MICRO-OBJECT ASSEMBLY PRINTER

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Summary: Highly sophisticated and integrated digital assembly printers can disrupt established supply chains and enable customized, local manufacturing of new complex, smart structures which bridge nano to macro scales. The government needs to investment in fundamental assembly and printer system technology to aid development of such extreme manufacturing tools.

Xerography Printers: Mass Customization through Assembly. The manufacturing of printed information (paper documents) continues to undergo a paradigm shift as traditional high volume commercial printing is displaced by digital printing, enabling mass customization, short runs, quick design cycles and local manufacturing. The dominant digital printing technology by volume is xerography (laser printers), which electrostatically assembles ~10^8 charge toner particles on a sheet of paper in <1 sec for under 1 cent/page. Viewed as an assembly technology, xerography is a million times faster than state of the art robotic pick and place, assembling 10^{10} particles/hr. This is an industrial manufacturing technology, as modern production digital printers output millions of sheets/month, yet the hardware all fits in a room, enabling localized production. Local, digital manufacturing, removes inventory and shipping costs, and enables design cycles of min/hrs, instead of days/months.

Electronics Revolution Based on Replication of Silicon Nanotechnology. For computation and memory, connecting billions of nanometer scale devices into an integrated silicon circuit (IC) has enabled Moore's scaling law, enabling the entire information economy. Scaling down the cost of a modern memory chip, amazingly, a single gigahertz ultra-large-scale integrated (ULSI) transistor now costs a nanodollar (\$$10^{-9}$). Processor designers can conceive and implement extremely complex systems on a chip (SOC), because the devices can be integrated so well.

Integrating Optimized Objects into Smart Matter Requires Assembly. However, Moore's law of integration is currently limited to silicon based devices over small areas and in high volume, primarily helping only computation and memory applications. Manufacturing requires billion dollar facilities, the allowed materials and processes are very limited, and design/fab cycles are in months. Recently developed nanotechnology materials and stablished device technology, such as optoelectronic devices, chemical sensors, MEMS, are not readily integrated with silicon ICs or even each other, due to process integration issues. Similar arguments can be made for mechanical materials, such as engineered microstructures and composites. Smart mechanical structures will have embedded electronics. Robotic pick and place is the established technology for integrating normally disparate technologies into a functional system (printed circuit board), but this is limited to typically 10-100 parts per system and with large chips and low granularity (millimeter or larger scales).

Micro-Object Printer Proposal: A Generalized Assembly Technology to Bridge Nano To Macro. Fundamental new manufacturing capability is required to enable massive integration of normally disparate devices into functional devices. A generalized mesoscale assembly process which could handle a wide variety of micro objects, bridging nano to macro scales, would extend Moore's law to smart matter. This could enable a new generation of highly sophisticated, complex structure and system designs, composed of millions of micro-objects, interconnected into a system. Applications include large area sensors and structures, and high performance flexible electronics, essentially smart matter which interacts with the environment (nano based sensor arrays, detector arrays, phased arrays, metamaterials, smart paper/packaging, engineered microstructures, intelligent structural materials, and LED displays). The ideal micro-object printer system would combine the best properties of xerography (high throughput, short run, large area), pick and place (heterogeneous) and system on a chip (complex, high density).

We envision a new manufacturing capability based on programmable assembly of millions of micro-objects over large areas. Analogous to toner in a xerographic printer, this "printer" would use "ink" consisting of prefabricated optimized active devices and the "paper image output" would be an interconnected functional system (Fig 1). The fundamental building blocks would be microchips which efficiently bridges optimized nanoscale devices to a macroscale system (Figure 2). Microscale chips could be a nanoscale sensor, a low noise amplifier, memory, a multi-layer compound semiconductor optoelectronic device, a new nanocomposite block, a ceramic chip for a thermoelectric composite, or any other object which can be made into an "ink". PARC has designs for such a printer based on advanced electrographic assembly techniques, and is looking for funding to perform the initial research. Xerox invented xerography and PARC built the first laser printer.

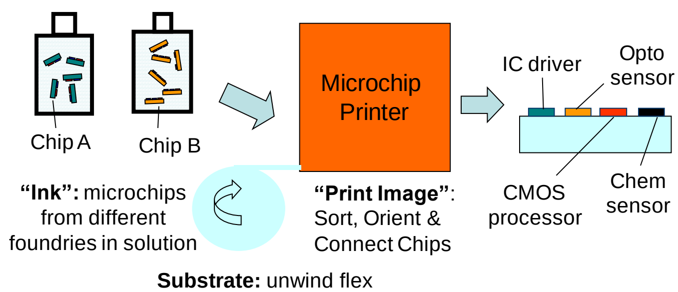

Figure 1. Schematic of a microchip printer which assembles and connects functional micro-chips.

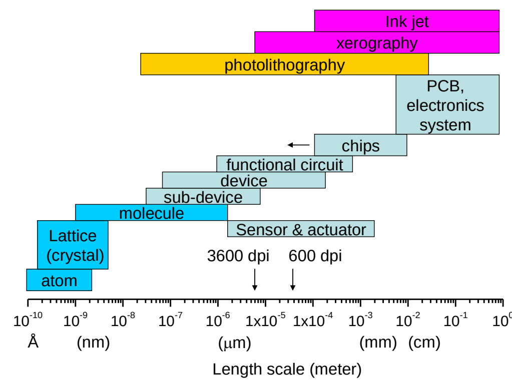

Figure 2. Chips are the natural unit to print to take advantage of existing established technologies.

Challenges: Funding, System Design, Standards. Printer systems are expensive to develop. Much research is needed to develop the basic processes and they need to be optimized and tightly integrated together. Private industry resists funding tooling development unless the specifications for a short term market are clear. Currently the little microassembly work around is primarily in academia, where systems are difficult to realize. In the long run, ink standards need to be defined because the ink would not be made by the printer manufacturer – the ink would come from pre-existing optimized foundries. This new library of objects would need new design tools, and a rapid design/fab cycle would create local manufacturing control and very different business models. We believe high throughput microassembly is a field which is due for focused government investment, as it has the potential to be the foundation of a new manufacturing platform. Realization of the full printer system would represent a fundamental new manufacturing capability, extending Moore's law for silicon circuits to other materials and granulated and large-area, sparse systems; smart matter which interacts with the environment. A simpler supply chain is possible, enabling rapid prototyping and more local manufacturing.