Researcher customizes nanoscale systems for large-scale impact in light and energy

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Silvija Gradečak has big intentions for small ingredients. The associate professor of materials science and engineering at MIT focuses on energy-conversion and light-harvesting through the use of nanomaterials. It's at these microscopic scales that she can customize individual components, meld the parts, and create a new kind of material.

The work is not without its challenges: There's the need to understand and delicately balance pieces on the atomic scale and then be able to take discoveries made in the lab and apply them to a bigger workspace.

But there are also great possibilities: Her solar cells could absorb and use more sunlight. Her light bulbs could last longer, and her thermoelectric devices could take heat that would be otherwise lost and turn it into energy. "We're looking for more efficient, more environmentally friendly, and less expensive technology with new capabilities," Gradečak says.

Working in closed spaces

One benefit of using nanomaterials is their scale, Gradečak says. The confined dimensions are ideal for tailoring the properties of electrons, photons, and protons, providing the chance to engineer individual nanoscale components and, using synthesis methods, control their properties and performance. For example, by changing the size and composition of nanomaterials, Gradečak can change a semiconductor's

energy band gap, allowing photons of different energies to be absorbed into a new type of solar cell.

The research is in its early stages, but Gradečak says the potential exists for various light-harvesting applications, specifically when it comes to efficiency. As it stands, within one hour, the Earth receives enough sunlight to supply one year's worth of energy. The problem is that only a portion of the sunlight is used with current solar technology.

Gradečak's cells could be customized to absorb different wavelengths and composed of several types of nanomaterials—nanowires, nanoparticles, and graphene—which each have a specific function in the new type of solar cells. The devices could be put onto buildings and other surfaces to take into account the needs of both a specific application and a given geographic location. Adding to that, the new solar cells are flexible, lightweight, and transparent—cells wouldn't be limited in their placement, but now could be used on curved and moving surfaces, such as cars and clothing. "Harvesting solar light would become a matter of convenience," she says.

Playing with colors

Another of her projects focuses on developing light-emitting diodes: Current sources of artificial light could last longer and be more efficient. As Gradečak says, they generate more heat than light. Light bulbs based on semiconducting diodes do exist and they are already more efficient, but they're also more expensive. Nanowires could hold the solution. They can be grown on a variety of substrates, thereby lowering the costs, and they don't contain the defects that are inherent in current technology.

The challenge with manufacturing lighting sources is producing the same colors and intensities as the sun, and making these comfortable for the human eye. In Gradečak's lab, she's designing a device that is able to

emit greens, blues, and reds in different ratios. With nanotechnology, she can tune the band gap of the materials and consequently change the wavelength. Simultaneously, she's working on technology that produces blue light that is transformed into reds and greens in different proportions with the use of phosphorus materials, which absorb blue light and re-emit it in a different color.

The overlying challenge with making a successful transition is understanding the nanocomponents and making them work together. Gradečak has developed a characterization technique that can determine how changing the composition and morphology of the nanomaterials changes the optical properties. Or, as she says, "What are the knobs that we need to tune during synthesis to obtain specific functionality?"

Along with that, Gradečak is looking at ways to enhance the flexibility and efficiency of solar cells, particularly through transparent electrodes. This is where her use of graphene plays a key role. Currently, indium tin oxide is the industry standard, but it's expensive. Graphene has one layer of carbon atoms, as well as the necessary conductivity and flexibility. The question that Gradečak continues to explore is how to deposit materials onto graphene such as to have them interface and produce a workable solar cell.

Controlling temperature

One of her other projects involves developing a thermoelectric device. Similar to a solar cell, this would harness thermal energy and convert it into electricity. For example, a car's engine generates a high temperature, but most of that energy goes to waste. Her hope is to capture that heat and ultimately use it to power the vehicle's electrical systems. Taken a step further, solar cells could be placed on that same car to heat or cool it. "It's a development that's well into the future, but one that would open up new ways of how we think about energy," Gradečak says.

With all her work, an essential aspect is mastering the issue of scale. She's working with atoms of different materials. Each one could be customized, but playing with one can affect others in untold ways. The correct interaction and balance can be found, but that's just one piece of the equation. The next and necessary step in the process is to take a finding in the lab that works at 1 square inch and translate it to real-life, practical, industry-needed size, all while preserving the quality and efficiency.

"Nanomaterials offer exciting opportunities, and understanding how to translate their properties to the macroscopic scale holds the key toward scalability and new energy applications that currently do not exist," Gradečak says.

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