Figure 5.14 illustrates the steps of transferring IC patterns from a mask to a wafer. The wafer is placed in a clean room that typically is illuminated with yellow light as photoresists are not sensitive to wavelengths greater than 0.5 μm. The wafer is held on a vacuum spindle, and approximately 1 cm³ of liquid resist is applied to the center of the wafer. The wafer is than spun for about 30 seconds. The thickness of the resulting resist film, l_R, is directly proportional to its viscosity as well as the percent solid content indigenous to the resist, and varies inversely with the spin speed. For spin speeds in the range of 1000 to 10000 rpm, film thicknesses of the order of 0.5 to 1 μm can be accomplished.

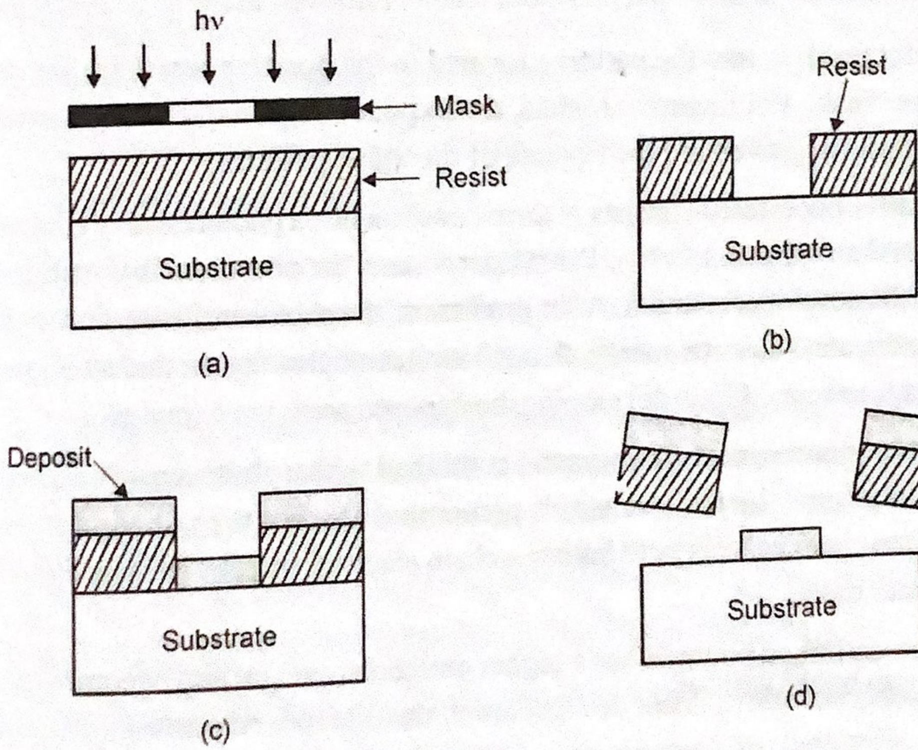

Figure 5.15: Lift-off process for pattern transfer

The wafer is then given a pre-exposure bake (80°C to 100°C) to remove solvent and improve adhesion. The wafer is aligned with respect to the mask in an optical lithographic system prior to exposure to UV or deep UV light.

For a positive photoresist, the exposed portions are dissolved in the developer solution. The wafer is then rinsed, dried, and then put in an ambient that etches the exposed insulating layer but does not attack the resist. Finally, the resist is stripped, leaving behind an insulator image (or pattern) that is the same as the opaque image on the mask.

For a negative photoresist, the exposed area becomes insoluble, and the final insulator pattern is the reverse of the opaque image on the mask.

The insulator image can be employed as a mask for subsequent processing. For instance, ion implantation can be performed to dope the exposed regions selectively. Figure 5.15 illustrates the lift-off technique. This method suffices if the film thickness is smaller than that of the photoresist.

Photoresist

A photoresist is a radiation-sensitive compound. For positive resists, the exposed region becomes more soluble and this more readily removed in the developing process.

The net result is that the patterns formed in the positive resist are the same as those on the mask. For negative resists, the exposed regions become less soluble, and the patterns engraved are the reverse of the mask patterns.

A positive photoresist consists of three constituents: a photoresistive compound, a base resin, and an organic solvent. Prior to exposure, the photosensitive compound is insoluble in the developer solution. After irradiation, the photosensitive compound in the exposed pattern areas absorbs energy, changes its chemical structure, and transforms into a more soluble species. Upon developing the exposed areas are expunged.

Negative photoresists are polymers combined with a photosensitive compound. Following exposure, the photosensitive compound absorbs the radiation energy and converts it into chemical energy to initiate a chain reaction, thereby causing crosslinking of the polymer molecules.

The cross-linked polymer has a higher molecular weight and becomes insoluble in the developer solution. After development, the unexposed portions are removed. One major drawback of a negative photoresist is that the resist absorbs developer solvent and swells, thus limiting the resolution of a negative photoresist.

5.12 Applications of Nanotechnology

Nanoscale materials have been used for many decades in several applications including mass-market consumer products. Well known is a glass for windows which is coated with titanium oxide nanoparticles that react to sunlight as break down dirt. When water hits the glass, it spread evenly over the glass surface instead of forming droplets and runs off rapidly, taking the dirt with it. Nanomaterials are highly used in vehicle industry to reinforce certain properties of vehicle bumpers and to improve the adhesive properties of paints.

There are two types of applications. The structural applications are based on the mechanical properties of the nano structured or nanophase materials. These are used to produce super plastic ceramics and extremely hard metals.

Functional applications are based on the transformation of external signals such as the filtering of the incident light, the change of electrical resistance in different gas concentrations and luminescent behaviour when electrically activated.

Other applications are:

- Sunglasses using protective and antireflective ultrathin polymer coatings.
- Scratch resistant coatings that are transparent, ultrathin, easy maintenance, well suited for daily use and reasonably priced.
- Windproof and waterproof cloths preventing wrinkling or staining and guarding against electrostatic discharges.
- Sunscreens and cosmetics based on nanotech are widely used because of their purity and cleanliness. For antiwrinkle creams, a polymer capsule is used to transport active agents like vitamins.
- Sports equipments like tennis rackets with carbon nanotubes have improved torsion and flex resistance. Long lasting tennis balls are made up of nanocoated inner core clay which increases the lifetime of conventional balls.
- In televisions, the electrons in a field effect display are fixed through vacuum at a layer of phosphorescent glass covered with pixels.
- Automobile fuel lines made with carbon nanotubes that inhibit static electricity and reduce the risk of explosions.
- A nano-improved golf ball that increases the efficiency of the transfer of energy from the club to the ball and reduces off-axis rotation for greater control.
- "Intelligent" nanocoatings for windows that reflect solar heat in the summer and transmit in winter.
- Cutting tools made of nanocrystalline materials, such as tungsten carbide, tantalum carbide and titanium carbide, are more wear and erosion-resistant, and last longer than their conventional (large-grained) counterparts. They are finding applications in the drills used to bore holes in circuit boards.

- A washing machine that inhibits bacterial growth on the cloths it washes. Samsung's Silver Care technology harnesses the antimicrobial properties of silver releasing 100 quadrillion silver ions into your cold-water wash. Silver is toxic to aquatic life, so *Samsung* has been notified by the EPA that their washing machine may be regulated as a pesticide. They make a refrigerator, too.

- Hydrogen storage devices

- Very thin permanent magnets with high energy products used for high density magnetic recording.

- Nanomaterials have very high magneto resistance. This property is also used in the magnetic storage devices.

- Make alloy from immiscible materials and high TC superconductors.

- Quantum wells, quantum dots and quantum wires have quantum confinement are produced from semiconductor nanomaterials which are acting as computer storage (memory) materials with high density.

- Nanomaterials have a large volume function of grain boundaries or large ratio between surface area and volume. This property is used to get improved mechanical properties like higher hardness in ceramics.

The nanomaterials find wide applications in fields such as coating & films, ceramics, adhesives, surface modifiers, packaging, fire retardants, pharmaceuticals, cosmetics, resins and glasses, magnetic materials, catalysts etc.

Some typical properties and possibilities of future applications of nanomaterials are tabulated below:

Table 5.2: Properties and applications of nanomaterials

Sl.No.	***Properties***	***Applications***
1.	Single magnetic domain	Magnetic recording, data encryption
2.	Small mean free path of electrons electrons in a solid	Special conductors
3.	High and selective optical absorption of Metal particles	Colour filters, solar absorbers,photo voltaics, Photographic materials, molecular filters
4.	Uniform mixture of different kinds of superfine particles	R & D of new materials
5.	Grain size too small for stable dislocation	High strength and hardness of metallic materials
6.	Surface interface–Large specific surface area	Catalysis, sensors
7.	Large surface area, small heat capacity	Heat exchange materials, combustion catalysis
8.	Optical devices based on transparent, rigid silica host	Tunable laser, semiconductors, non-linear optics, pick-up lens, photo-chromic
9.	Photovoltaic	Power cables, superconductors
10.	Cluster coating and metallization	Special resistors, temperature sensors

5.12.1 Aerospace components

Due to the risks involved in flying, aircraft manufacturers strive to make the aerospace components stronger, tougher, and last longer. One of the key properties required of the aircraft components is the fatigue strength, which decreases with the component's age. By making the components out of stronger materials, the life of the aircraft is greatly increased. The fatigue strength increases with a reduction in the grain size of the material. Nanomaterials provide such a significant reduction in the grain size over conventional materials that the fatigue life is increased by an average of 200-300%.

Furthermore, components made of nanomaterials are stronger and can operate at higher temperatures; aircrafts can fly faster and more efficiently (for the same amount of aviation fuel). In spacecrafts, elevated-temperature strength of the material is crucial because the components (such as rocket engines, thrusters, and vectoring nozzles) operate at much higher temperatures than aircrafts and higher speeds. Nanomaterials are perfect candidates for spacecraft applications, as well.

5.12.2 Sensors

Ceramics are hard, brittle and difficult to machine. However, with a reduction in grain size to the nanoscale, ceramic ductility can be increased. Zirconia, normally a hard, brittle ceramic, has even been rendered superplastic (for example, able to be deformed up to 300% of its original length).

Nanocrystalline ceramics, such as silicon nitride and silicon carbide, have been used in such automotive applications as high-strength springs, ball bearings and valve lifters, because they can be easily formed and machined, as well as exhibiting excellent chemical and high-temperature properties.

They are also used as components in high-temperature furnaces. Nanocrystalline ceramics can be pressed into complex net shapes and sintered at significantly lower temperatures than conventional ceramics.

In their widest sense, nanotechnologies have been used by industries for decades (semiconductors), and in some cases considerably longer (chemicals). However, developments over the past 20years in the tools used to characterise materials, have led to an increased understanding of the behaviour and properties of matter at very small size scales.

Increased knowledge of the relationship between the structure and properties of nanomaterials has enabled the production of materials and devices with higher performance and increased functionality. This progress has taken place steadily over several years; so, at least so far, the influence of nanotechnologies on industry can be described as evolutionary rather than revolutionary. This is also evident in the current production rates of nanoparticles and nanomaterials which, although increasing, are negligible compared with bulk chemicals and materials.

5.12.3 Medicine

Applications in the field of medicine are especially promising. Areas such as disease diagnosis, drug delivery and molecular imaging are being intensively researched.

The small size of nanoparticles endows them with properties that can be very useful in oncology, particularly in imaging. Quantum dots (nanoparticles with quantum confinement properties, such as size-tunable light emission), when used in conjunction with MRI (magnetic resonance imaging), can produce exceptional images of tumor sites. These nanoparticles are much brighter than organic dyes and only need one light source for excitation. This means that the use of fluorescent quantum dots could produce a higher contrast image and at a lower cost than today's organic dyes used as contrast media.

Another nanoproperty, high surface area to volume ratio, allows many functional groups to be attached to a nanoparticle, which can seek out and bind to certain tumor cells. Additionally, the small size of nanoparticles (10 to 100 nanometers), allows them to preferentially accumulate at tumor sites (because tumors lack an effective lymphatic drainage system). A very exciting research question is how to make these imaging nanoparticles do more things for cancer. For instance, is it possible to manufacture multifunctional nanoparticles that would detect, image, and then proceed to treat a tumor? This question is under vigorous investigation; the answer to which could shape the future of cancer treatment. A promising new cancer treatment that may one day replace radiation and chemotherapy is edging closer to human trials. Kanzius RF therapy attaches microscopic nanoparticles to cancer cells and then the RF (radio frequency) transmitter apparatus exposes the nanoparticles to the radio frequency signal they heat up, destroying the cancer cells, but don't damage healthy cells nearby.

- Target therapies
- Image single cells
- Develop biosensors to: Monitor therapy within a cell, Screen for disease markers, Create biomaterials and engineered tissues.

With the growing side effects of recently introduced drug aAntibiotics and the developing resistance of germs to these drugs, the interest in use of silver has recently been rekindled. The colloidal silver solutions are far more effective than silver nitrate and require far less quantities of Silver (less than 0.25% of the Silver in Silver Nitrate used before). Silver is non toxic to the human body and has been used in preparation of food items in India for hundreds of years e.g. Silver foil on sweets. During the past few years, the technology for making Nano sized particles of Silver has developed to a great extent and the broad spectrum antibiotic properties of silver have thereby been enhanced to cover in more effective manner all kinds of gram positive and gram negative bacteria. Nano silver particles are also highly effective against fungi and viruses of all types including hepatitis, herpes and HIV virus, to name a few.

The drug, a compound known as TAK-779, was originally found to bind to a specific location on human T-cells, which blocks the HIV virus' entry to the body's immune system. Unfortunately, the portion of the drug's molecule that made binding possible had unpleasant side effects. When that portion of the molecule- an ammonium salt-was removed, the drug lost its binding ability.

That's when Melander and colleagues from the University of North Carolina at Chapel Hill and the University of Colorado at Boulder turned to gold as the answer. The element is non-reactive in the human body, and would be the perfect "scaffold" to attach molecules of the drug to in the absence of the ammonium salt, holding the drug molecules together and concentrating their effect.

"The idea is that by attaching these individual molecules of the drug with a weak binding ability to the gold nanoparticle, you can magnify their ability to bind," Melander says.

The researchers' theory proved correct. They started with a modified version of TAK-779, which didn't include the harmful ammonium salt. After testing, they found that attaching 12 molecules of the modified drug (SDC-1721) to one nanoparticle of gold restored the drug's ability to prevent HIV infection in primary cultured patient cells. When only one molecule of the drug was attached to the gold nanoparticle, the compound was unable to prevent HIV infection, indicating that the multivalency of the drug was important for its activity.

Current medical implants, such as orthopaedic implants and heart valves, are made of titanium and stainless steel alloys, primarily because they are biocompatible. Unfortunately, in some cases these metal alloys may wear out within the lifetime of the patient. Nanocrystalline zirconium oxide (zirconia) is hard, wearresistant, bio-corrosion resistant and bio-compatible. It therefore presents an attractive alternative material for implants. It and other nanoceramics can also be made as strong, light aerogels by sol–gel techniques. Nanocrystalline silicon carbide is a candidate material for artificial heart valves primarily because of its low weight, high strength and inertness.

In future, *Nanonets* – networks of carbon nanotubes enable numerous basic electronic functions at low cost. The durable nature of nanonets make them suitable devices, like electronic paper, flexible touch screens, solar cells, sensors.

5.13 Disadvantages and Risks of Nanotechnology

Initial costs will be high and products will be exclusive; eventually prices fall. Manufacturers aren't required to disclose the presence of nano-materials in their labeling.

Some nanoparticles are extremely combustible so they could spontaneously burst into flames. Some nanomaterials seem to linger in the environment. Nanoparticles can enter the body and its vital organs [through the skin and nasal passage], including the brain, much more easily than can larger particles. There seems to be a significant danger that public acceptance of a whole range of beneficial applications of nanotechnologies, particularly in the environmental domain, might be threatened by too close an association with military applications.

In conclusion, nanotechnologies will have an impact across many branches of science and technology and can be expected to influence a range of areas of human endeavour.

Points to Remember

1. Richard Feynmans - "There's plenty of room at the bottom" 1959, 29th Dec (Annual meeting of American physical society at the California institute of technology)
2. Gordon Moore, Head of research at fairchild semiconductors (Founder of Intel) suggested in 1965 issue of Electronics that "The number of transistors that could be crammed into of each new generation of chips would remain roughly same."
3. Two laws of Moore

   Moore's 1st Law

   The amount of space required to install a transistor on a chip shrinks by roughly half every 18 months.

   Moore's 2nd Law

   The cost of building a chip manufacturing plant doubles with every other chip generation or roughly every 36 months.

4. Future of Moore's Law – Semiconductor industry crisis
   1) Overheating – solved by Nanotechnology
   2) Chip manufacturing – solved by Nanotechnology
   3) The material crisis – solved by Nanotechnology
   4) Quantum effects – solved by Nanotechnology
   – Small object that behaves as a whole units in terms of transport properties (diameter range 100 nm to 2500 nm for fine particles for nanoparticles 1 to 100 nm)
5. Surface area more than bulk materials and surface/volume high

   (E.g.) Cu bulk rod 50 nm scale can be bent but same rod made up of nanoparticles can't be bent since they don't exhibit malleability and ductility.
6. *Quantum dots – Electrons confined in all three dimensions*

   Quantum computing, biological analysis

$$\text{Band gap} \propto \frac{1}{\text{size of dot}}$$

   Quantum wires – Electrons confined in 2 dimensions

   High electrical conductivity, light weight, small diameter, low chemical reactivity and high tensile strength.

   Quantum wells – Electrons confined in one dimension

   Sharper density of states use in diode lasers.
7. Nanomanipulation means scanning probe micriscope offers a means to carry out precise and controlled manipulation of atoms, molecules and nanostructures on a surface.
8. Lithography means the process of transferring a pattern into a reactive polymer film, termed as resist which will subsequently be used to replicate that pattern into a underlying thin film (or) substrate.