How Will We Manufacture at the Nanoscale?

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Information technology has prospered as scientists and engineers have learned to make "bits" ever smaller. As the leading microelectronics manufacturers push the limits of 193 nm optical lithography and wait for the maturing of deep-UV technology, how long can ongoing exponential reductions in critical feature sizes be sustained? There is no physical reason we cannot learn to design and build objects with complex structure defined on all length scales down to the atomic scale. However, the development of such a capability in high-volume manufacturing will depend on the existence of strong economic drivers as well as on technical feasibility. New drivers for continued miniaturization of information technology are emerging. In particular, new non-volatile memory devices with active volumes of just a few cubic nanometers are feasible, and the competitive forces driving the market for denser, cheaper memory are enormous. Also, new and exciting applications for distributed networks of inexpensive, intelligent, wirelessly-connected sensors are on the horizon. At the same time, technical capabilities in nanoscale patterning continue to advance. Conventional optical lithography won't allow us to impart structural information at the atomic and molecular scale, but scanning-probe and other emerging lithographic processes will. Current research in nanostructured materials and devices suggests how lithographic processes can be increasingly combined with near-equilibrium chemical synthetic processes to produce the structures and devices of information technology. Over the next few decades, it should become possible to design and control the structure of an object on all length scales, from the atomic to the macroscopic, and to do so cheaply and reliably in manufacturing.