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Laser Applications in Nano Technology

Sridhar Goud Arelli
Asst professor in physics

1.Abstract:

Nanotechnologies provide the potential to enhance energy efficiency across all branches of industry and to economically leverage renewable energy production through new technological solutions and optimized production technologies. In the long run, essential contributions to sustainable energy supply and the global climate protection policy will be achieved. Here, Nano technological innovations are brought to bear on each part of the value-added chain in the energy sector.The word 'Laser' stands for Light Amplification by Stimulated Emission of Radiations. Laser is biggest achieve of twentieth century in the field of research. The first laser was developed by Theodore Mailman in USA. It consist of a ruby rod around which a flash tube is bounded. When this rod was subjected to intense flashes of ordinary light it produced pulses of red laser light within a year of investigation-other laser using solids, liquids and gases were developed.

2.Introduction in to Nanotechnologies:

Nanotechnologies are worldwide regarded as key technologies for innovations and technological progress in almost all branches of economy. Nanotechnologies refer to the target-oriented technical utilization of objects and structures in a size in the range of 1 and 100 nm.

They are less seen as basic technologies in the classic sense with a clear and distinct definition, than they describe interdisciplinary and cross-sector research approaches, for example in electronics, optics, biotechnology or new materials, using effects and phenomena which are only found in the Nano cosmos.

Principle of Laser:

In material, atoms in excited state E2 can jump to lower energy state E1 by emitting photons of frequency

$$v = \frac{E_2 - E_1}{h}$$

The emitted photons are in all possible direction and are out of phase with each other, such type of emission is called *spontaneous emission*. If photon of frequency $v = \frac{E_2 - E_1}{h}$ incident on the atoms in excited state E_2 the atoms in state E_2 are

Compelled to come down to lower energy state E1 such an emission is called stimulated emission. Further in this case energy (E2 - E1) is added to the incident photon in phase. As light wave or photon are all in phase so reinforce or, amplify each other. Such a process of amplifying light wave by stimulating atoms or molecules to emit identical waves is known as light amplification by stimulated emission of radiation Z Laser.

Nanotechnologies describe the creation, analysis and application of structures, molecular Materials, inner interfaces and surfaces with at least one critical dimension or with manufacturing tolerances (typically) below 100 nanometres. The decisive factor is that new functionalities and properties resulting from the Nano scalability of system components are used for the improvement of existing products or the development of new products and application options.

Such new effects and possibilities are predominantly based on the ratio of surface-to-volume atoms and on the quantum-mechanical behaviour of the elements of the material.

Einstein Coefficients:

Let N1 and N2 represents the number in energy levels E1 and E2 respectively. Let density of radiation of particular frequency ν be represent by u (ν) then the absorption rate will be proportional to,

(i) The density of radiation u (ν)

(ii) The number of atoms N1

Thus, absorption rate = B12 N1 u (ν).
Where B12 is the coefficient of proportionality and is a characteristics of energy level.Let us now consider the reverse process namely the emission of radiation at a particular frequency v when the atom de-excites from level E2 to E1. Einstein pointed out that an atom in the excited level can make a transition to a lower energy level either through spontaneous or through stimulated process. In spontaneous emission, the rate will be independent of energy density of radiation field u (v) and depends only on the number of atoms present in the upper energy level.Rate of spontaneous transition = A21N2 Where A21 represents the probability of spontaneous transition.But rate of stimulated emission will depend not only upon number of atoms in upper energy level but also the energy density.Rate of stimulated transition = B21N2 u (v) Where B21 u (v), given probability of stimulated transition, in steady state.Rate of upward transition = Rate of downward transition using equation (I), (2) and (3) we get,

N1 B12 u (v) = N2 A21 + N2B21 U (V)
Or (N1 B12 – N2B21) U (V) = N2A21
U (V) = N2 A21/ N1B12 – N2 B21
U (V) = A21 / (N1/N2) B12- B21

It has been 25 years since the scanning tunnelling microscope (STM) was invented, followed four years later by the atomic force microscope, and that's when nanoscience and nanotechnology really started to take off. Various forms of scanning probe microscopes based on these discoveries are essential for many areas of today's research.

Scanning probe techniques have become the workhorse of nanoscience and nanotechnology research. Here is a Scanning Electron Microscope (SEM) image of a gold tip for Near-field Scanning Optical Microscopy (SNOM) obtained by Focussed Ion Beam (FIB) milling. The small tip at the centre of the structure measures some tens of nanometres.

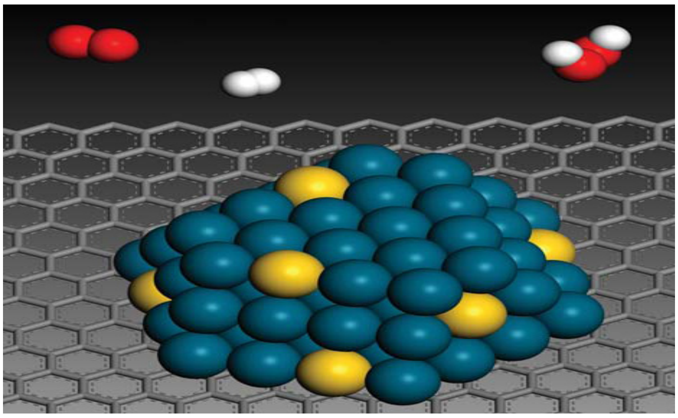

Figure 1: hydrogen peroxide

Nanoparticles of a gold-palladium (yellow-blue) alloy supported on acid-treated carbon (grey) directly catalysing hydrogen peroxide formation from hydrogen (white) and oxygen (red) while shutting off unwanted hydrogen peroxide decompositionCurrent applications of nanoscale materials include very thin coatings used, for example, in electronics and active surfaces (for example, self-cleaning windows). In most applications the nanoscale components will be fixed or embedded but in some, such as those used in cosmetics and in some pilot environmental remediation applications, free nanoparticles are used. The ability to machine materials to very high precision and accuracy (better than 100nm) is leading to considerable benefits in a wide range of industrial sectors, for example in the production of components for the information and communication technology, automotive and aerospace industries.

3.Nano effects as a Basis for Product Innovations:

In contrast to coarser-structured materials, nanomaterials dispose of drastically modified properties concerning physical, chemical and biological features. Physical material properties of a solid, such as electric conductivity, magnetism, fluorescence, hardness or strength change fundamentally in accordance to the number and arrangement of the interacting atoms, ions and molecules.

In contrast to macroscopic solids, electrons in a nanocluster can only adopt certain "quantised" energy states influenced by the number of interacting atoms.

This results in characteristic fluorescence properties which vary strongly with the size of the cluster.

A cadmium telluride particle of 2 nm, for example fluoresces green light, while a particle of 5 nm fluoresces red light.

Such quantum dots principally allow a significant enhancement of the quantum yield of solar cells and thus of their conversion efficiency. Even chemical material properties depend much on the arrangement and structuring of atoms and molecules.

Nano structuring usually achieves significantly higher chemical reactivity, since materials broken down to nanoscale substructures show a strongly increased ratio of reactive surface atoms to inert particles in a solid.

In a particle with a diameter of 20 nm, for example approx. 10 % of the atoms are on the surface, while in a particle of 1 nm the ratio of reactive surface atoms amounts to already 99 %.

In biology, nanomaterials play a decisive role, too, since nearly all biological processes are controlled by nanoscale structural components such as nucleic acid, proteins etc.

The structuring of complex bio-logical systems, like cells and organs, occurs according to the self-organization principle, where individual molecules are assembled to larger units on the basis of chemical interactions and molecular recognition mechanisms.

In the history of evolution, nature succeeded in realizing extremely complex reaction mechanisms, such as photosynthesis, due to the highly efficient interaction of such "molecular machines".

This is the basis for life on earth and also for today's energy supply, which is mainly based on the utilization of fossil energy supplies generated by photosynthesis during the history of earth.

3.1 Milestones in the development of nanotechnology:

In a lecture in 1959 to the American Physical Society, "There's Plenty of Room at the Bottom," American Noblest Richard P. Feynman presented his audience with a vision of what could be done with extreme miniaturization.

He began his lecture by noting that the Lord's Prayer had been written on the head of a pin and asked, why cannot we write the entire 24 volumes of the Encyclopædia Britannica on the head of a pin? Let's see what would be involved.

The head of a pin is a sixteenth of an inch across.If you magnify it by 25,000 diameters, the area of the head of the pin is then equal to the area of all the pages of the Encyclopædia Britannica.

Therefore, all it is necessary to do is to reduce in size all the writing in the Encyclopædia by 25,000 times. Is that possible? The resolving power of the eye is about 1/120 of an inch—that is roughly the diameter of one of the little dots on the fine half-tone reproductions in the Encyclopædia.

This, when you magnify it by 25,000 times, is still 80 angstroms in diameter—32 atoms across, in an ordinary metal. In other words, one of those dots still would contain in its area 1,000 atoms.

So, each dot can easily be adjusted in size as required by the photoengraving, and there is no question that there is enough room on the head of a pin to put all of the Encyclopædia Britannica.

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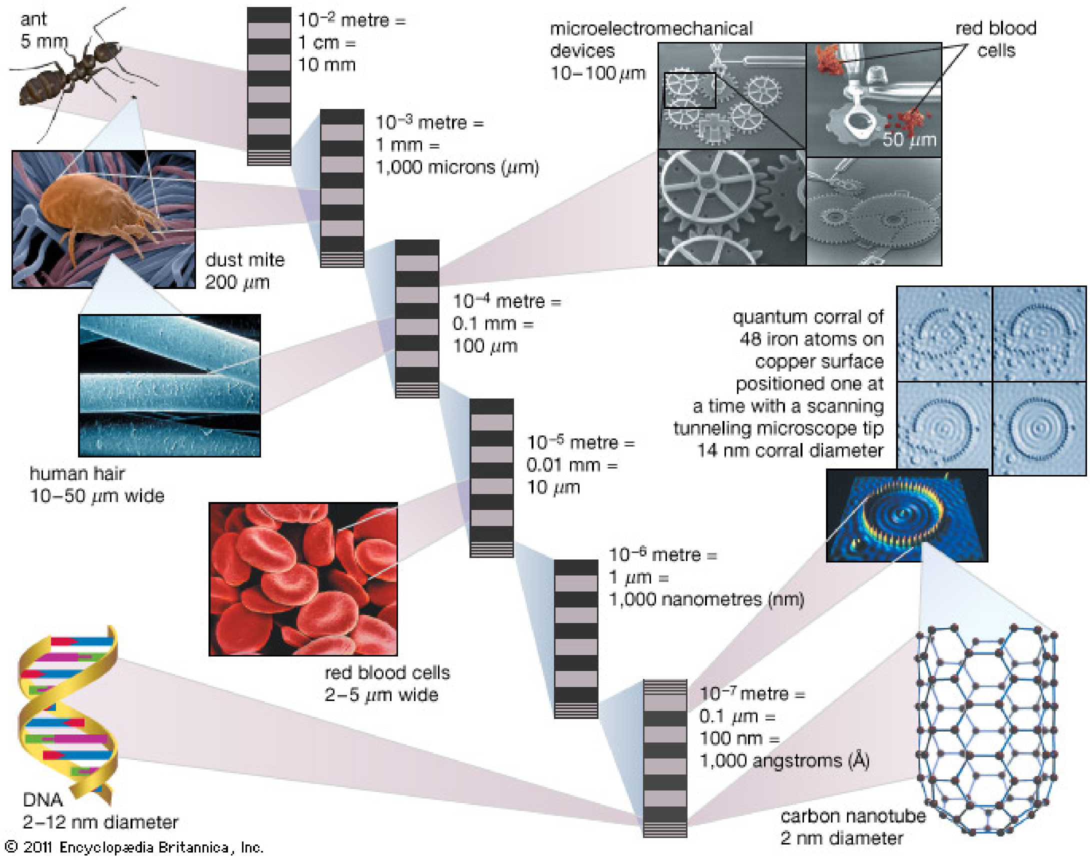

Figure 2: Carbon nanotube

Feynman was intrigued by biology and pointed out that cells are very tiny, but they are very active; they manufacture various substances; they walk around; they wiggle; and they do all kinds of marvellous things—all on a very small scale. Also, they store information. Perhaps the biggest barrier to following these prophetic thoughts was simply the immediate lack of tools to manipulate and visualize matter at such a small scale. The availability of tools has always been an enabling aspect of the advance of all science and technology, and some of the key tools for nanotechnology are discussed in the next section, Pioneers.

Starting with a 1981 paper in the Proceedings of the National Academy of Sciences and following with two popular books, Engines of Creation (1986) and Nano systems (1992), American scientist K. Eric Drexler became one of the foremost advocates of nanotechnology. Cells and tissues in the human body are built and maintained by molecular machinery, but sometimes that machinery proves inadequate: viruses multiply, cancer cells spread, or systems age and deteriorate.

As one might expect, new molecular machines and computers of subcellular size could support the body's own mechanisms. Devices containing Nano computers interfaced to molecular sensors and effectors could serve as an augmented immune system, searching out and destroying viruses and cancer cells. Similar devices programmed as repair machines could enter living cells to edit out viral DNA sequences and repair molecular damage. Such machines would bring surgical control to the molecular level, opening broad new horizons in medicine.

3.2.Properties at the nanoscale:

At nanoscale dimensions the properties of materials no longer depend solely on composition and structure in the usual sense. Nanomaterials display new phenomena associated with quantized effects and with the preponderance of surfaces and interfaces.Quantized effects arise in the nanometre regime because the overall dimensions of objects are comparable to the characteristic wavelength for fundamental excitations in materials.

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For example, electron wave functions (see also de Broglie wave) in semiconductors are typically on the order of 10 to 100 nanometres. Such excitations include the wavelength of electrons, photons, phonons, and magnums, to name a few. These excitations carry the quanta of energy through materials and thus determine the dynamics of their propagation and transformation from one form to another.

When the size of structures is comparable to the quanta themselves, it influences how these excitations move through and interact in the material. Small structures may limit flow, create wave interference effects, and otherwise bring into play quantum mechanical selection rules not apparent at larger dimensions.

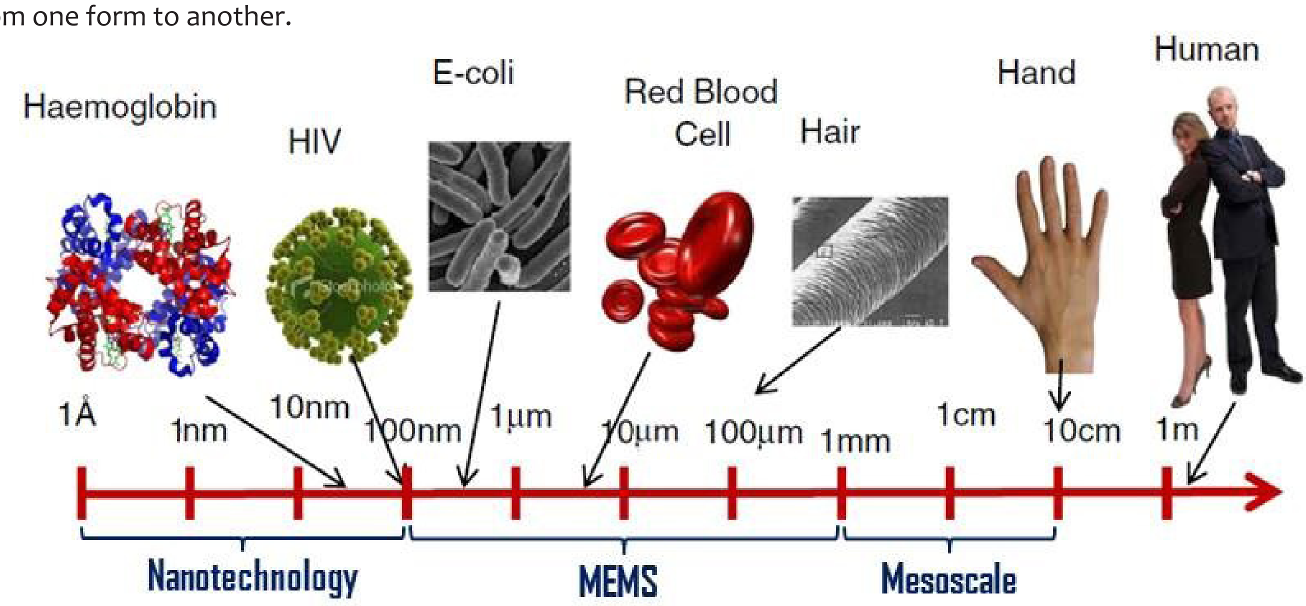

Figure 3: MEMS Devices for biomedical application

3.3 Energy Storage:

Energy stores are indispensable at different points of the supply chain from energy conversion to end user. What is mainly relevant is the storage of electric current as the most universal energy source, which is reversibly stored either as electric energy or in the form of other kinds of energy, like chemical energy (e.g. hydrogen storage) or mechanical energy (pressure accumulator and pumped storage). In addition to this, the storage of heat energy, above all for heat supply in buildings, plays an important role. Pumped Storage and Compressed-Air-Storage Usually, pumped storage hydro power stations are used to store large amounts of electric power in the grids. In case of excess power, water is pumped into a storage lake situated at a higher level, which can be discharged if required and the water can be used for power generation through turbines. Thus large amounts of energy can be stored with an efficiency of approx. 80 % and fed back to the grid in the form of electric current to cover short-term peak demands.

The increasing number of renewable energy sources with discontinuous, fluctuating power demand results in increasing requirements for power stores in the grid, which have previously mainly been used to profit from the price differences between off-peak and on-peak demand, and which were able to cover peak demand even without the extension of the maximum grid capacity. To compensate power fluctuations of wind and solar energy plants, pumped storages are suitable to only a limited extent, since they are usually too far away from the feeding sources (especially in case of wind energy) and further extension is ecologically critical due to high landscape consumption. Therefore, to meet the growing demand for efficient power stores, other kinds of storage, such as compressed-air stores are used, where air is pumped into subsurface chambers by means of electric compressors and, if required, electric current can be recovered using gas turbines. A disadvantage of this technology is the relatively low efficiency of currently approx. 55 %, which could be increased to approx. 70 % through the recovery of heat from air compression. Electrical energy stores like lithium-ion batteries are also considered as alternatives, especially for decentralized energy storage.

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Future applications with laser:

The carbon nanotubes also can be delivered to diseased cells by direct injection. "In breast cancer, for example, there might come a time when we inject nanotubes into the tumor and expose the breast to near-infrared light," he says. This benign therapy could potentially eliminate months of debilitating chemotherapy and radiation treatment, he adds."The laser we used is a 3-centimeter beam that's held like a flashlight," he notes. "We can take the beam and put anywhere we want. We can shine it on a local area of the skin or inside an internal organ using a fiber-optic device."Dai has applied for a patent on the procedure through Stanford's Office of Technology Licensing (OTL).

He also has patented another technique that's designed to deliver molecules of DNA, RNA or protein directly into the cell nucleus to fight various infections and diseases. That method uses pulses of near-infrared light to shake the therapeutic molecule loose from the nanotube after they have entered the cell. "Nanotechnology has long been known for its applications in electronics," Dai concludes. "But this experiment is a wonderful example of nanobiotechnology—using the unique properties of nanomaterials to advance biology and medicine."

4.Application Potentials of Nanotechnology: Lighting Engineering:

Nanotechnological applications in the field of lighting engineering first and foremost concern the development and use of energy efficient LED on the basis of inorganic and organic semiconductor materials. Due to the compact design, the variable color scheme and the high energy yield, the LED-technology has already tapped great market potentials in the illumination of displays, buildings and cars. The still poorly developed organic light-emitting diodes provide the potential for extensive lighting surfaces and screens on flexible substrates which allow the integration into many fields of interior equipment. Nanotechnological approaches arise, for instance, for the further optimization of LED through quantum dots which help improve energy efficiency and light yield. Furthermore, nanoscale light emitting particles contribute to the minimization of scattering effects of LED, and thus to the enhancement of the light yield.

The particles need to be coated in order to increase particle stability.The further development of OLED will also depend on nanotechnological innovations, which concern, inter alia, the optimization of the field carrier materials, succession and thickness of layers, application of dopants and the purity of the materials used (see practical example, Merck).

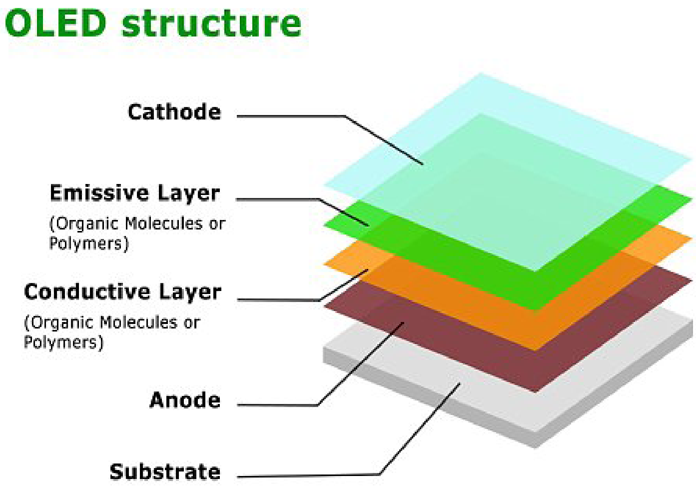

Figure 5: Organic light-emitting diodes (OLED)

4.1 Applications of Laser:

Scientists at Stanford University have developed a new laser therapy that destroys cancer cells but leaves healthy ones unharmed. The new, non-invasive treatment is described in a study published in the Aug. 1 online edition of the Proceedings of the National Academy of Sciences (PNAS).Laser have found The Nanophotonics Group deals with investigation on producing and characterizing optical components for plasmonics and metamaterials using nonlinear 2-D /3D laser lithography. The Nanolithography Group deals with the development of new lithography systems, for example two-photon-polymerization systems (2PP) for rapid prototyping of microstructured implants. The Biofabrication Group and the Laser Micromachining Group were formed, and the Nano-Materials Group was integrated into the department. The Biofabrication Group investigates two-photon-polymerization (2PP) applications and a laser-based cell printing process for biology and medical uses. 3-D support structures – so-called scaffolds – are directly generated using 2PP, or through reforming biocompatible or biological materials, and then populated with cells.

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For investigations on cell behavior, or for tissue generation, vital cells are arranged in two- or three-dimensional patterns using the printing technique. In the Laser Micromachining Group, ultra-short pulsed laser-based material processing is being developed, investigated and optimized for industrial applications. The goal is to advance fundamental and application-oriented laser material processing on the micro and nano levels. The Nano-Materials Group explores the generation of nanoparticles and nanomaterials using pulsed laser ablation in liquids. Using this method, nanoparticles can be made of almost any material, with high purity and high process reliability, since potentially harmful emissions are prevented by the liquid ablation medium.

Laser generated nanoparticles have many fields of application, especially in medicine and energy technology.wide applications in following fields:Structures generated with short pulse laser lithography can be used to realize photonic and plasmonic components and metamaterials. These structures can also be used for surface functionalization, micromechanics and microfluidics, for example for producing 3-D scaffolds from biological cell material, or for implants for biomedical technology.

(i) Material Processing: For mechanical and Metallurgical engineers, a knowledge of laser technology is of great use, laser can cut, drill, weld, remove metal from surfaces and perform their operations even at surface in accessible by mechanical methods.

(ii) Communication: Laser play the essential role in using thin strands of glass fibres to transmit light signal that can be received and translated in to communication format. With the help of laser beam, the distance between the earth and moon has been measured within accuracy of an inch. Laser can be used in computers to transmit an entire memory bank from one computer to another.

(iii) Medicine: Surgeons use laser to burnup brain tumours and remove tattoos. Blood vessels are reconnected by laser welding. He-Ne laser is used to stimulate nerves in the wrist and ankles for treatment of paralysis. Eye surgeons use laser to perform operation of common eye diseases e.g., glaucoma, cataract and diabetic retinopathy. Laser acupuncture is becoming popular for some disorders and relief pain.

(iv) Applications in physics and chemistry: Laser has initiated quite new fields of investigation in physics. An interesting example is of non-linear optics with special mansion of harmonic generation and stimulated scattering. In the field of chemistry, laser used for both for diagnostic purposes and for producing invertible chemical change i.e., laser photochemistry. In diagnostic techniques particularly resonant Raman scattering and coherent antismoke, Raman scattering gave considerable information on the structure and property of poly atomic molecules. The most interesting chemical application for laser is in the field of photochemistry.

(v) Military Applications: Due to great quality of energy which the laser can concentrate, it has been mentioned as potential 'death day' type of incendiary weapon for use against energy missiles much research has been done in the field of laser weaponry e.g., development of higher energy output devices at great efficiency and active destructive effects of laser beam.

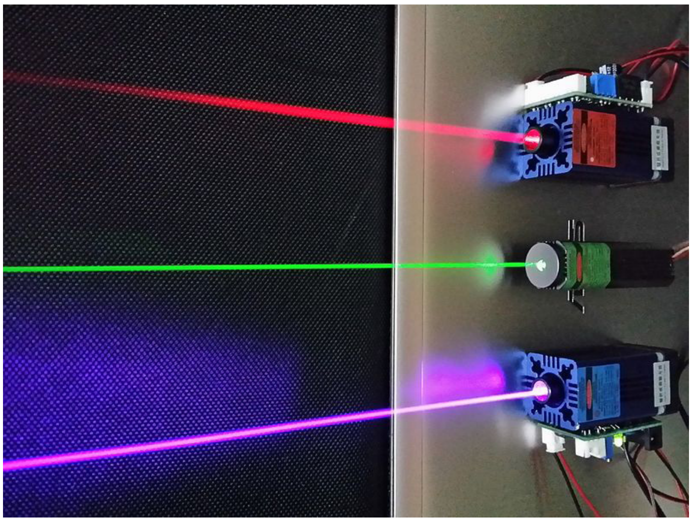

Figure 4: Laser modules.

Continuous lasers with narrow radiation line and possibility to detune the output wavelength are used for spectroscopy of nano-objects (Raman scattering, light absorption in a wide spectral range), structural characterisation of semiconductor structures, for studies of photo-dynamic action of inorganic semiconductor nano-particles, for investigation into mechanisms of bio-synthesis of inorganic semiconductors, for research to create new types of optical devices for reading and writing data, as well as in many other problems within the industry of nano-systems and materials

Lasers with ultra-fast light pulses (femtosecond, picosecond) are applied in studies of ultra-fast physico-chemical processes in nano-objects, in research related to plasmonics and meta-materials, optical trapping of nano-particles and their manipulation (laser "tweezers"), for generation of terahertz radiation from interaction of light with semiconducting or metallic nanostructures, in micro- and nano-processing of materials, and in modification of substances under action of laser radiation.

With the explosive development of research in this field new promising nano-technological applications of femto- and pico-second lasers constantly emerge. It is possible to draw many interesting examples, such as nano-surgery-laser operations on individual living cells (micro-injections into separate cells through holes in the cellular membrane made with the help of a femtosecond laser operating in near IR range), rapid virus detection by Raman response amplified by introduced silver nano-rods.

5.Conclusion:

In view of a globally increasing energy demand, threatening climatic changes due to continuously increasing carbon dioxide emissions, as well as the foreseeable scarcity of fossil fuels, the development and provision of sustainable methods for power generation belong to the most urgent challenges of mankind. Massive effort at political and economic level is required to basically modernize the existing energy system. Growing efficiency and new methods through Nano technological know-how may play a key role for the required innovation in the energy sector. Nanotechnological components provide potentials for the more efficient utilization of energy reserves and the more economical development of renewables.

This brochure provides a number of examples for possible applications and developments in which Hessian enterprises and research facilities are actively involved. When implementing Nano technological innovations in the energy sector, the macroeconomic and social context must not be lost sight of. The design of a future energy system requires long-term investments in research activities based on realistic potential assessments and the careful adaptation of the individual supply chain components.

In case of renewable energy production by wind or solar energy, for example, it has to be considered that power generation occurs discontinuously and energy stores have to be provided as buffers to balance the fluctuating demand. When replacing fossil fuels, not only their function as energy source, but also as energy store has to be taken into account, for instance in the automotive sector. Here, alternatives must be found for the long-term storage of energy and its availability at short notice and in an efficient infrastructure.

The move into hydrogen economy and the increased utilization of biofuels are discussed as solutions for the future, which, however, require considerable investments and technological leaps, inter alia on the basis of nanotechnologies. Further challenges of the energy sector are the optimization and integration of mobile energy supply systems for the operation of wireless electronic devices, tools and sensors, which have become a key factor in modern industrial society.

To enable the immediate practical implementation of Nano technological innovations in such a broad field like the energy sector, an interbank and interdisciplinary dialog with all players involved will be required. This brochure wants to contribute to building a bridge and providing generally understandable information for coordinated and target oriented acting in politics, economy and society.

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