Flexible nanowire electronics that can attach to any material developed at Stanford

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Stanford researchers have developed a new method of attaching nanowire electronics to the surface of virtually any object, regardless of its shape or what material it is made of. The method could be used in making everything from wearable electronics and flexible computer displays to high-efficiency solar cells and ultrasensitive biosensors.

Nanowire electronics are promising building blocks for virtually every digital electronic device used today, including computers, cameras and cell phones. The electronic circuitry is typically fabricated on a silicon chip. The circuitry adheres to the surface of the chip during fabrication and is extremely difficult to detach, so when the circuitry is incorporated into an electronic device, it remains attached to the chip. But silicon chips are rigid and brittle, limiting the possible uses of wearable and flexible nanowire electronics.

The key to the new method is coating the surface of the silicon wafer with a thin layer of nickel before fabricating the electronic circuitry. Nickel and silicon are both hydrophilic, or "water-loving," meaning when they are exposed to water after fabrication of nanowire devices is finished, the water easily penetrates between the two materials, detaching the nickel and the overlying electronics from the silicon wafer.

"The detachment process can be done at room temperature in water and only takes a few seconds," said Xiaolin Zheng, an assistant professor of mechanical engineering, who led the research group that developed the process. "The transfer process is almost 100 percent successful, meaning the devices can be transferred without sustaining any damage."

After detachment, the silicon wafers are clean and ready to reuse, which should reduce manufacturing costs significantly.

Zheng is one of the authors of a paper describing the method that will be published in an upcoming issue of *Nano Letters*. The paper is available online now. Chi Hwan Lee and Dong Rip Kim, both graduate students in Zheng's lab, are coauthors.

After applying the nickel layer to the silicon chip, the researchers also laid down an ultrathin layer of a polymer to act as an insulator and provide mechanical support for the electronics.

The ultrathin polymer layer is also extremely flexible, which is what allows Zheng and her team to attach their nanowire electronics to a wide range of shapes and materials including paper, textiles, plastics, glass, aluminum foil, latex gloves – even a crumpled Coke can and a mashed plastic water bottle.

"The polymer layers we're using are about 15 times thinner than the plastic wrap you use to cover a plate of food," Zheng said. "Since the polymer has such a great degree of flexibility, you can wrap the polymer with nanowire devices on top over anything while conformally following the shape of any object."

Currently her team has been working with polymer layers about 800 nanometers thick. A nanometer is one millionth of a millimeter.

But what really makes the devices so flexible, what allows the devices to bend with the flexible substrate, is the short length of the nanowires used to fabricate the circuitry.

"The length of these nanowires is only a couple thousandths of a millimeter long," Zheng said. "Compared to the curvature of the objects we're attaching them to, that is really short, so there is very little strain on the nanowires."

Because the nanowires are so short, when they are placed on a convoluted surface –even the sharp bends of a mashed up plastic water bottle – it is as if the surface is practically flat.

The devices can also easily be applied to a surface, removed and applied again to another surface, repeatedly, without degrading the circuitry.

Some of the major applications of the process that Zheng foresees will be in the area of biological research. Nanowire devices could be attached directly to heart or brain tissues to measure the electrical signals from those tissues.

"Researchers could measure heart arrhythmias or how a neuron fires," she said. "Those signals are electrical, but to measure them you need a very conformable, very thin coating that allows the signals to propagate across the substrate."

The transfer process could also be used in developing high-efficiency flexible solar cells and would likely have uses in robotics, as well.

"The possibilities are really unlimited," Zheng said.

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