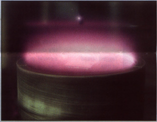
Three Ways to Make Nanotubes

Zap, Bake or Blast

Sumio Iijima may have been the first to see a nanotube, but he was undoubtedly not the first to make one. In fact, Neandertals may have made minuscule quantities of nanotubes, unwittingly, in the fires that warmed their caves. Split by heat, carbon atoms recombine however they can in soot, some in amorphous blobs but others in soccerball-shaped spheres called buckyballs or in long cylindrical capsules called buckytubes or nanotubes. Scientists have discovered three ways to make soot that contains a reasonably high yield of nanotubes. So far, however, the three methods suffer some serious limitations: all produce mixtures of nanotubes with a wide range of lengths, many defects and a variety of twists to them.

A BIG SPARK

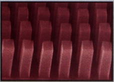
In 1992 Thomas Ebbesen and Pulickel M. Ajayan of the NEC Fundamental Research Laboratory in Tsukuba, Japan, published the first method for making macroscopic quantities of nanotubes. It is almost Frankensteinian in its design: wire two graphite rods to a power supply, place them millimeters apart and throw the switch. As 100 amps of juice spark between the rods, carbon vaporizes into a hot plasma (*right*). Some of it recondenses in the form of nanotubes.


OAK RIDGE NATIONAL LABORATORY

Typical yield: Up to 30 percent by weight
Advantages: High temperatures and metal catalysts added to the rods can produce both single-walled and multiwalled nanotubes with few or no structural defects.
Limitations: Tubes tend to be short (50 microns or less) and deposited in random sizes and directions.

A HOT GAS

Morinubo Endo of Shinshu University in Nagano, Japan, was the first to make nanotubes with this method, which is called chemical vapor deposition (CVD). This recipe is also fairly simple. Place a substrate in an oven, heat to 600 degrees Celsius and slowly add a carbon-bearing gas such as methane. As the gas decomposes, it frees up carbon atoms, which can recombine in the form of nanotubes.

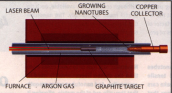

HONGJIE DAI Stanford University

Jie Liu and his colleagues at Duke University recently invented a porous catalyst that they claim can convert almost all the carbon in a feed gas to nanotubes. By printing patterns of catalyst particles on the substrate, Hongjie Dai and his colleagues at Stanford University have been able to control where the tubes form (*left*) and have been working to combine this controlled growth with standard silicon technology.

Typical yield: 20 to nearly 100 percent
Advantages: CVD is the easiest of the three methods to scale up to industrial production. It may be able to make nanotubes of great length, which is necessary for fibers to be used in composites.
Limitations: Nanotubes made this way are usually multiwalled and are often riddled with defects. As a result, the tubes have only one tenth the tensile strength of those made by arc discharge.

A LASER BLAST

Richard Smalley and his co-workers at Rice University were blasting metal with intense laser pulses to produce fancier metal molecules when the news broke about the discovery of nanotubes. They swapped the metal in their setup for graphite rods and soon produced carbon nanotubes by using laser pulses instead of electricity to generate the hot carbon gas from which nanotubes form (*left*). Trying various catalysts, the group hit on conditions that produce prodigious amounts of single-walled nanotubes.



CLEO VILETT

Typical yield: Up to 70 percent
Advantages: Produces primarily single-walled nanotubes, with a diameter range that can be controlled by varying the reaction temperature.
Limitations: This method is by far the most costly, because it requires very expensive lasers. —*P.G.C. and P.A.*