Michigan

Humans have been cooling metal mixtures from liquid to solid for thousands of years. But surprisingly, not much is known about exactly what happens during the process of solidification. Particularly puzzling is the solidification of eutectics, which are mixtures of two or more solid phases.

Ashwin Shahani, an assistant professor of materials science and engineering at the University of Michigan, is working to solve the mystery of eutectic solidification, and his research has revealed an intricate and beautiful universe of nanoscale rods, sheets and spirals that form spontaneously in cooling metal alloys.

We sat down recently to talk with him about his latest paper, "Multi-Step Crystallization of Self-Organized Spiral Eutectics," and how it could lead to a new generation of lightweight alloys and optical products with properties superior to monolithic materials.

What motivated you to study metal solidification?

I think it's one of the most remarkable feats of nature. How can these elaborate patterns form spontaneously from a disordered liquid? Why does nature choose one pattern or configuration over another? A lot of it is just inborn curiosity and the joy of sharing it with my students.

Why is it important to understand how these nanoscale structures form?

A material's nanoscale structure changes its properties. So if we can understand why a given structure forms, we can design a manufacturing process to recreate it, or even change it to build in specific properties that we want. We can make materials that are lighter, or stronger, or that bend light in a certain way, for example.

What could those new materials be used for?

A material that bends light in a certain way could be used to make an invisibility coating. You could engineer a single sheet of metal with properties that differ along its surface—for example an airplane wing that's stronger in some places and lighter in others. You could make lighter and more fuel-efficient automotive components. The possibilities are just about endless.

Why can't we make these materials using existing

manufacturing methods?

We can, but it's extremely difficult and time-consuming. If we want to fabricate a nanoscale spiral pattern, for example, we have to use lithography to print each tiny spiral. That's not practical for large-scale manufacturing. But what if you could cause those spirals to self-assemble just by cooling the liquid differently or slightly changing its mix of metals? That would make the process much faster and more scalable.

If humans have been using solidification for so long, why hasn't someone already figured this out?

Because in the past, this kind of research relied on sectioning up a material that has already solidified and looking at it under the microscope. And that gives you a very limited view of how solidification happens.

We're using a unique combination of multiscale and multimodal imaging technologies to create a 3-D picture of what's happening in real time during the solidification process. It involves combining a lot of different imaging techniques that can give us a cohesive picture from the scale of micrometers all the way down to individual atoms.

What are some of the challenges of combining all those technologies?

One of the biggest challenges is that high-resolution 3-D images are just so data-intensive. That makes this a big data challenge as well as a materials science challenge. Obviously, just having a high level of computing power is important, but we've also introduced some novel strategies. For example, we've begun using machine learning algorithms to comb through our data and find things that are noteworthy.

What's the next step for this research?

Most engineering materials consist of not just two components but a cocktail of elements. So right now, we're looking at how chemistry affects the solidification process. If I add a small amount of another metal to the molten mix, how does that change the nanoscale structures that form? It's another step toward understanding and ultimately controlling these structures.

More information: Saman Moniri et al, Multi-Step Crystallization of Self-Organized Spiral Eutectics, *Small* (2020). DOI: 10.1002/smll.201906146

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