Fashioning Functional Fabrics

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Juan Hinestroza, an assistant professor of Fiber Science in the Department of Fiber Science and Apparel Design in the College of Human Ecology at Cornell University, cannot wait for one of his PhD students to disappear. But not in a bad way—her disappearance would mark the successful culmination of years of research. Christina Diaz, a doctoral candidate, is attempting to coat cotton fabrics with nanoparticles having functional polymer molecules attached to their surfaces. These particles are aimed at reducing the near-infrared signal of fabrics, potentially making them invisible to someone wearing night vision goggles in the dark. The defense industry is interested in such a fabric for soldiers' uniforms for nighttime maneuvers.

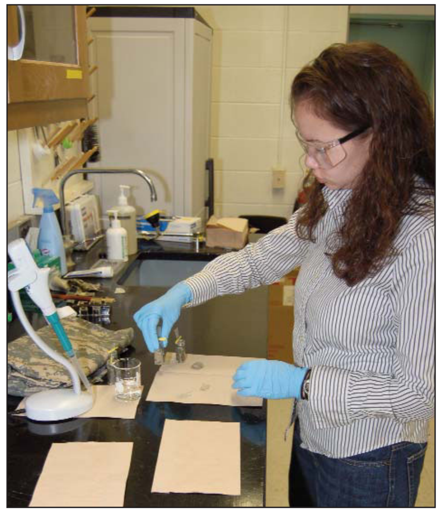
"I told her she can graduate the day she becomes invisible," Hinestroza said. "I'll be wearing my night vision goggles and if I cannot see her, she gets her PhD." He waits a beat before dropping the well-timed punchline. "She told me that she would just not show up."

This project is one of many that Hinestroza is leading in his efforts to understand the interface between natural and synthetic materials, which is his overriding scientific passion. After starting five years ago by depositing 20-nm-thick polymer films on natural fibers, he switched to working with inorganic films. The next step was to move from thins films to discrete nanomoieties—specifically, nanoparticles.

"We started with silver, gold, and platinum, and then we moved to ruthenium and palladium," Hinestroza said. "Initially we were interested in how the static charge of these particles interacted with these fibers, but now we are finding applications for these platforms—killing bacteria, decomposing toxic gases, and detecting viruses or allergens."

All of this functionality is possible on a flexible, wearable substrate, like cotton. And it is this property—wearability—that brought Hinestroza's group the most publicity they have received to date, including unexpected coverage by ABC News, CNN, NPR, and the BBC, among others. These high profile media outlets became interested in this arcane scientific research when nanoparticles made their premier on the runway at the April 2007 Cornell Design League fashion show, as coatings on a designer dress and jacket.

None of this would have happened without the inspiration of Olivia Ong, then a design student in Cornell's College of Human Ecology's Department of Fiber Science and Apparel Design. Ong, who graduated in December 2007, was one of Hinestroza's undergraduate students, so she was aware of his pioneering attempts to incorporate nanoparticles into fabrics. She decided to use some of these fabrics in her "Glitterati" line for that year's annual fashion show.



Christina Diaz, a doctoral candidate at Cornell in Juan Hinestroza's group, prepares nylon-cotton camouflage fabric coated with colloidal polystyrene particles through convective and electrostatic self-assembly. Her goal is to make the fabric invisible to someone wearing night vision goggles.

Hinestroza admits that he was skeptical at first when Ong approached him about the project. While she knew something about the scientific applications of the nanoparticle fabrics, she seemed to be mostly interested in the colors, as one might expect from a designer. But in this case even the color of the fabric has a novel scientific aspect—it is based on the size and spacing of the nanoparticles, and not on a dye. The way light interacts with the nanoparticles before it reaches the eye to be interpreted as a color is known as the "plasmonic color" phenomenon. Hinestroza had some interest in plasmonic colors, but they were not his priority at the time.

"Because I am a scientist, the project would probably have ended right there. But I'm a faculty member and I would never discourage a student's 'crazy' idea," he said, laughing. "So we decided to play the game."

And he is glad they did. "We started to understand how different a designer's thinking is from a scientist's." Being chemical engineers, Hinestroza and his postdoctoral associate Hong Dong began scaling up the nanoparticle deposition process by going to Home Depot and buying big plastic containers to treat the larger pieces of cotton fabrics. Dong chemically induced a positive charge in the cotton fiber so the negatively charged silver nanoparticles in the container's solution would assemble electrostatically.

When they dipped Ong's cotton fabric into the solution containing silver nanoparticles 10–20 nm in diameter, the results were not satisfactory the first time—the resulting colors were not the ones that Ong had envisioned. Hinestroza and Dong relearned the engineering lesson that scaling up is not as simple as it seems. The second attempt was more successful.

"We had to tune the colors that she wanted, and Olivia understood the limitations of the process," Hinestroza said. "It was a great learning experience for both of us. Olivia took these pieces of cloth and made them into a beautiful dress."

In addition to the yellow-orange dress, Ong also fashioned cotton coated with palladium nanoparticles into a denim (heavy cotton fabric) jacket with a metallic sheen. Both garments received good reviews from the fashion reporters. But at a cost of approximately $10,000 for this small project, it is unlikely that these fabrics will be seen at The Gap anytime soon. Still, Hinestroza said it was worth it: "It would have been easier to say 'no' to Olivia and to focus on writing scientific papers, but this was fun, and it allowed us to communicate the themes of nanotechnology using materials that people can easily relate to, that they can touch."

The publicity from national and international media did not hurt either. Fortunately, they presented a balanced coverage that combined the fashion aspects with the scientific ones. The reporters noted that silver is an antibacterial agent, and so silver nanoparticles in a garment could impart antibacterial protection to the wearer. The palladium particles in the jacket could oxidize smog. And the conformal coating of the nanoparticles on a garment's surface could repel aqueous and oil-based compounds, preventing stains. The metal particles are so small that the fabric is as pliable as cotton itself, so the wearer does not have to sacrifice comfort.

Beyond fashion, there is great interest in catalytically active fabrics for tents that could decompose toxic gases while soldiers or campers sleep inside, providing unprecedented protection. Hinestroza's group also wants to explore "interactive camouflage"—the ability for a uniform to change colors depending on its surroundings, like a chameleon.

"You can take these particles and move them with the proper stimuli," Hinestroza said. "One part of the fabric will be green and the other will be gray, and it will mimic the color of the environment, just by controlling the particle size and the spacing." Of course the fabric would have to sense its surroundings in order to mimic them, and the ability to change the spacing of nanoparticles on fabrics is a challenge that remains to be solved.

"My goal is ultimately for the technology to be like Adobe Photoshop for fabrics," Hinestroza said. "When you open the palette, and a person says, 'I want this color,' it tells you what particle size you need, and what atoms you can use, then you can produce it from the specification. That's my dream, but of course we're far away from that. But I think it's possible."

The catalytic and color aspects of nanoparticle-coated fibers are just a small part of Hinestroza's work and dreams. Again, his scientific passion is to understand the interface between natural and synthetic materials. How do these two different media interact, and what can they be used for?

One answer is that the electron-rich pores of cellulosic materials like wood and cotton can be used as nanoreactors in which to grow nanoparticles of a controlled size. The confined geometry of the pores restricts the nanoparticle size. What Hinestroza loves about this is that "you are using something natural to produce something synthetic. It's amazing because you can use a cotton fiber as a size-exclusion system to make metal nanoparticles of 1 nm up to 20 nm. We have done chemical reactions inside natural fibers." One of the great advantages of this technology is that it is possible to turn a waste product like scrap wood into a nanoreactor to produce nanoparticles. The high electron density of the cellulose helps in the synthesis.

But the world is full of natural fibers composed of cellulose, which is why several months ago Hinestroza found himself in the Amazon rainforests, studying fibers that grow only there. "They have fantastic properties and structures that can be harnessed for high-performance applications," Hinestroza said. He was particularly interested in sisal, a very stiff fiber that is used locally for the reinforcement of concrete.

Many other rainforest fibers are used in local construction. "I was able to see structures built with natural fibers from those places, and that's what got my attention," Hinestroza said. "These people already know how to use them, and we can try to understand why they are using them." He said that these fibers are sustainable materials, and that they only grow in the rainforest because of the incredible amount of humidity and unique environmental conditions found there. He is currently working to establish a collaboration between Cornell and other universities in the United States and universities in Argentina, Mexico, Brazil, and Colombia—his native country—to understand the chemistry of these unique natural materials.

Juan Hinestroza, an assistant professor at Cornell University, works with intergenerational teams of senior citizens and Cornell students applying basic knowledge of new fibers and fibrous materials to solve problems facing the elders in Ithaca, NY.

Outside the glamor of the fashion runway and the beauty of the Amazon, Hinestroza works hard at Cornell University to instill in his students a sense of the power of science to connect with and solve problems within their community. He has a very active outreach program that connects his 18-to-23 year old students with 65-to-81 year old senior citizens. The students use their knowledge of fibers and other aspects of materials science to address the problems of senior citizens. A course called "Fiber Science and Apparel Design 466—Textiles, Apparel and Innovation," is part of the intergenerational design initiative known as the Living Environments Aging Partnership (LEAP), which is just one aspect of this outreach effort. Over the course of several years, students have worked closely with their senior citizen co-investigators to develop and apply for patents on products such as a walker that also functions as a chair, a cane, and a handbag; and an oversized electronic pillbox that reminds them when to take their pills and the correct dosage, with memory foam that makes it easier for arthritic hands to open the pillbox. Other designs they have collaborated on include a garment that provides continuous, real-time monitoring of vital signs and contacts a doctor in a medical emergency, and a shoe with a temperature regulator to counteract the common problem of cold feet that some elderly people experience.

At the other end of the age scale, Hinestroza hopes that the interesting applications at the interface of nanoparticles and fibers—nighttime invisibility, interactive color, and antibacterial clothing—will show children that science can be cool, and might inspire them to pursue science as a career. He also hopes that his own story, as a boy from the mountains of Colombia who found success through science, might be inspirational.

"I think that is really important, especially for members of minority groups like me, to have a mentor or a role model to follow. When they see someone like them being successful, they will believe in themselves," Hinestroza said. Turning his sense of humor on himself, he adds, "They will see that everyone can be a professor—even a fool like Juan." □