In the process called mask lithography, the resist is irradiated through the mask which is in contact or in proximity with resist surface. In another process called scanning lithography, a scanning beam irradiates the resists surface point by point through a computer controlled programme.

1. Phtolithography

It is an optical method by which patterns are transferred on to a substrate. The process uses a light sensitive polymer, called a photoresist. It is exposed and developed to form three-dimensional relief images on to the substrate. The process generally uses UV light (360-460nm). This is used in semiconductor industry for fabricating integrated circuits.

2. E-Beam Lithography

The process used a tightly focused beam of electrons to scan across the surface of an electron-sensitive resist film, such as poly methyl methacrylate. The higher resolution in the technique is achieved due to scattering of the electrons in the resist film and the substrate.

3. Nano Contact Printing

It is a form of soft lithography which uses relief patterns on a master or template made of polydimethylsiloxane (PDMS) stamp to form patterns of nanolayers of ink on the surface of a substrate. It may be used in surface chemistry and cell biology especially for analyzing DNA.

4. Nanospehre Lithography

In nanosphere lithography an ensemble of nanospheres ordered on a surface are used as a mask. The nanospheres are dispersed in a liquid (i.e. a colloid) and a droplet placed on a surface and left to dry. Depending on the surface properties (e.g charge) and media used in the colloid (e.g. presence of electrolytes) the nanoshphere will self-assemble in an ordered pattern. In some conditions, a colloidal crystal is obtained: each manoparticle is surrounded by six other nanospheres. This regular arrangement can be used to create ordered structures on surfaces.

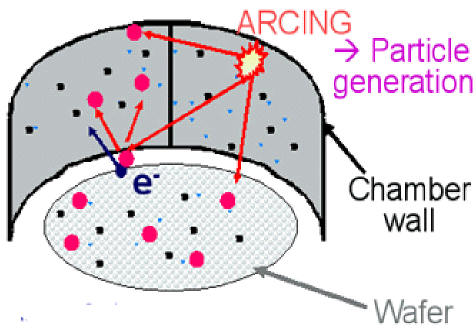
5. Colloidal Lithography

It is based on the same principles of a nanosphere lithography of using a colloid as a mask for the fabrication of nanostructures on surfaces. In this process, electrostatic forces are emplayed to obtain short-range ordered arrays of nanoshperes on the surface. The array can then be used to create a number of different nanostructures through process like etching.

Bottom-up Method

1. Plasma Arcing

It is one of the methods of gas-phase fabrication like chemical Vapour deposition. The process was a Plasma. A gas is ionized between two electrodes with a potential difference. An arcing device is made of two electrodes (Anode and cathode) and an arc that passes from one electrode to another. The anode vaporizes as electrons are taken from it by the potential difference. This is communed during reaction. For example, a carbon electrode is used to produce carbon nanotubes. Positively charged ions pass to the other electrode, pick up electrons and are deposited to form nanotubes.



2. Chemical Vapour Deposition

In this process the substrate (wafer) is exposed to one or more volatile precursors which react and/ or decompose on the substrate surface to produce the desired deposit. This process is very useful in semiconductor industry for producing ICs such as the one made of Gallium-Arsenide. Similarly, polysilicon may be used in photovoltaic devices.

3. Sol-gel Synthesis

It is one of the methods of liquid-phase fabrication like molecular beam epitaxy. The sol-gel process involves the evolution of networks through the formation of a colloidal suspension (Sol) and gelation of the sol to form a network in a continuous liquid phase (gel), It is very commonly used to make silica gel. Likewise, aluminosilicate gels are very useful in making tubular structure.

First of all, hydrolysis reaction takes place in which -OR group (R represents a hydrocarbon or any other organic moiety, i.e. group) is replaced with an -OH (hydroxyl) group. Following hydrolysis, the sol starts to condense and polymerize. This leads to the growth of particles and reach dimension of a few nanometers depending on pH and other conditions.

The particles then agglomerate, i.e. a network starts to form throughout the liquid medium, resulting in thickening, which form the gel.

4. Molecular Beam Epitaxy (MBE)

'Epitaxy' is the deposition of a crystalline overlayer on a crystalline substrate. This layer is called epitaxial layer. Molecular beam epitaxy takes place in high vacuum or ultra-high vacuum (10^{-8}pa). MBE makes it possible to fabricate crystals one atomic layer at a time. The growth process is highly controlled to avoid contaminants being introduced during the crystal growth. A range of surface analysis techniques used to monitor the growth process and ensure purity of the crystal. MBE is presently used in the semiconductor industry, where the performance of the device (e.g. computer chip) depends on precise control of dopants in semiconductors and on the production of extremely this crystal layers with hyper-abrupt interfaces. MBE is used for the fabrication of numerous important devices such as light emitting diodes, laser diodes, field effect transistors, read/white heads for computer drive and more.

5.5 Applications of Nanotechnology

In Medicine

It involves number of application as in drug delivery, therapy, diagnostics, anti-microbial techniques as well as in cell repair.

Researches are being conducted to develop techniques employing nanoparticles to deliver drugs, especially in cancer, diabetes, fungal infections, viral infections and gene therapy. Liposome's, discovered in mid 1960s were the original models of nanoscaled drug delivery devices. A liposome is a spherical vesicle composed of lamellar phase lipid bilayer. They may be multi-lamellar with more than one membrane or unilamellar with single membrane. They have an aqueous interior. These lipsomes can be loaded with drugs either in aqueous compartment or, in the lipid membrane. Usually water soluble drugs are loaded in aqueous compartment and lipid soluble drugs are incorporated in the liposomal membrane. Liposomes can be targeted to specific organ or tissue by passive as well as active methods. As the liposomal drug acts minimally on other tissues, the safety profile is better than non-liposomal drug.

Nanopores designed by Desai & Ferrari consist of wafers with high density of pores (20 nm diameter). The pores allow entry of oxygen, glucose and other products like insulin to pass through. Researches in US have also developed nanoparticles that can be taken orally and pass through the lining of the intestines into the bloodstream. This should allow drugs that must now be delivered with a shot to be taken in pill form.

In therapy techniques, nanosponges have been developed that absorb toxins and remove them from bloodstream. The nanosponges are polymer nanoparticles coated with a red blood cell membrane. This membrane allows the nanosponges to move freely in the bloodstream and attract the toxins. Nanoparticles composed of polyethylene glycol-hydrophilic carbon clusters (PEG-HCC) have been found to absorb free radicals at a much higher rate. This ability may reduce the harm that is caused by the release of free radicals after a brain injury. A sensor using carbon nanotubes embedded in a gel can be injected under the skin to monitor the level of nitric oxide in the bloodstream. It indicates inflammation.

Similarly, gold nanorods have been used to detect kidney damage because these rods attach to the type of protein generated by damaged kidneys. When protein accumulates on the nanorod the colour of the nanorod shift. In anti-microbial techniques, nanocrystalline silver is used for the treatment of moulds. Last but not the least, nanorobots could actually be programmed to repair specific diseased cells.

In Information & Communication

Developments are taking place on ultra-integrated opto electronics combined with powerful wireless technology as low price mass products. Memory storage before the advent of nanotechnology relied on transistors, but now reconfigurable arrays are formed for storing large amount of data in small spaces. Molecular electronics based on carbon nanotubes can possibly be used. Nano amplification and chip embedding is used for building semi-conductors devices which can even maintain and neutralize the electric flow. Integrated nanocircuits are used in silicon chips to reduce the size of the processors. A laser has been developed that uses a nanopatterned silicon surface. It helps produce light with much tighter frequency control. This may allow much higher data rates for information transmission over fibre optics. Cadmium selenide nano crystals deposited on plastic sheets have been shown to form flexible electronic circuits.

In Fuel cells

Catalysts are used in fuel cells using hydrogen or methanol to produce hydrogen ions. Platinum is typically used in this process as catalyst. Fuel cells contain membranes that allow hydrogen other atoms or ions, such as oxygen, to pass through. Researchers at Copenhagen have demonstrated the ability to significantly reduce the amount of platinum needed as a catalyst. Another research is being conducted to develop a catalyst without forming a sheet of graphene coated with cobalt nanoparticles. A catalyst using platinum-cobalt nanoparticles has been developed that produces 12 times more catalytic activity than pure platinum.

In Space

Bio-nanorobots may be of great help to astronauts in case of emergency. Scientists anticipate two types: an outer robot layer and an inner. The outer layer would function separately from the astronaut's spacesuit. These may respond to dangerous spacesuit issues like ruptures. NASA is working on a project to use nano-materials to build extremely lightweight spaceship. Scientists are trying to use carbon nanotubes to make the cable needed for the space elevator, a system which could significantly reduce the cost of sending materials into orbit.

Other Applications

- Nanowhiskers cause water to break up making the fabric both water and stain resistant.
- Silver nanoparticles used in fabric kill bacteria making clothing odour-resistant.
- Nanotechnology can enable sensors to detect very small amounts of chemical vapour. Various types of detecting elements such as carbon nanotubes, zinc oxide nanowires or palladium nanoparticles may be used.
- Pellets containing nanostructured palladium and gold as catalyst may be used to breakdown chlorinated compounds contaminating ground water.
- Graphene with the holes the size of a nanometer or less can be used to remove ions from water.
- Carbon nanotubes can be used as reverse osmosis membranes.
- Silver chloride nanowires may be used as photocatalysts to decompose organic molecules in polluted water.

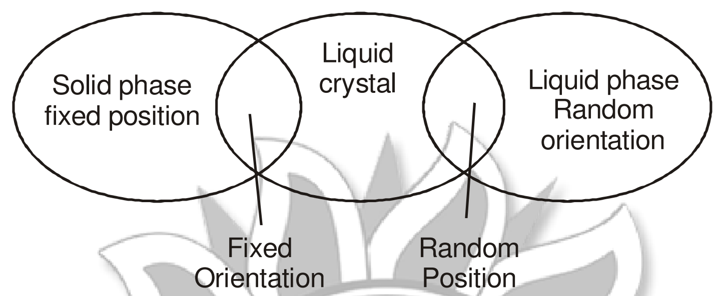
5.6 Overview of Some Nanomaterials

1. Liquid crystals

The liquid crystal state is a distinct phase of matter observed between the crystalline (solid) and isotropic (liquid) states. Like a liquid it flows, and like a crystal, it can display long-range molecular order. In other words, such crystals combine the fluidity of ordinary liquids with electrical and optical properties of crystalline solids. They change their molecular and super molecular organisation drastically as an effect of very small external perturbations. The molecules in liquid crystal display (LCD) for instance are reoriented by relatively weak electrical fields. Liquid crystal (LCs) materials generally have several common characteristics. Among these are a rod-like molecular structure, rigidness of the long axis, and strong dipoles and / or easily polarizable substituents. The distinguishing characteristic of liquid crystalline state is the tendency of the molecules (mesogens) to a point along a common axis called the 'director'. This tendency leads to a condition known as anisotropy. It means that the properties of a material depend on the direction in which they are measured. The anisotropic nature of LCs is responsible for the unique optical properties.

The study of LCs began in 1888 by Friedrich Reinitzer who observed the material cholesteryl benzoate to behave like LC. There are several phases identified such as:

Figure 5.7: Liquid Crystal Phase



1. Nematics:

In this phase the molecules tend to have same alignment but their positions are not correlated.

2. Cholesterics

I n this phase the molecules tend to have the same alignment which varies regularly through the medium with a periodicity. The position of the molecules are not correlated.

3. Smectics

In this phase, the molecules tend to lie in the planes with no configurational order within the planes and are oriented perpendicular to the planes.

Liquid crystals are divided into three groups-

1. **Thermotropic:** These consist of organic molecules, typically having coupled double bonds, and exhibit a phase transition as temperature is changed.
2. **Lyotropic:** They consist of organic molecules which are water loving (amphiphitic) and exhibit a phase transition as a function of both temperature and concentration of the molecules.
3. **Metallotropic :** They consist of both organic and inorganic molecules and their transition depend not only on temperature and concentration but also on the organic-inorganic composition ratio.

Applications

1. The most common application of liquid crystal technology is liquid crystal displays (LCD). A liquid crystal display consists of an array of tiny segments (called pixels) that can be manipulated to present information. A thin film of liquid crystal is placed between two pieces of glass or transparent plastic.

2. Cholesteric liquid crystal reflect light with a wavelength equal to the pitch. Because the pitch is dependent upon temperature, the colour reflected also is dependent upon temperature. Liquid crystals make it possible to accurately gauge temperature just by looking at the colour. Hence, they are used in liquid crystal thermometers.

3. A new area being explored is optical imaging. In this technology a liquid crystal cell is placed between two layers of photoconductor. Light is applied to the photoconductor, which increases the material's conductivity. This causes an electric field to develop in the liquid crystal corresponding to the intensity of the light. The electric pattern can be transmitted by an electrode which enables the image to be recorded.

1. Nanocrystalline Metals

These are classical metals and alloys that have an ultra fine crystalline structure below 100nm. They exhibit extraordinary mechanical and physical properties, which make them interesting for many applications. e.g. Aluminum, magnesium etc. These may be used in magnetic recording and magnetic sensing.

2. Ferro fluids

These are colloidal mixtures which consist of ferro or ferromagnetic nano particles suspended in a carrier fluid which is usually an organic solvent or water. Such Ferro fluids may be used in mechanical engineering for vehicle suspension and breaking systems.

3. Polymeric Nanofibres

Nanofibres are nanostructured fibrous materials which are frequently used in electro-spinning and related fabrication technologies. Nanofibres are highly porous. These may also be used in making wound healing membranes and filtration applications.

4. Quantum Dots (QDs)

Quantum dots are made of semiconductor materials and have a discrete quantized energy spectrum, so it can absorb a specific wavelength and emit a monochromatic colour. QDs like metal nano-particles, are very useful in the fields like environmental monitoring, medical diagnostics and treatment. QDs are also being investigated as novel light source to improve LED technology and in solar cell technology.

5. Titanium dioxide

Titanium dioxide is the most widely used white pigment because of its brightness (white colour) and very high refractive index. It is used in paints, plastics, toothpastes, papers etc. In sunscreens with a physical blocker, titanium dioxide is used both because of its high refractive index and its resistance to discolouration under ultraviolet light.

6. Carbon Nanotubes

Carbon Nanotubes are allotrope of carbon. It is a nanosize cylinder of carbon atoms. A sheet of carbon atoms is rolled into a tube which is called carbon nanotube. With the right arrangement of atoms a carbon nanotube may be hundred times stronger than steel. They can also be effective semiconductors. Hence they may be a realistic option for transistors, microprocessors and other electronics.

7. Nano Composites

A nanocomposite is a material reinforced by nanoscale articles or nanostructures which are discerned through the bulk material. It typically contains an inorganic solid containing an organic component or vice versa or two or more inorganic/organic phases in same combinational form. An inorganic matrix is ceramic Reinforced by nanoscale particles or nanostructures of metal or, organic (e.g. carbon–based) substance. One the other hand, an organic matrix is a polymer reinforced by nanoscale particles or nanostructures by inorganic substance like clay. Nano composites may be used in gas turbines, aerospace material, automobiles etc.

5.7 Nanotechnology in India

Nanotechnology development is characterized by increased investment in research and development (R&D), development of research infrastructure, inter–disciplinary education and training system together with development of entrepreneurship, technology transfer and innovation and, contribution to economic growth. The development of Nanotechnology in India is in early stages with policy initiatives directed towards promoting R&D. It is largely a government—led initiative. The enabling nature of nanotechnology and its ability to develop along with exiting technologies, make it extremely useful to address developmental challenges in sectors like energy, water, agriculture, health, environment etc. According to The Energy Research Institute (TERI) "Enabling energy storage, production and conversion within renewable energy frameworks could be a potential area where nanotechnology application might aid India's development. Nanotechnology interventions might be sought at specific junctures to improve the quantity and quality of water and wastewater systems".

The Department of science and Technology (DST) is the apex agency engaged in the development of nanotechnology in India. It has taken number of initiatives such as:

1. Nano Science & Technology Mission (NSTM)

NSTM or, Nano Mission is an umbrella programme for capacity building which envisages the overall development of this field of research in India and also for tapping some of its applied potential for nation's development. It was for a period of five years with an allocation of Rs.1000 cr. It was an initiative (NSTI) for a period of 2001–06. The basic objectives of Nano mission, *inter alia*, include:

1. Funding the basic research and creation of centres of excellence.
2. Infrastructure development of nanoscience and technology research.
3. Promotion of application oriented R&D projects, establishment of Nano Applications and Technology Development Centres, Nano–Technology Business Incubators, etc.
4. Special efforts for increased industrial participation directly or through Public Private Partnership (PPP) ventures.
5. Effective education and training for development of human resource.
6. To forge academia–industry partnership at the international level.

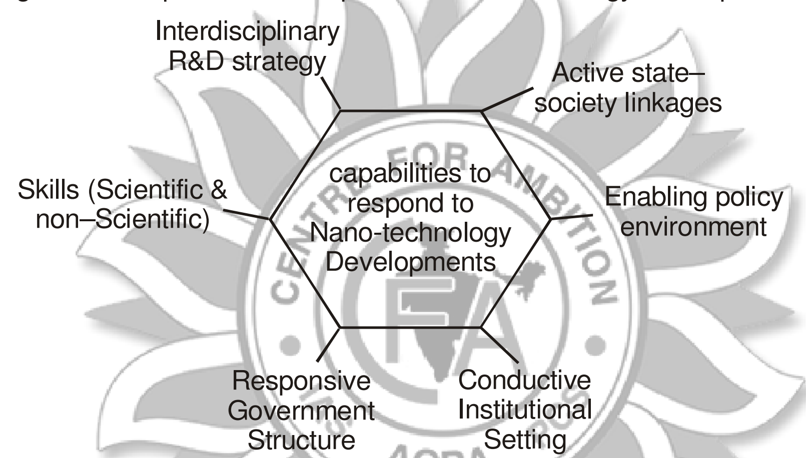
2. Strengthening of Characterization Facilities

The Department of science and Technology (DST) has established an array of sophisticated equipments such as optical tweezes, Nano Indenter, Transaction Election Microscope, Atomic Force Microscope, Scanning Tunneling Microscope etc. at various locations in the country.

3. Centres of Excellence

The DST has sanctioned eleven Centres of Excellence (CoEs) for housing latest facilities for sharing information with scientists. This aims at promoting research on nanoscale systems. Developing clear national strategies to engage with the emerging technology is its imperative. This requires development of both scientific & non–scientific skills and interdisciplinary approaches apart from others (Sec Fig 5.9)

Figure 5.9: Capabilities to respond to nano technology developments



Source: TERI

5.8 Challenges and Risks

The risks involved with nanotechnology are hetorogenous and include environmental, health, occupational and socio–economic risks. By virtue of their size, nano materials like other tiny particles might be able to enter the human body and those of other species imperceptibly through various pathways – inhalation, ingestion, dermal contact etc. It is also believed that nano–particles could disrupt cellular, enzymatic and other organ-related functions posing health hazards. Nano particles might be non–biodegradable and on disposal, might form a new class of non-biodegradable pollutants posing threats to air, water and soil causing their pollution.

Development of an adequate risk governance framework for addressing risks that surround nano technology is vital for its responsible development. This will allow reaping benefits while immersing risks. Apart from risks, nanotechnology development and its governance also face some other challenges, such as–

- Gap between basic research and application.
- Regulatory capacity and information asymmetry and absence of inter agency coordination.

- Technical and financial constraints.
- Engineering and customizing the nano–based system to local requirements addressing heterogenous risks.

Certainly, nanotechnology is comprehensive in its reach and inter disciplinary in nature. However, not only accountability its applications but also its effective regulation need to be ensured. Its socially embedded nature entails that its credibility depends on fostering partnerships among the various stakeholders.

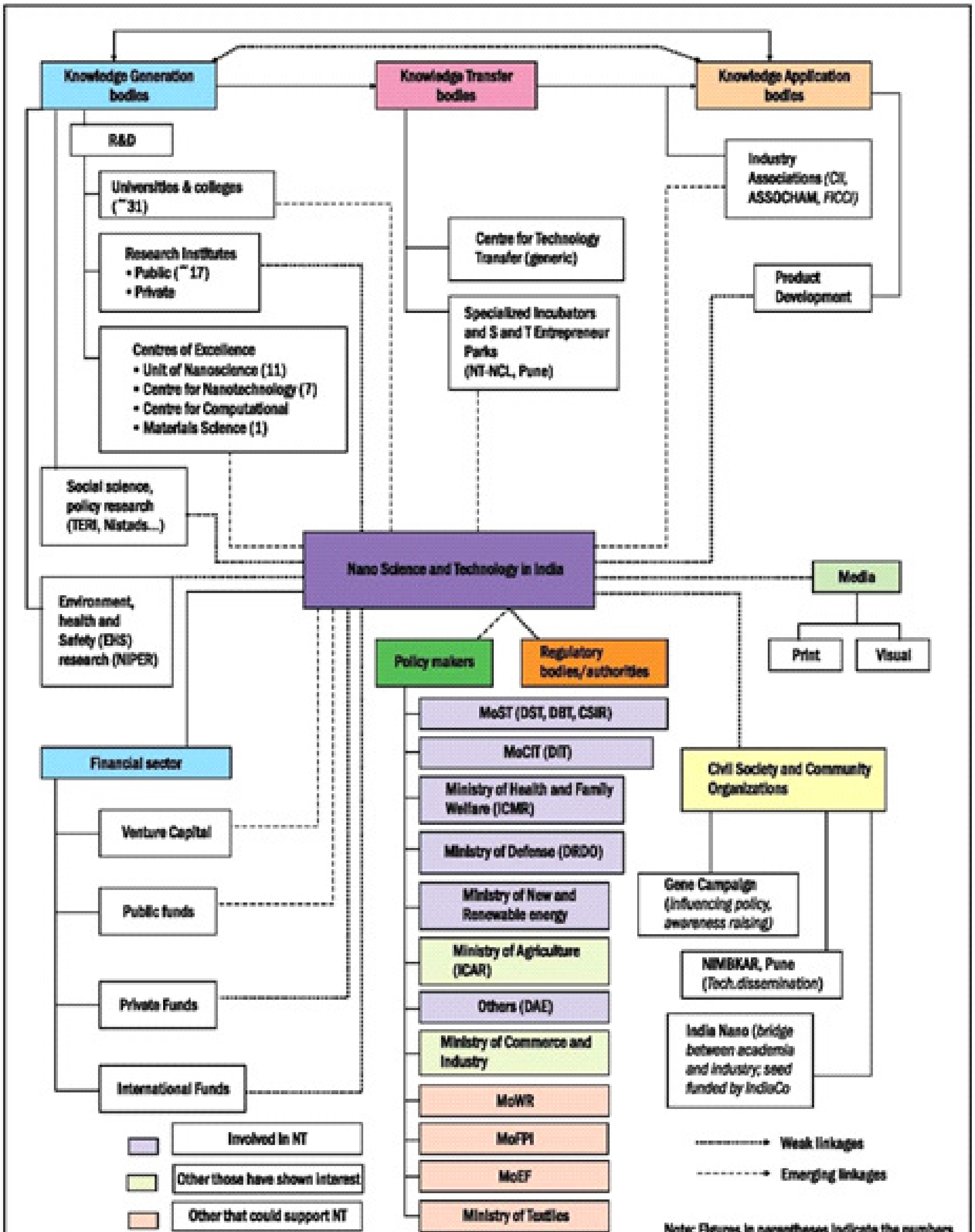


Figure: Mapping of Stakeholders in Nanotechnology in India