

## A Nanorevolution

Things are getting smaller. At the leading edge of today's technology, smaller seems to be better. Sometimes the scale at which a device will work serves to label the technology. "Microlithography" is a good example. The "micro-" was prepended to indicate that structures measured in units of micrometers (at first many micrometers) were involved. Science at the micrometer<sup>1</sup> scale became so prevalent that the same unit is referred to by the shorter "micron"<sup>2</sup> for convenience.

The products of the technology have attracted the same prefixing syndrome—e.g., "microelectronics." As circuit packing density is an important figure of merit, the race for further miniaturization<sup>3</sup> is intense. Cautious and conservative folks, as they saw the one-micron benchmark yielding, began to speak of *submicron* lithography. A point must have been crossed in the past when it was more exciting and saleable to say one hundred microns than one-tenth of a millimeter.<sup>4</sup> A similar psychological threshold has been passed recently in the micron range. Witness the infiltration of the prefix "nano-" into the lexicon.<sup>5</sup> The new name of Cornell's National Research and Resource Facility for Submicron Structures is the National Nanofabrication Facility (see Up Close feature in the July 1988 MRS BULLETIN). We are hearing of nanostructures, nanoengineering and, no doubt within the next 10<sup>17</sup> nanoseconds or so, we'll be saying nanoelectronics.

Atomic resolution characterization and molecular level engineering is just about upon us and is not confined to electronics. Microbiology will become nanobiology. The TEM and STM will be the TEN and STN. (You guessed it! The nanoscope will be a common tool.) The era of the nanometer<sup>6</sup> will have arrived. We should anticipate the contraction to "nanon" and an ever expanding application of nano-'s new found popularity. In fact, one example already suggested to describe the production end of the revolution is "nanofacturing."<sup>7</sup>

Although the evolution of the language into nanospeak may be inevitable, we can't claim absolute confidence in the trend. After all, if history is any guide, there are many linguistic trends that can only be "predicted" through hindsight. When technology was in the millimeter<sup>8</sup> era, few, if any, milliwords were spawned. Rather the term "mini-"<sup>9</sup> was and is used extensively. Thus the mainframe computer shrunk to the minicomputer which shrunk to the microcomputer which may shrink to the nanocomputer (that six-inch Cray-equivalent cube relying on hybrid semi- + superconductor technology). Time will tell. The absence of the millicomputer mitigates in favor of the survival of nano- because milli-'s root specifies a definite factor of 10<sup>±3</sup> whereas nano-'s, like mini-'s and micro-'s, root simply implies generic smallness. The same consideration applies to bigness. The precise "kilo-"<sup>10</sup> has penetrated the language far less than has the generic "mega-"<sup>11</sup>.

Lest we worry that this trend may go on in the same way for yet another three orders of magnitude, be assured that that is unlikely. It's true that abstract and aesthetic concepts, such as the picoscopic significance of the points made above, can garner qualifying prefixes with impunity, but the natural scale of matter mitigates against picoelectronics and femtocomputers. We close with a warning that smaller is not always better and trends toward the infinitesimal should be watched closely. For instance, the efficiency gained by our technological advances into nanospace could be utterly thwarted by the concomitant advent of nanomanagement.

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1. The standard abbreviation for micrometer is  $\mu\text{m}$  using the Greek  $\mu$  instead of a lower case *m* for micro- because the *m* had been spoken for by milli- when things were one thousand times bigger. Since micro- derives from the Greek *mikros* (small, little), a Greek symbol may be quite appropriate.
2. Micron is actually closer to the original Greek *mikron* (neuter singular of *mikros*).
3. We'll get to "mini-" shortly.
4. We'll get to "milli-" shortly too.
5. Originally from the Greek *nanos*, the word was taken into Latin as *nanus* meaning dwarf.
6. The unit standardization movement has brought the nanometer to the fore and relegated the angstrom to secondary usage. Notwithstanding the Greek origin of nano-, the abbreviation for nanometer is *nm*, not *num*. One should not expect consistency in such matters.
7. T. Loucks in a preliminary progress report for Panel 4 of the National Research Council's Materials Science and Engineering Study (circa 1987).
8. Milli- is a product of inverse logic. It is from the Latin root meaning one thousand. The form "mille-" is also found. Thus millipede is an arthropod with a thousand legs and a millennium is a thousand years. But Latin also gives us the word *millesimus* for one thousandth, demonstrating that one can name the small entity according to how large a number of them is required to make the corresponding large one.
9. Contrary to what one might guess, "minimum" from the Latin *minimus* meaning smallest or least is not the origin of the "mini-" prefix. Rather it derives through the Italian *miniatura* from the medieval Latin *miniatus* (rubricated or illuminated) and has come to imply smallness because it referred to the methods used to create and display miniature reproductions.
10. "Kilo-" originates through the French from the Greek *chilioi*, meaning one thousand.
11. "Mega-" comes from the Greek *megas* meaning large, great, vast, or powerful.