Nanomanufacturing and Fabrication

By Matthew Margolis

Manufacturing is "the transformation of raw materials into finished goods for sale, or intermediate processes involving the production or finishing of semi-manufactures. It is a large branch of industry and of secondary production." Fabrication is an analogous term that is often used in relation with the steel and semiconductor industries.[1] Manufacturing and fabrication have long been a part of civilization but the roots of modern methods can be traced back to the Industrial revolution.[1] Now in the nanotechnology revolution manufacturing is once again changing both society and the way that we make things.

In the world of nanotechnology there are two general approaches to manufacturing, top down and bottom up. Top down is when you start with something large and chop, sculpt or otherwise remove and reshape parts until you arrive at your desired object. This is the approach that an artist takes when sculpting a figure in clay. They start with a large brick and carve out parts until a little monkey or human is all that is left.[2]

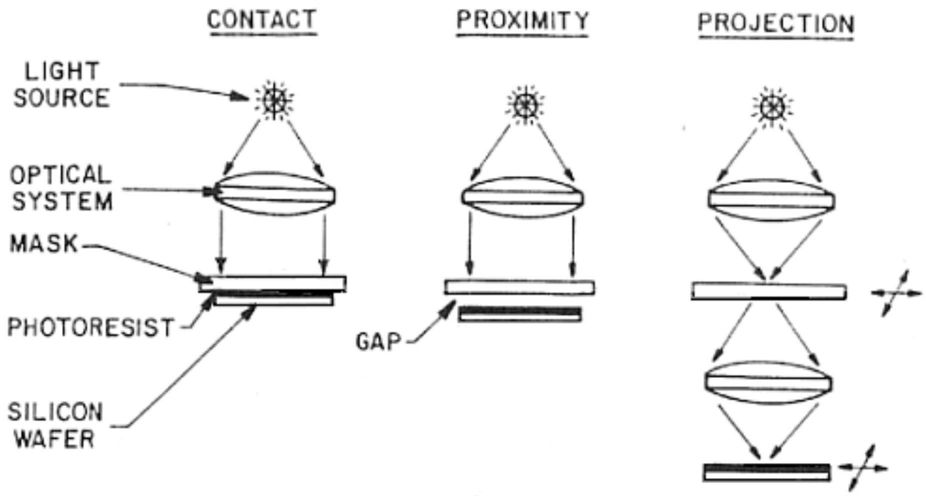
Bottom up fabrication is the exact opposite in that you start with small pieces and build up to larger objects. When you were a kid building spaceships out of individual Lego bricks you were using a bottom up approach.[3] When a Toyota mechanized car builder pieces together the engine in your new Prius it doesn't sculpt the entire thing out of a raw steel block, it assembles lots of individual components to form the greater working part.

Today both techniques are used in industry. Top down tends to produce a lot of waste materials and require lots of time and machinery. In the future many hope that bottom up will lead the way to self assembling nanostructures. Bottom up self-assembling procedures may lead to a manufacturing industry where simply bathing or spraying a surface in a nanoparticle suspension will produce a finished product. One area where bottom up and more advanced top down fabrication technologies are needed is the realm of lithography for chip fabrication.[4]

Traditional lithography is a method of replicating an image that was invented in 1798 by Alois Senefelder. It makes use of the fact that oil and water do not mix. The part of the stone that carries the material to be transferred to paper is covered in grease. Ink is then applied and the stone is washed off with water. The only ink that remains is over the grease. The stone is then pushed onto the paper and transfers the image.[5]

Modern photolithography operates along the same principles but is optical in nature. Like original lithography its purpose is to transfer an image onto a surface. The first step in photolithography is to prep the silicon wafer that you plan to print onto. Silicone dioxide and a photoresist, a photosensitive chemical, are deposited onto the wafer. There are two types of photoresists, positive and negative. Positive photoresists become more soluble when exposed to light. Negative photoresists become less soluble when exposed to light. Negative resists were popular during the early days of photolithography but positive resists allow for smaller features to be transferred onto a wafer so they are now favored. Next you need to soft bake the wafer. This removes solvents from the photoresists and actually makes the wafer photosensitive.[6]

The next step is mask alignment. The mask is a "square glass plate with a patterned emulsion of metal film on one side" [5] Once the mask is aligned light is shown through the mask at the wafer and the desired features are produced. There are three different exposure methods that are often used in masked photolithography; contact, proximity, and projection.[5]



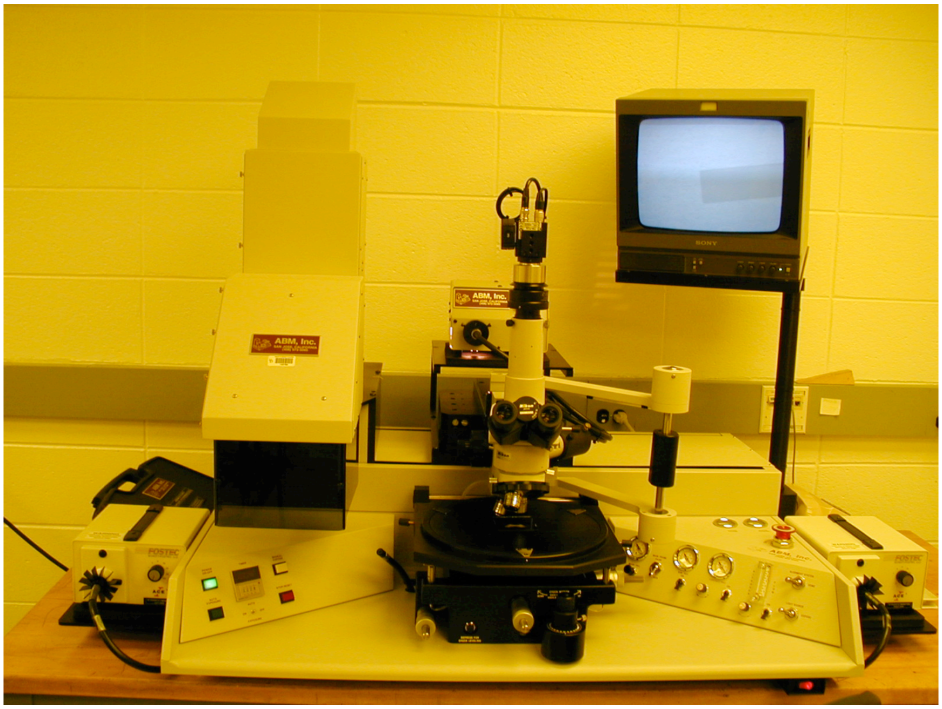
[5]

Contact printing is just what it sounds like, the mask and photoresist are brought into contact with each other. This type of printing allows for high resolutions but endangers the mask as anything between the mask and the photoresist may come into contact with the mask and subsequently damage it. Proximity printing provides that there is a 10 to 25 micron gap between the mask and the photoresist. The added distance means that the mask is safer but lower resolutions are produced than contact printing. Projection printing ensures the safety of the mask by placing it far away from the photoresist. However, because of this distance it is impossible to expose the entire wafer at a high resolution. Instead only part of the wafer is exposed at a time. Resolutions comparable to contact printing are possible.[5]

Next the wafer is developed and hard baked. These last two steps remove excess photoresist and harden the wafers layers. After hard baking the photolithography process is completed.[5]

Traditional photolithography has some major problems. As of September 2003 chipmakers like Intel and AMD were able to churn about 0.13 and 0.18 micron features. Progress down in size has been slow and costly. If we are to keep up with Moore's law we will need to get a lot smaller a lot faster than modern photolithography will allow. One possible solution to this size issue is nanoimprint lithography. With nanoimprint lithography you create a mold with nanoscale features and then press that mold into a soft polymer. Like when you make a waffle. The polymer is then cured using UV light. Certain companies claim that features as small as 10 nanometers can be achieved with nanoimprint lithography. There are also claims that nanoimprint lithography tools can be as much as 10 times cheaper than traditional projection photolithography tools. Motorola is interested in this technology and has already thrown some money at it.[7]

Another option is to look towards the subatomic electron with e-beam lithography. Where photolithographic masks can cost over a million dollars to develop e-beam lithography is maskless. Originally developed at IBM in the 1970s the e-beam directly writes on a wafer. No mask is needed. Unfortunately it can take more than 10 hours to complete a single 200mm wafer.[7] While this time is acceptable enough for use in some research labs and government organizations it is not feasible for a large chip maker like Intel to convert its fabrication facilities over to e-beam technology just yet. One proposal for increasing throughput is to use a programmable mask that either allows electrons over a particular spot on the wafer through or blocks them. If you point enough electron beams at the wafer and have the mask close over areas that should not be exposed then you should be able to finish a wafer much faster than if you just use one beam.[8]



http://www.ee.udel.edu/~dprather/facilities/uvduvlithography.jpg An e-beam lithography system.

While the future of nanomanufacturing and nanofabrication is still uncertain the societal impacts are becoming more and more visible. Already the manufacturing sector and research into manufacturing are feeling the nanofever and its repercussions. In Albany, New York, The Albany Nanotech Initiative which is partnered up with IBM is already impacting the national workforce. While jobs are being added out in Albany jobs are being cut in California where the state's budget problems are keeping it from investing heavily in nanotechnology.[8] Intel who is based in California has its R&D facility in Oregon and it seems content to watch the state competition from a distance for now. AMD announced a joint venture with Albany Nanotech at the beginning of 2003. It would seem that the money and the jobs are going east. As of 2003 the Albany Nanotech Initiative had raised 1.2 billion dollars, more than all the other nano initiatives in the country combined.[9]

http://www.nystar.state.ny.us/Assets/photos/pr/36-04b.jpg A meeting of the Albany Nanotech Initiative

The cost of producing a new fabrication plant has topped one billion dollars. Intel, the leading manufacturing company in the semiconductor industry has decided to stop building new fabrication plants. They will retool existing plants but the one billion dollar and higher price tag on a new plant has become prohibitive for the chip giant.[10] China is doing the opposite. There, new foundry businesses are springing up left and right. A foundry company is one that is fabless. These technology companies like NVIDIA, ATI and Broadcom don't have their own chip making facilities.[11] Instead they take advantage of already existing facilities and of new facilities that can be built because more than one company is going to share the hefty price tag. This move towards foundry startups may cause substantial job loss in the US in addition to putting the big players like Intel and AMD under added pressure to increase production.[12]

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