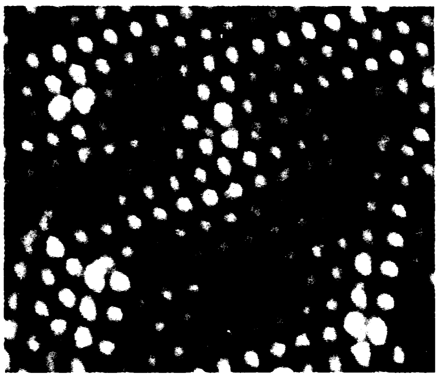
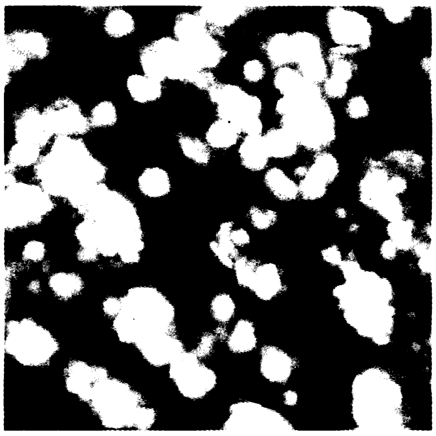
Hydrogen can peel atoms off layer by layer





Boland/IBM

Scanning tunneling microscope images show how new hydrogen technique shoves aside the surface atoms of a germanium semiconductor (top), exposing its underlying atomic structure (left).

By harnessing hydrogen's tendency to be selective about the chemical bonds it breaks, chemists can now peer at the underlying structure of semiconductors and control the growth and quality of thin films more precisely.

Recent advances in scanning tunneling microscopy made it possible to resolve atomic details of a material's surface, but little of what lies below. Now, chemist John J. Boland of the IBM Thomas J. Watson Research Center in Yorktown Heights, N.Y., has used hydrogen to remove or shove aside atoms on the surface of semiconductors so that he can train his microscope on atoms one or more layers down. By peeling layers away, "we get an in-depth view, almost a cross-section," Boland says.

Other scientists have had to probe underlying structure by trying to look between atoms on the surface, he adds.

Within any material, atoms tend to arrange themselves into a stable, low-energy configuration. Because they lack an upper layer with which to bond, however, those on the surface must arrange themselves differently. The germanium atoms on a semiconductor surface, for example, form three strained bonds with like atoms below, leaving one unlinked "bond" protruding upward.

In Boland's studies, incoming hydrogen atoms first link up with any free bonds sticking out of the semiconductor. Then hydrogen goes after the most strained bonds, which exist between the surface atoms and those directly below. Sometimes four hydrogen atoms surround — and free — a germanium atom, releasing it as a volatile compound. In other cases, hydrogen forces the surface atoms to clump, exposing patches of an underlying layer.

Bonds between those underlying germanium atoms are less strained and therefore strong enough to resist being snipped free by hydrogen. Consequently, hydrogen can link with those atoms' free bonding sites, but does not break bonds within the semiconductor.

Using this approach, Boland made very clear scanning tunneling microscope images of germanium. In the Jan. 10 SCIENCE, he shows that the layer directly below the surface structurally matches the bulk of the semiconductor. This contrasts with silicon, in which the penultimate layer still contains some strain and thus differs from the bulk structure below.

To study silicon, Boland and his IBM colleagues controlled the hydrogen-reaction conditions so that they could break bonds of specific strengths — peeling off silicon atoms one layer at a time. "You can actually pace the chemistry, and pacing the chemistry is very important," says Boland.

This approach also lets the IBM group modify thin films as they are made. When chemists deposit a material on silicon — to make computer chips, for example — some atoms link up to the silicon via strained bonds, while others form stable connections. The strained bonds represent weak spots. But by halting deposition of that substance midway and allowing the hydrogen to snip out weak bonds, "we can make very much better high-quality films," says Boland. This approach also allowed the IBM scientists to make thin-film transistors in fewer steps than usual. *— E. Pennisi*

Clues to the origins of flowering plants

Meticulous microscopic examinations of the primitive seeds of a desert shrub commonly known as "Mormon tea" have yielded new evidence concerning the evolutionary link between flowering and nonflowering plants.

The research suggests that a now-extinct ancestor of the lanky shrub — whose scientific name is *Ephedra* — first evolved a seed structure called the endosperm to nourish its developing plant embryos. William E. Friedman, a botanist at the University of Georgia in Athens, speculates that this innovation set the stage for the evolution of flowering plants by providing a more efficient means for plants to nurture successive generations.

In the Jan. 17 SCIENCE, Friedman reports that the starchy endosperm that makes up the bulk of most plants' seeds is really the fraternal twin of the embryo it feeds. As such, he says, "it is essentially a deviant plant embryo" that develops from a second fertilized egg within the plant ovary.

Paleobotanists surmise that before the advent of endosperm, all growing plant embryos fed on cells from their embryo sacs — the maternal tissue that gives rise to unfertilized eggs. But this strategy had a serious limitation, Friedman explains. Plants had to develop plump, nutrient-rich embryo sacs even before their offspring were conceived — investments of time and energy that didn't pay off if the eggs never got fertilized by a sperm cell or if the young embryos died on the vine.

Because endosperm is spawned at the same time as each embryo — and always grows just a little faster than its twin baby plant — it ensures that plants don't make such needless investments, Friedman says. Spending less time and energy on reproduction could have allowed early plants to evolve more sophisticated life cycles that included flowering, he asserts.

Endosperm is also a richer source of food for developing plants than embryo sac cells, Friedman says. Because it contains genes from both the maternal and paternal plants, it is less likely to have a defect caused by one faulty gene. And because it bears multiple copies of both parent plants' genes, it has extra sets of blueprints for building up greater stores of food faster, Friedman says.

He found traces of endosperm's evolution within 34 fertilized eggs collected from *Ephedra* plants growing wild outside Tucson, Ariz. Using a microscope, he observed that in all instances, each of the *Ephedra* sperm cells' two nuclei had fused with an egg. Even though the extra fertilized egg later dies off — and the nonflowering *Ephedra*'s embryo ultimately feeds on its embryo sac cells — Friedman says this is evidence of how endosperm once formed.

Lloyd Mogensen, a plant embryologist at Northern Arizona University in Flagstaff, agrees that Friedman has "nailed down" the origin of endosperm. "This is the first example ... of how endosperm came into being genetically," Mogensen says.

Two years ago, researchers described a 110-million-year-old fossil containing an herb-like plant bearing the oldest known flowers (SN: 2/10/90, p.85). The buds are likely descendants of *Ephedra*'s flowering ancestral cousin. *— C. Ezzell*