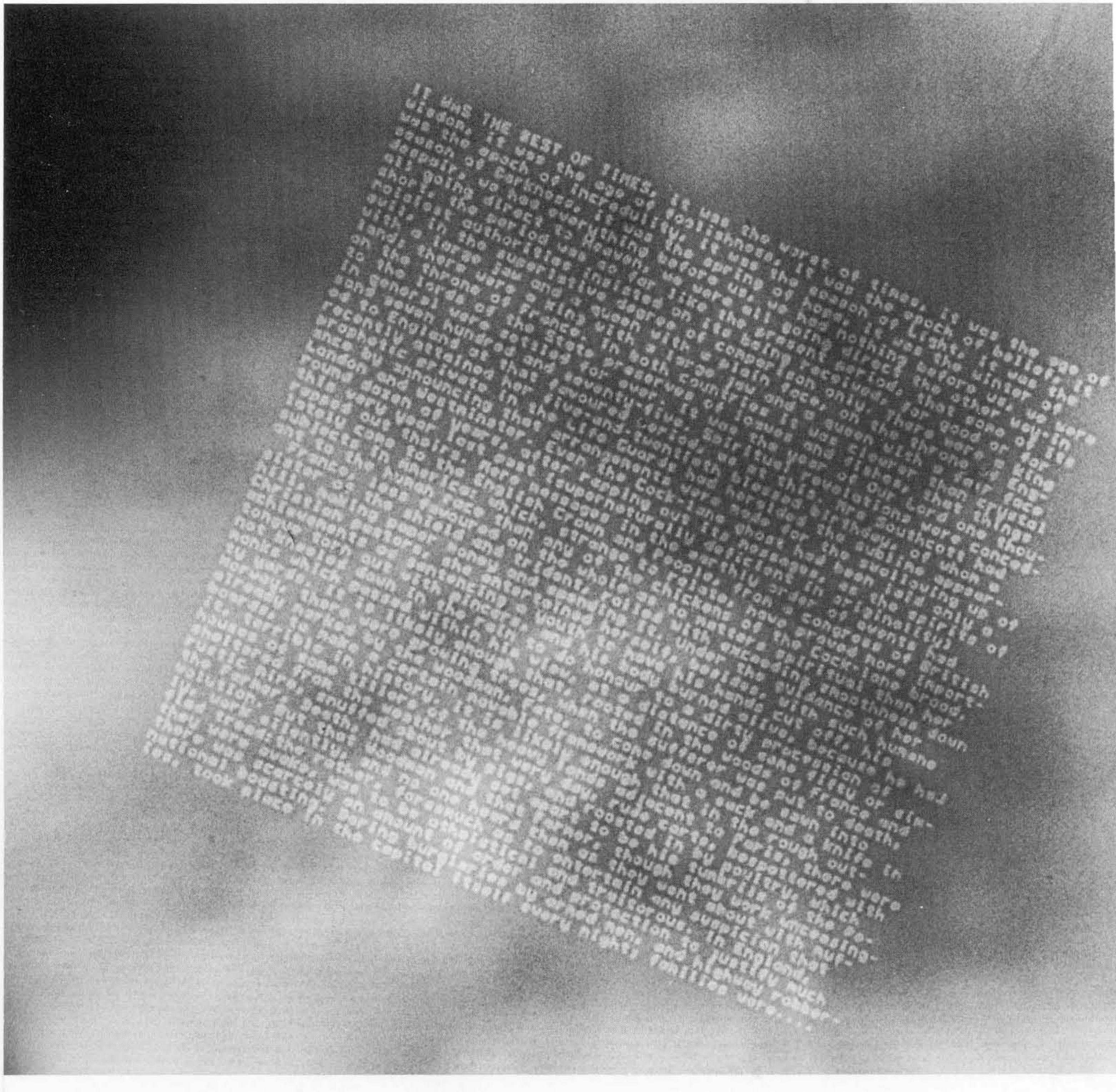

IT WAS THE BEST OF TIMES, it was the worst of times,

Tiny *Tale* Gets Grand

THE CHALLENGE HAD STOOD for 26 years: "It is my intention to offer a prize of $1,000 to the first guy who can take the information on the page of a book and put it on an area 1/25,000 smaller in linear scale in such manner that it can be read by an electron microscope."

Richard P. Feynman, the Richard Chace Tolman Professor of Theoretical Physics, announced this offer at the American Physical Society's annual meeting at Caltech. It came at the end of his talk, "There's Plenty of Room at the Bottom," discussing the "problem of manipulating and controlling things on a small scale." The talk, and the challenge, were published in the February 1960 issue of *Engineering & Science.*

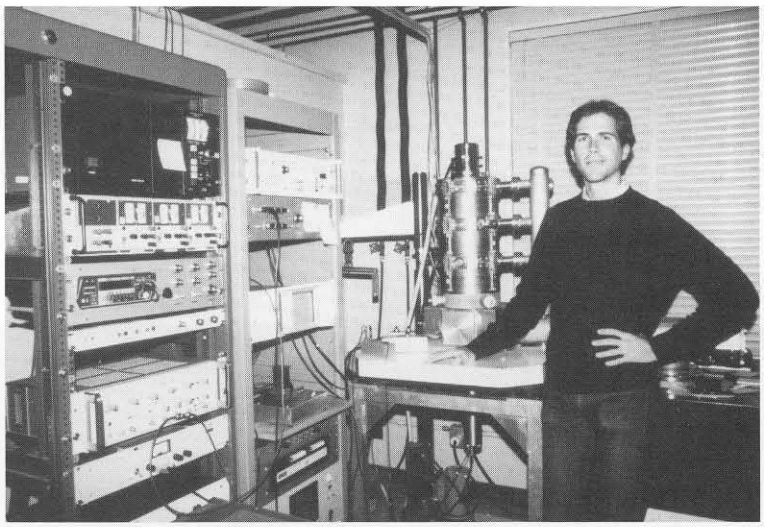
Tom Newman was three years old at the time and not in any hurry. In November 1985 Newman, a Stanford grad student in electrical engineering, collected the $1,000 prize with the evidence shown opposite — the opening page of *A Tale of Two Cities* reduced to an area 5.9 × 5.9 micrometers and magnified back to legible size by an electron microscope.

In his letter to Newman accompanying the check, Feynman wrote: "Congratulations to you and your colleagues. You have certainly satisfied my idea of what I wanted to give a prize for. Others have apparently made as small or smaller marks, but no one tried to print an entire page. And on a 512 × 512 dot printer! Each dot is only about 60 atoms on a side. I can't quite manage to imagine the square 1/160 mm on a side onto which all that is printed. It would be 20 times too small on a side to see with the naked eye. Only 10 wavelengths of light. The entire Encyclopaedia Brittanica, perhaps 50,000 to 100,000 pages of your size would be on less than 2 mm on a side — the head of a small plain pin."

The idea of writing the entire 24 volumes of the Enclyclopaedia Britannica on the head of a pin (and all the books in the world on an area of about three square yards) figured prominently in Feynman's original article, which not only prophesied that such fine writing could be done but also described how to do it.

"A simpler way might be this (though I am not sure it would work): We take light and, through an optical microscope running backwards, we focus it onto a very small photoelectric screen. Then electrons come away from the screen where the light is shining. These electrons are focused down in size by the electron microscope lenses to impinge directly upon the surface of the metal. Will such a beam etch away the metal if it is run long enough? I don't know."

A few months after Feynman's speech, researchers in Germany actually did use an electron beam for fine writing. Newman, who also used an electron beam to etch the prizewinning page, considers Feynman a "visionary" for having had such foresight.



Tom Newman poses with his electron beam lithography equipment.

Feynman offered another prize in 1960 for a rotating electric motor, 1/64th inch cubed. That one was claimed in the same year by William McLellan (Caltech BS 1950), who had spent 2½ months of lunch hours building it with the help of a microscope, a watchmaker's lathe, and a toothpick. It is enshrined on permanent display in East Bridge and is a standard stop on campus tours. Although the article had stated only Feynman's *intention* of offering a prize, and not actually an offer of one, and although McLellan had done it for the challenge of the problem and not for the money, Feynman's conscience began to bother him and he coughed up the $1,000 after all. But the December 1960 *E&S* carrying the news of McLellan's victory, also took note of Feynman's "worried thoughts."

"Daily, he expects to meet the man who has accomplished this spectacular feat. And, daily, the thought haunts him — because, in the meantime, Feynman has been married, bought a house and, what with one thing and another, hasn't *got* another spare $1,000.

"This, then, is a public appeal by *Engineering and Science*, to all inventors, who are now at work trying to write small and collect the Second Feynman Prize — TAKE YOUR TIME! WORK SLOWLY! RELAX!"

The appeal was heeded. But "Plenty of Room at the Bottom" had become a classic of sorts and was still being handed around a quarter of a century later among people interested in such things. R. Fabian Pease, Stanford professor of electrical engineering and Newman's advisor, remembers seeing it first in 1966 when he was an assistant professor at Berkeley. It was another Stanford graduate student, Ken Polasko, who first brought it to Newman's attention and suggested going for the prize. "We had an idea no one had done it," says Newman, "or we would have heard about it." But Newman also thought it was a "neat paper" and "fun to read just for itself," and, like the first prizewinner, he was more interested in the problem than in the money.

The problem fit in nicely with his doctoral research, which concerned improving the throughput of electron beam lithography to make the process useful in the production of VLSI chips and in the ultra-high-resolution fabrication of very small electron devices. Newman had designed a system for such enhancement of electron beam lithography using a multiple-beam approach, in which the beams are independently modulated as they are scanned in an array over a surface, giving, in effect, a dot-matrix writer. (This work was supported by the Army Electronics and Development Command.) At the time the old *E&S* article surfaced, he was looking for a good demonstration of pattern generation for his apparatus — some random, arbitrary pattern. "Text is ideal," says Newman, "because it has so many different shapes."

He chose *A Tale of Two Cities* because it was one of his favorite novels — but also because it had a well-known opening paragraph and a first page of about the right size. He used a beam of electrons about one five-millionth of an inch in diameter to scan the text across a thin plastic membrane. The exposed regions were then etched away by being dissolved in ethanol. Although Newman had all the basic tools already and got a good start on the project over a weekend, it took about a month of concentrated hard work to get the text to a point where it was adequately legible. "Using text was tougher than we had thought," says Pease. "It turned out to be an excellent technological exercise." Eventually Ann Marshall of Stanford's Center for Materials Research was able to tune her electron microscope to get a readable image.

And then Newman sent Feynman a telegram asking if anyone had yet collected the prize. No one had. In addition to being $1,000 richer (Feynman was no longer financially strapped), Newman also passed his PhD orals on December 4. Included as part of his oral presentation was the prizewinning page of *A Tale of Two Cities* as further demonstration of computer-controlled pattern generation in electron beam lithography. □ — *JD*