Chemistry and the Incredibly Shrinking Circuit

Small is beautiful in microelectronics. The more microscopic transistors that can be etched into a microprocessor chip, the greater the density of magnetically stored bits that can be crammed onto a hard drive, and the more that electronic devices can be miniaturized, the better. Computer chip densities have long doubled every 18 months (Moore's Law) and hard-disk memory densities currently double every 9 months, although both will eventually face interference and quantum mechanics-imposed limits. The connecting wires in integrated circuits have shrunk from hair-size, 1 micron, diameters to submicron (0.1 microns = 100nm) sizes. The race is on to develop a whole new generation of even smaller nanocircuits, using a whole new generation of rapidly emerging nanotechnologies. Since atoms and small molecules are themselves typically only several nm in size, many scientists see the key to nanocircuit construction in their direct interaction, that is ... in chemistry.

ISF grantees Jacob Sagiv and Rivka Maoz have developed a highly general, bottom-up, all-chemical approach that could revolutionize this area. They first use self-assembly techniques to coat a silicon chip with a single layer of inexpensive organosilane (OS) molecules. By delivering ultrasmall electrical pulses, an atomic force microscope (AFM) tip can "write" information on this smooth surface by altering the chemical composition of the OS-molecules it encounters. For example, it can induce the replacement of their rather inert terminal methyl (CH_3) groups with more reactive carboxyl (COOH) groups. Silver ions are readily attracted to these altered sites where they automatically create lines of silver-carboxylate salt. Adding hydrazine (N_2H_4) reduces the silver ions to neutral metallic silver atoms, forming a permanent string of conducting silver nanoparticles along the line originally traced by the ATM tip.

The reactive carboxyl groups are, conversely, restored by this process, and the cycle can be repeated to fill in the gaps of these nanowires with more silver, albeit at the expense of increasing the nanowire's thickness. Silver nanowires 6000 nm long and less than 70 nm wide have already been produced (see figures), with considerable improvement possible. Except for the original tracing of the wire location by the AFM tip, the self-assembling molecules do all the construction work through chemistry.

Similarly, AFM-carboxyl "writing" on a n-octadecyl-trichloro-silane (OTS) monolayer, can be followed by attaching highly reactive nonadecenyl-trichoro-silane (NTS) to the carboxyl groups.

Photochemically reacting this NTS upper-story with hydrogen sulfide (H_2S) produces a top surface containing a mixture of disulfide (-S-S-) and thiol (-SH) groups. The latter bind cadmium ions which can be exposed to more H_2S to form nanosize cadmium sulfide (CdS) particles. Finally, treatment of this surface with a solution of $HAuCl_4$ results in the formation of made-to-order strands of metallic gold nanoparticles containing small sulfur cores. Many other such self-assemblied nanostructures are possible using this highly flexible, general approach.

The ISF is funding many other organic nanotechnology-related research projects, including work by S. Yitzchaik on organic nanotransistors (starting with 2-6 nm thin organic field effect, OFET, transistors), R. Tenne and K. Gartzman on nanotubes, I. Wilner on photo- and electro-active nanoengineered surfaces, A. Yarin and T. Milo on nanofibers and C. Sukenik on nanoscale reagents and reactions involving organic thin films. Israel is, and intends to remain, an important, internationally competitive part of this field's future.