

Unmanufacturability

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The transition from nanoscience to nanotechnology for any given structure occurs when one can achieve (i) right-first-time design, then (ii) fabrication to design, and finally when (iii) reverse engineering passes a threshold that implies that an engineered product has been achieved. Although further success involves satisfying a market need at an acceptable cost, the initial threshold is one between science and technology. An attempt is made to define the interface in terms of the tools currently available for manufacture in the electronics and photonics industry, and to consider several areas of contemporary research.

If trying to make a defined area by first etching a hole in a resist, atoms are taken away one at a time. If the hole is 3 nm in diameter, there are ideally 80 atoms in the last plane, and by the statistics of random numbers the actual number of atoms removed in a given attempt will vary by ~ 9 . If an array of such holes is filled in to form an array of pixels with $\sigma = 12\%$ for the area of the individual pixels, the result is not a product – the range of energy levels of confined states in the pixels is far too wide. Band transport between pixels is impossible and the optical spectrum from the array is too broad to be useful for anything for the same reason. Indeed, even if an ideal array could be made atom by atom in some heroic effort, it would be impossible to wire up the array or to write, store, or read out information from the pixels. Indeed, taking the current standard of 6σ manufacture, anything below a 7 nm half-pitch cannot satisfy this manufacturability criterion with a 10% spread of properties being tolerated.

This result places limits on what device performance can be achieved, set by the method of production, rather than the size of fundamental constants or specific materials properties (as in the Johnson criteria for semiconductor devices). Many of the ideas proposed for new devices that rely on quantum dots or wires, carbon nanotubes or grapheme, fall foul of this manufacturability constraint. The relevant research should be redirected towards working closer to the limits of real manufacture rather than pursuing science that is intrinsically unexploitable.