THE SHINY GRAY Flexible ELECTRIC SANDWICH WRAP

A plastic film that folds and stretches like Saran and also conducts electricity can hardly fail to find uses and fascinate scientists

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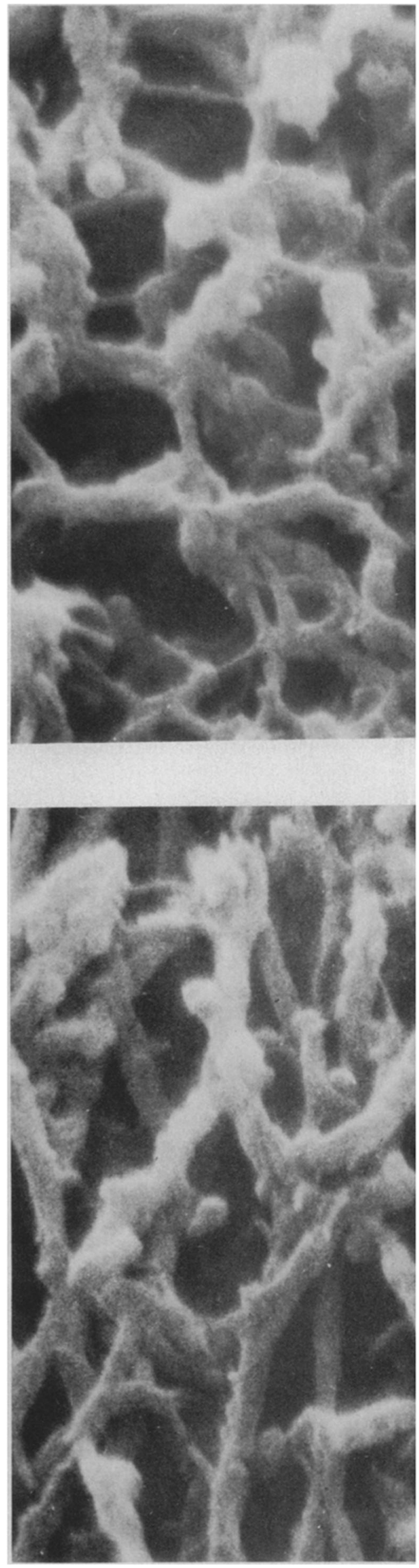
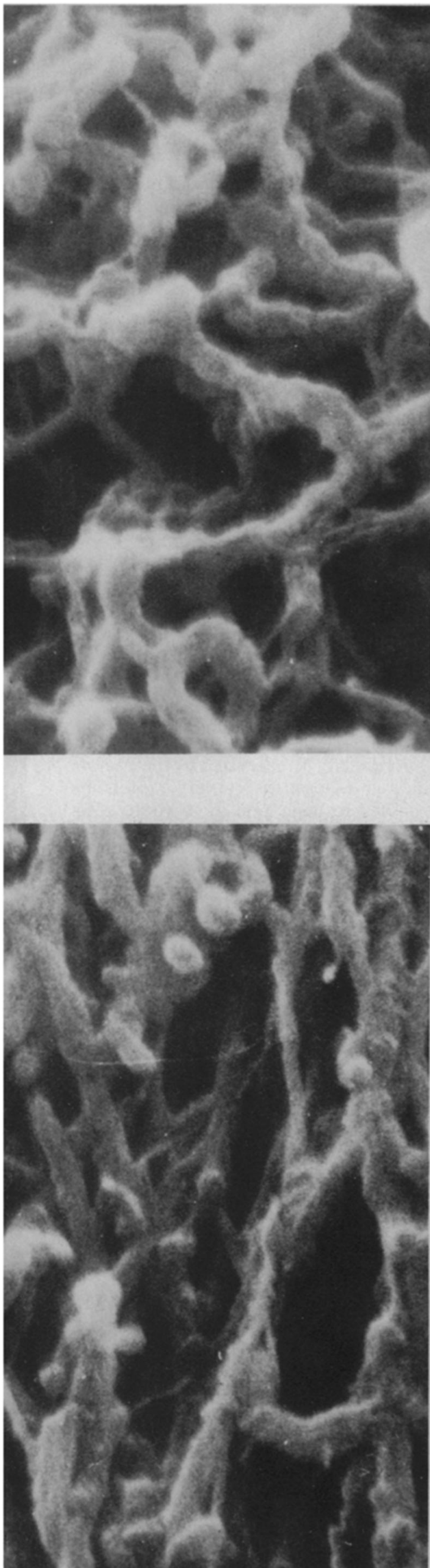


Polyacetylene is one of the simplest synthetic polymers. Its backbone is a chain of carbon atoms joined by bonds that alternate between single and double. To each carbon one hydrogen atom is bound laterally. The chemical formula is simply $(CH)_x$. Polyacetylene has been known for decades as a dark powder. A development of a few years ago that seems to have happened by accident showed how to make it into a film, and polyacetylene is now under investigation for strange and potentially useful electrical properties. It is called "an electrically conducting plastic."

According to Esther M. Conwell of the Xerox Webster Research Center in Rochester, N.Y., who reviewed research on polyacetylene at the recent meeting of the American Physical Society in New Orleans, about five years ago a graduate student wanted to prepare some polyacetylene. The usual method is to put acetylene gas and a catalyst in a flash chamber, and the flash reaction gives polyacetylene. This student used too much catalyst and instead of the familiar dark powder got a shiny gray film. The film looks like aluminum foil but has the flexibility and stretchability of plastic wrap. Examination under an electron microscope shows that it is made of a spaghetti-like mass of tiny fibrils.

As made, the polyacetylene film is a *p*-type semiconductor with a very low conductivity, a hundred-thousandth (10^{-5})



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Scanning electron micrograph of polyacetylene. The upper photo shows the random fibrils (diameter ~ 200Å) that make up a shiny gray film when acetylene gas is catalyzed into an electrically conducting plastic. The lower photo shows the partial alignment from stretch orientation.

to a millionth (10^{-6}) of a reciprocal ohm-centimeter. (A *p*-type semiconductor is one in which the current consists of holes, places where electrons should be, but aren't. In a solid, holes act like moving positive charges.)

Then, says Conwell, "someone got the idea of doping it to increase its conductivity." Doping of polymers, adding small amounts of other substances with the intention of changing physical properties, is an old scientific and technological technique. Conwell calls it "a cottage industry." The surprise was that doping polyacetylene raises its conductivity up to metallic amounts.

Doping with arsenic pentafluoride, chlorine or bromine enhances polyacetylene's *p*-type conductivity. Doping with sodium or lithium makes it an *n*-type conductor, one where the current consists of electrons. Conductivities as high as 1,000 reciprocal ohm-centimeters are measured. Adding electron donors (substances that contribute electrons to the supply of conduction electrons) to the undoped material can depress its already low *p*-type conductivity to levels as low as a billionth to a ten-billionth (10^{-9} to 10^{-10}) of a reciprocal ohm-centimeter. That means that a total change in conductivity amounting to a factor of 10^{12} to 10^{13} is available — a possibility that previously has been unheard of.

The way that polyacetylene conducts changes, too. Doping above a certain level (if the dopant is arsenic pentafluoride the critical level is about one percent) produces an abrupt change from semiconductor type conductivity to a metallic type. This is reflected in the large increase in the amount of conductivity.

As made, polyacetylene conducts electricity equally well in all directions, but when it is doped and stretched to orient the fibrils in a certain direction, it becomes very nearly a one-dimensional conductor. The fibrils are bonded to each other laterally so there is some transverse conduction, but conduction in the direction of the fibrils is 16 times as easy as transverse to them.

The behavior of polyacetylene's conductivity when the film is chilled is not like that of known metals. Metal conductivity increases with cooling, and some metals even become superconducting at very low temperatures. Polyacetylene's conductivity decreases as the temperature decreases.

Investigations of these properties and attempts at theoretical explanations are still in a very fluid stage. A good example is studies of the magnetic susceptibility of polyacetylene. Although the magnetic properties of the film could conceivably be of practical use some day, the main interest now is what the magnetic susceptibility reveals about the activity of electrons in the material. Different research groups tend to differ. The Xerox and IBM groups differ not only on the interpretation but on the measurements themselves.

Yet there are theories being propounded. The one that has gotten the most attention is the soliton theory. A soliton is a solitary, single wave. In nature waves usually come in trains as can be seen any day on the ocean, but under certain special conditions a soliton may appear, a solitary undulation, one wavelength's worth, that travels across flatness. Solitons appear in many parts of physics, and their properties are a fascinating subject in mathematics and mathematical physics.

In the polyacetylene theory the soliton is a boundary, a narrow transition region between two different arrangements of trans-polyacetylene. (There are two types of bonding arrangement for polyacetylene, called cis- and trans-. Trans-polyacetylene is the kind that has all these interesting properties.) The soliton is a moving boundary. It rolls through the material picking up one arrangement in front of itself and laying down the other behind. The difference between the two arrangements involves electrons and holes, and so the soliton effectively moves an electron or a hole through the material.

The soliton theory explains a number of things in the behavior of polyacetylene, but, says Conwell, it does not explain the semiconductor-to-metal change in the conductivity property. For this the IBM group have come up with a suggestion that relies on the dopants. As she describes it, they propose that in the undoped film the electric potential, that is, the factor that determines how conduction electrons will move, is periodic, strong near the atoms in the chain, weak between them. Introduction of dopant atoms, which come to rest here and there, adds a random element to the potential. Building up the randomness changes the electron behavior from semiconductor to metallic. Conwell pronounces herself not ready to agree. She can't quite see it happening that way, she says.

However its behavior may be understood in the end, it seems that plastic that conducts like a metal will have many uses in electronic circuitry. Some of them are likely to have no precedent in current practice and to emerge only from an understanding of polyacetylene derived from the fundamental scientific studies. There are also foreseeable uses for polyacetylene's semiconductor properties. The material can be made in both *n* and *p* types, which means that a kind of self *n*-*p* junction is possible. The same quality makes it possible that polyacetylene will be used in batteries. □