MICROSCOPY TODAY

JULY/AUGUST 2000

ISSUE #00-6

THE SAME THING THAT MAKES A CARROT ORANGE ALSO MAKES A MOLECULAR WIRE

Stephen W. Carmichael[1], Mayo Clinic

The atomic force microscope (AFM) has been used in many ways to extract information from biologic specimens. Now Gerry Leatherman, Edgar Durantini, Devens Gust, Tom Moore, Anna Moore, Simon Stone, Ziniu Zhou, Peter Rez, YangZhang Liu, and Stuart Lindsay have used conduction atomic force microscopy (CAFM) to demonstrate that a molecule of carotene can function as a molecular wire.

Leatherman *et al.* synthesized carotene and then examined the molecules with the scanning tunneling microscope (STM). They could image spots that averaged 2 nm in diameter, although the size of the spots varied widely due to the geometry of the probe tip. Interestingly, the number of spots increased with the concentration of carotene, but the average size of the spots did not change. This made it clear that they were able to image carotene molecules with the STM, and that the carotene did not form large aggregates. For these initial imaging studies the carotene was suspended in a film of dodecanethiol.

For CAFM, a conventional microscope was used with a force-sensing cantilever coated with platinum and connected to a low-noise current amplifier. Initial attempts to image carotene molecules in dodecanethiol films were not successful, probably because the carotene molecules protruded from the film and were moved or damaged during the scan. This problem was solved by putting the carotene in a film of docosanethiol, which is a molecule of about the same length as carotene. This is analogous to inserting a relatively flexible thread (the carotene) among stiff bristles of a hairbrush (the docosanethiol molecules). If the thread is inserted among shorter bristles (dodecanethiol), then the thread is unsupported and floppy. If the thread and stiff bristles are approximately the same length, then the thread is supported and its end can be imaged. Conveniently, all of these linear molecules assembled as a monolayer, just as bristles of a hairbrush could be considered a monolayer. To carry this analogy further, the back of the hairbrush (the substrate that the carotene and the docosanethiol are attached to) is conductive (gold was used). The docosanethiol is an insulator, so when the surface was imaged by CAFM, the carotene molecules embedded in the film were seen to conduct a current, just as if you passed a ammeter probe over the surface of our hairbrush, and the threads were a conductive wire and the bristles non-conductive. The carotene was found to behave ohmically with a resistance of approximately 4.2 ± 0.7 gigaohms, over a million times more conductive than a saturated hydrocarbon molecule of similar length!

Now for the part about the carrots. Carotene is a natural molecule that gives color to carrots, and many other plants as well. The optical properties of carotene come from electronic states that are delocalized over a chain of about twenty carbon atoms connected by alternating single and double bonds. Apparently, this same molecular arrangement allows carotene to act as an ohmic resistor. This is interesting, but the real value of the CAFM, as shown by Leatherman *et al.*, is that it is possible to insert a conductive molecule into an insulating matrix and determine the electrical properties of the molecule in a straightforward manner. This technique will help us understand the mechanisms of molecular conduction as more molecular systems are studied in the future. ■

1. The author gratefully acknowledges Dr. Stuart Lindsay for reviewing this article.

2. Leatherman, G., E.N. Durantini, D. Gust, T.A. Moore, A.L. Moore, S. Stone, Z. Zhou, P. Rez, Y.Z. Liu, and S.M. Lindsay, Carotene as a molecular wire: Conducting atomic force microscopy, *J. Phys. Chem. B* 103:4006-4010, 1999.

INDEX OF ARTICLES