Application of LASERs in Material Science and Engineering

LASER welding, LASER cutting, LASER cladding, LASER peening, LASER Surface Chemistry, Purification of Materials and LASER Induced Polymerization

LASER welding

- Laser beam welding is a technique in manufacturing whereby two or more pieces of material (usually metal) are joined together by the use of a laser beam.
- The weld is formed as the intense laser light rapidly heats the material – typically calculated in Milli-seconds.
- The primary types of lasers used in welding and cutting are:
  Gas LASERs, Solid state LASERs and Diode LASERs
- Lasers are used for materials that are difficult to weld using other methods, for hard to access areas and for extremely small components.
- In laser welding the absorption of energy by a material is affected by many factors such as the type of laser, the incident power density and the base metal's surface condition.

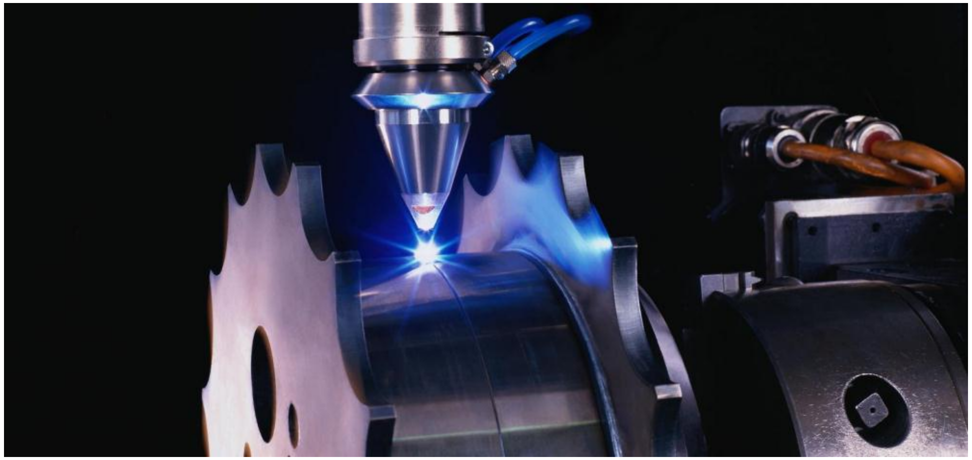
- Laser output is not electrical in nature and does not require a flow of electrical current. This eliminates any effect of magnetism, and does not limit the process to electrically conductive materials.

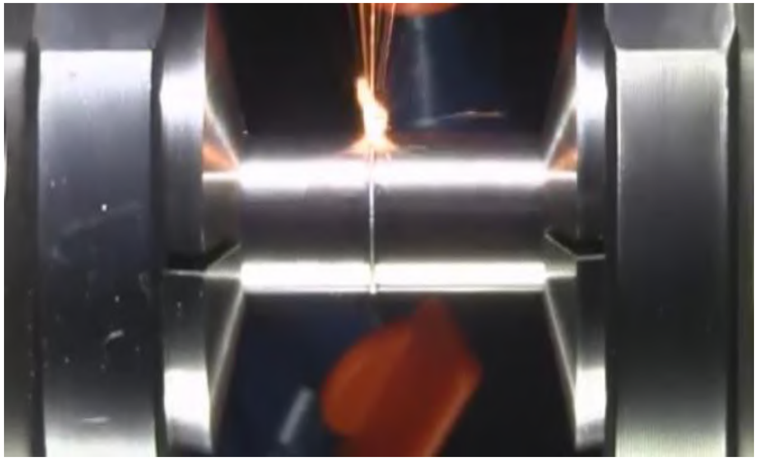
- Lasers can interact with any material. It doesn't require a vacuum and it does not produce x-rays.

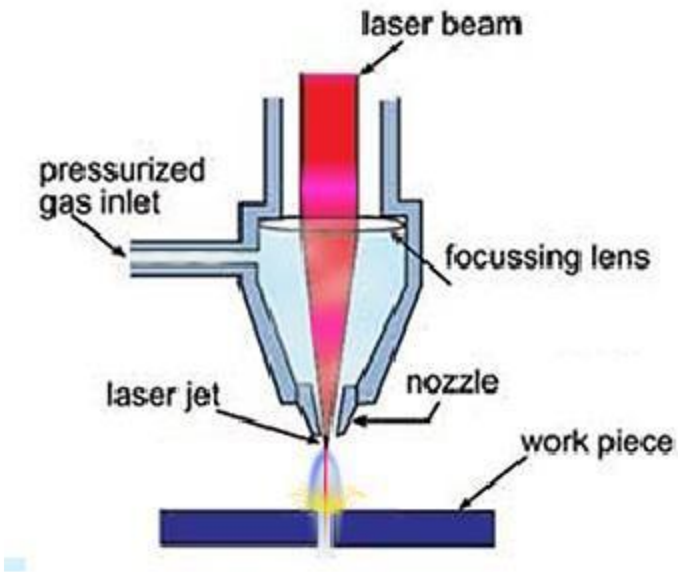
- Laser output is not electrical in nature and does not require a flow of electrical current. This eliminates any effect of magnetism, and does not limit the process to electrically conductive materials.

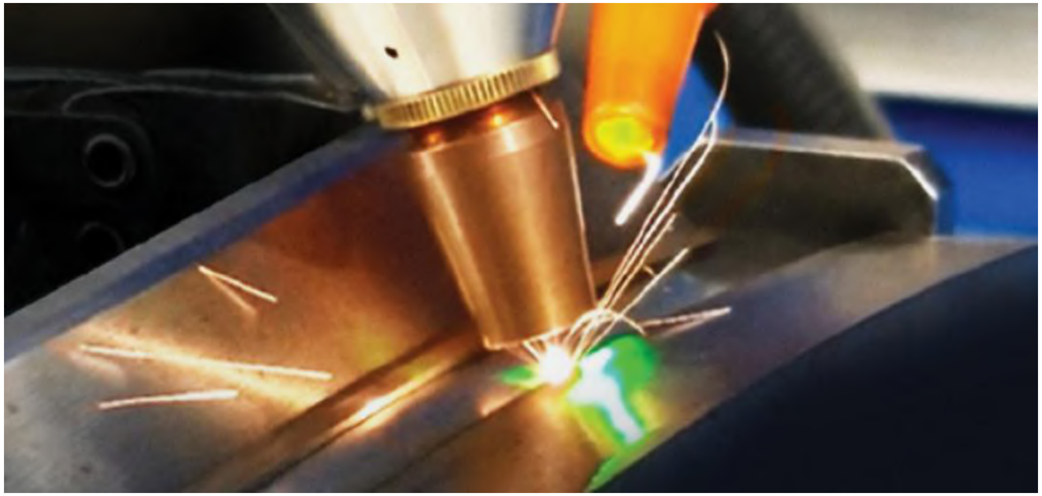
- The laser beam has been used to weld carbon steels, high strength low alloy steels, aluminium, stainless steel, titanium etc.

- Limitations are - Rapid cooling rate may cause cracking in some metals
  High capital cost for equipment
  Optical surfaces of the laser are easily damaged
  High maintenance costs






laser beam
pressurized gas inlet
focussing lens
laser jet
nozzle
work piece



LASER Cutting

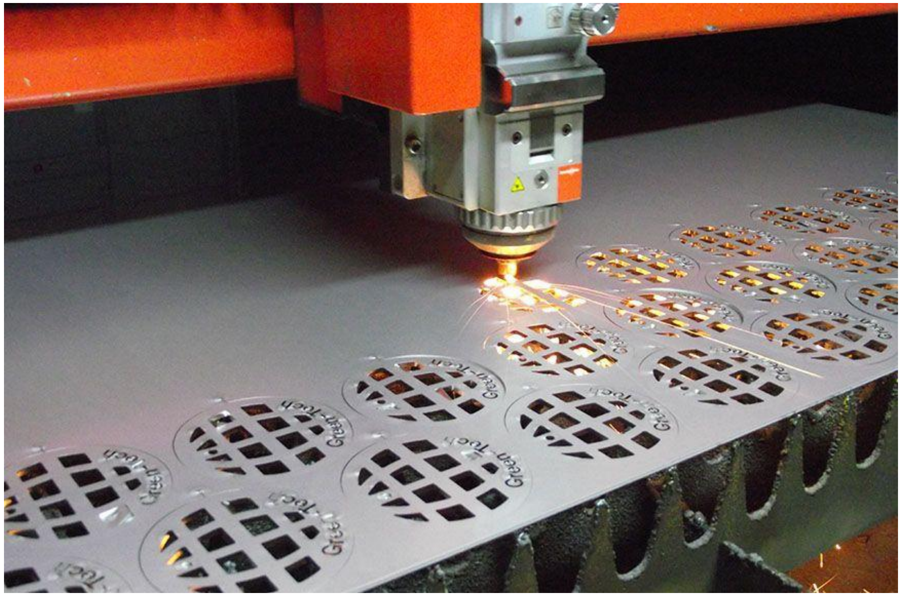
- Laser cutting works by directing the output of a high-power laser most commonly through optics.

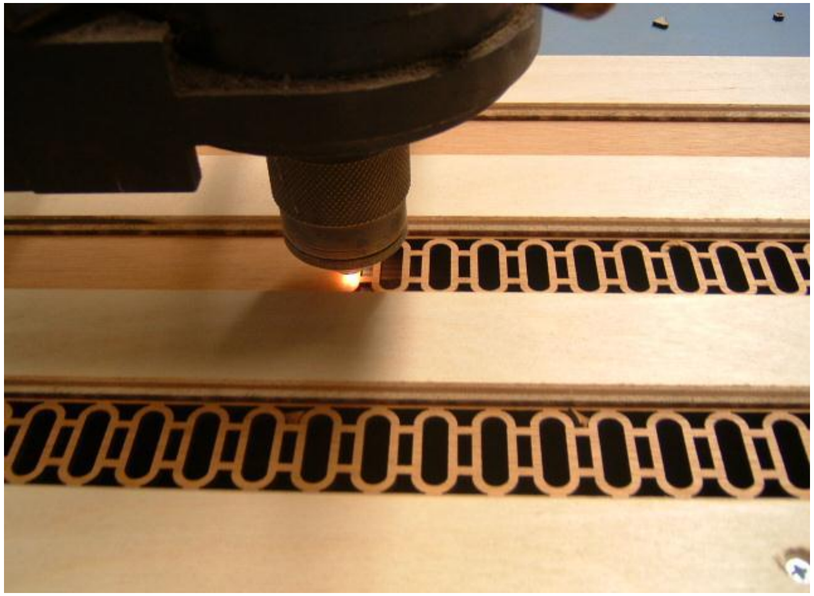
- The laser optics and CNC (computer numerical control) are used to direct the material or the laser beam generated.

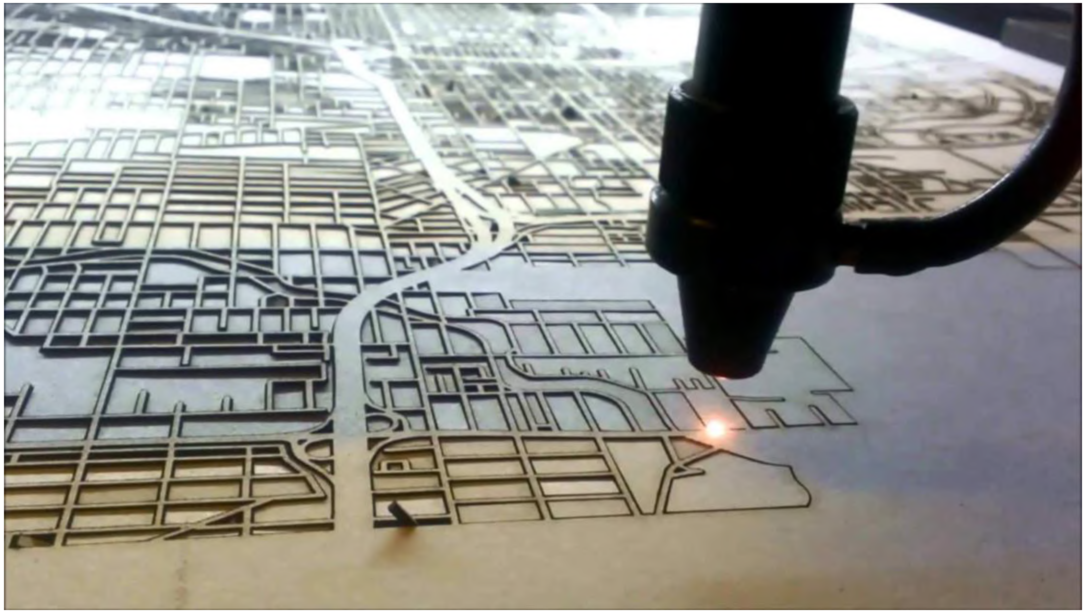
- The focused laser beam is directed at the material, which then either melts, burns, vaporizes away, or is blown away by a jet of gas, leaving an edge with a high-quality surface finish. Industrial laser cutters are used to cut flat-sheet material as well as structural and piping materials.

- Piercing usually involves a high-power pulsed laser beam which slowly makes a hole in the material, taking around 5–15 seconds for 0.5-inch-thick (13 mm) stainless steel, for example.

Laser : Fundamentals and Applications







There are three main types of lasers used in laser cutting.

- ❑ The CO_2 laser is suited for cutting, boring, and engraving.
- ❑ Nd laser is used for boring and where high energy but low repetition are required.
- ❑ The Nd-YAG laser is used where very high power is needed and for boring and engraving.

Advantages of laser cutting over mechanical cutting

- ❖ Easier work holding
- ❖ reduced contamination of work piece.
- ❖ Precision may be better, since the laser beam does not wear during the process.
- ❖ There is also a reduced chance of warping the material that is being cut, as laser systems have a small heat – affected zone.
- ❖ Some materials are also very difficult or impossible to cut by more traditional means.

Additionally,

Laser cutting for metals has the advantages over plasma cutting of being more precise and using less energy when cutting sheet metal; however, most industrial lasers cannot cut through the greater metal thickness that plasma can.

LASER Cladding

Laser Cladding or Laser Deposition is a processing technique used for adding one material to the surface of another in a controlled manner.

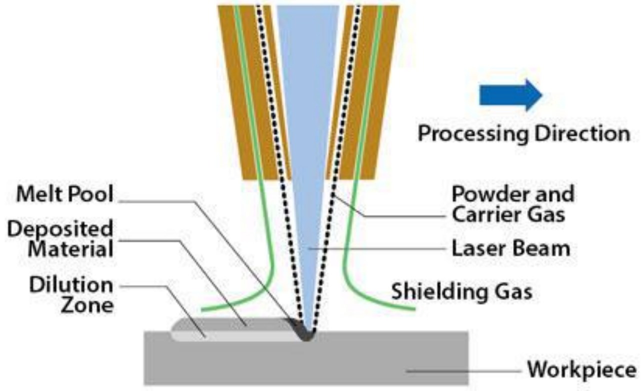
A stream of a desired powder is fed into a focused laser beam as it is scanned across the target surface, leaving behind a deposited coating of the chosen material.

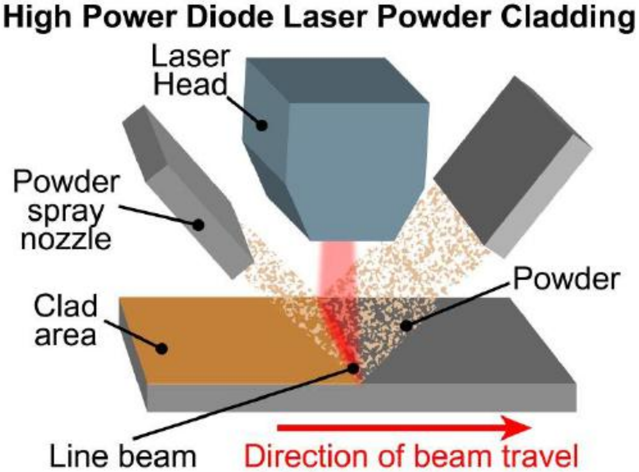
Advantages

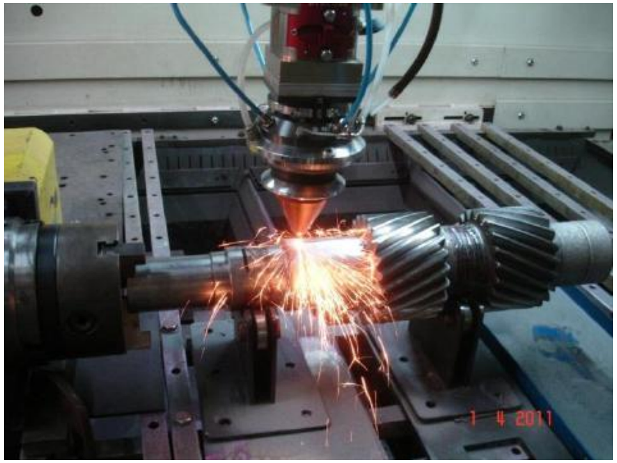
- This enables the applied material to be deposited selectively just where it is required.
- Additional material can be placed precisely where desired.
- A very wide choice of different materials can be both deposited and deposited onto.
- Deposits are fully fused to the substrate with little or no porosity.
- Minimal heat input results in narrow HAZ (heat affected zone).

- Minimal heat input also results in limited distortion of the substrate and reduces the need for additional corrective machining.

- Easy to automate and integrate into CAD/CAM and CNC production environments.







LASER Peening

Laser peening (LP), or laser shock peening (LSP), is a surface engineering process used to impart beneficial residual stresses in materials.

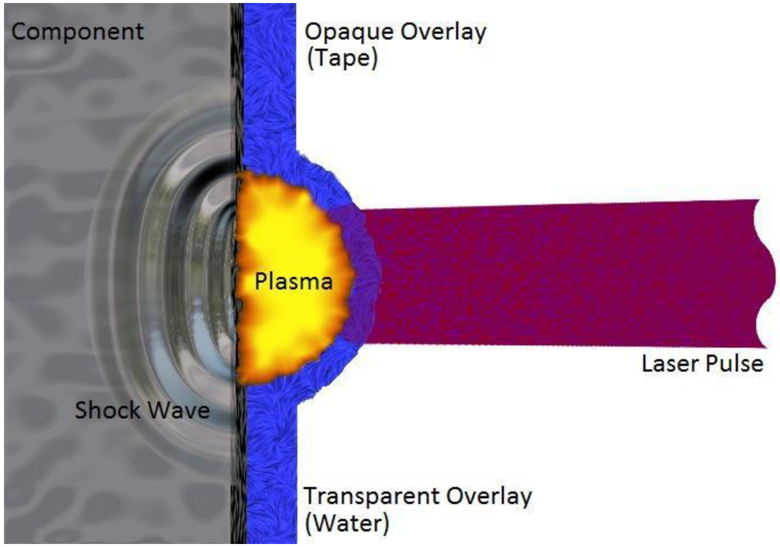
The deep, high magnitude compressive residual stresses induced by laser peening increase the resistance of materials to surface-related failures, such as fatigue, fretting fatigue and stress corrosion cracking.

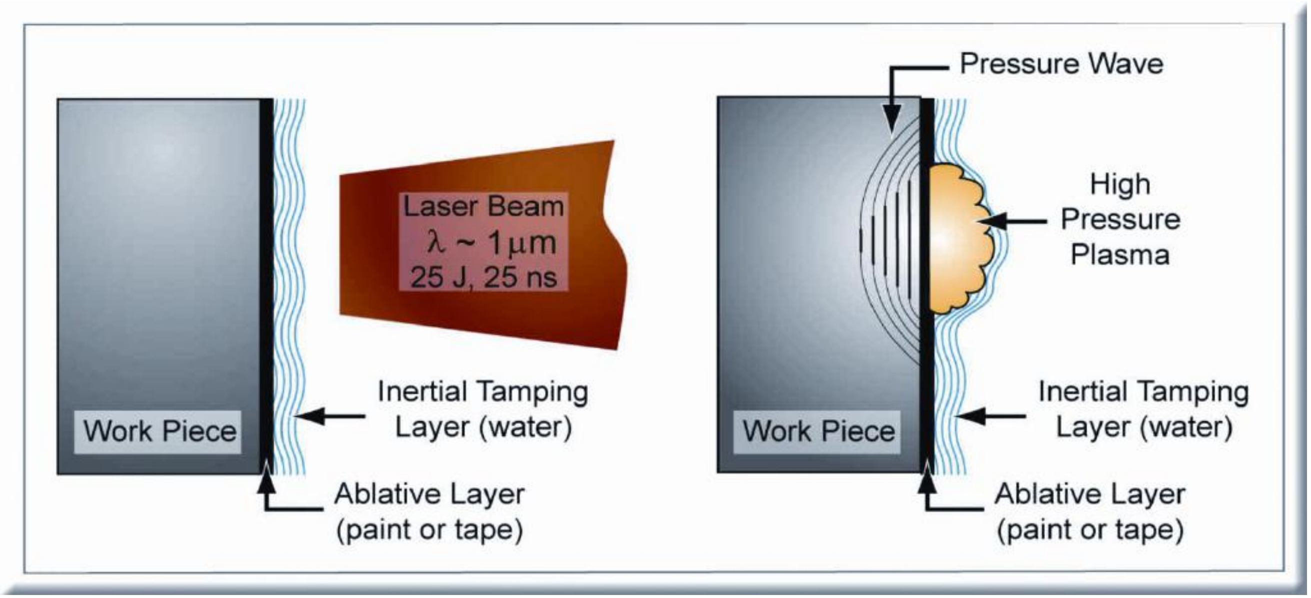
Advantages

- This enables the applied material to be deposited selectively just where it is required.
- Fundamentally, laser peening can be accomplished with only two components: a transparent overlay and a high energy, pulsed laser system.
- A very wide choice of different materials can be both deposited and deposited onto.
- The transparent overlay confines the plasma formed at the target surface by the laser beam. It is also often beneficial to use a thin overlay, opaque to the laser beam, between the water overlay and the target surface.

- This opaque overlay can provide either one or each of three benefits:
  - protect the target surface from potentially detrimental thermal effects from the laser beam,
  - provide a consistent surface for the laser beam-material interaction and,
  - if the overlay impedance is less than that of the target surface, increase the magnitude of the shock wave entering the target

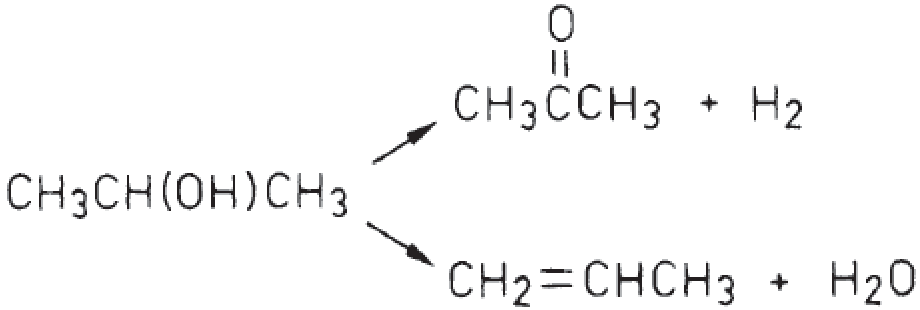
- Laser pulses are generally applied sequentially on the target to treat areas larger than the laser spot size. Laser beam shapes are customizable to circular, elliptical, square, and other profiles to provide the most convenient and efficient processing conditions. The spot size applied depends on a number of factors that include material, laser system characteristics and other processing factors.

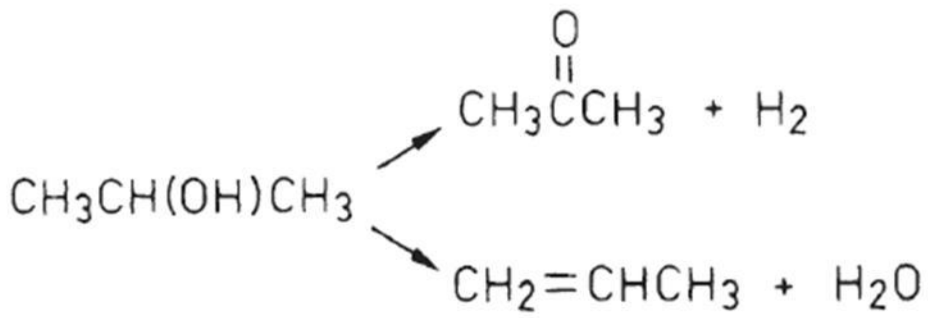

Component
Opaque Overlay
(Tape)
Plasma
Laser Pulse
Shock Wave
Transparent Overlay
(Water)


Laser Beam
λ ~ 1 μm
25 J, 25 ns
Inertial Tamping
Layer (water)
Work Piece
Ablative Layer
(paint or tape)
Pressure Wave
High
Pressure
Plasma
Inertial Tamping
Layer (water)
Work Piece
Ablative Layer
(paint or tape)

Laser Surface Engineering

- Many of the most important topics in this field concern the treatment of semiconductor surfaces and therein hold enormous potential for application in the manufacture of microelectronic devices.
- It is worth noting that excimer lasers in particular produce emission in a very useful wavelength range, where photon energies are sufficient to break chemical bonds in a variety of compounds involving the Group IV elements.
- For example, in the dissociation of propan-2-ol over CuO using 1070.5 cm^{-1} radiation from a CO_2 laser , there are two competing reaction pathways leading to different products





- The product ratio : propanone/propene can be varied from 0.02 to 6, depending on the orientation of the catalytic surface relative to the laser beam.

- Many laser-induced surface engineering involves the principle of depositing a thin film covering onto a substrate surface by decomposition of a gas. This method is known the laser field as *laser chemical vapour deposition.*

- The mask-free writing of an adsorbate onto semi-conductor surfaces by laser deposition provides a classic illustration of an application facilitated by the distinctive properties of laser light.

- The principle involved in the process of deposition may be either pyrolytic or photolytic by nature.

  For both types of deposition, laser irradiances are typically of the order 10^{12} W m^{-2}, and the partial vapour pressure of the vapour in the range 10^{-3}-1 atm.

  Under these conditions, rates of deposition with a scanning laser beam are typically between 0.1 and 100 μm S^{-1}.

Pyrolytic deposition involves thermal reaction and is, in general, an indirect result of the surface heating produced by the laser radiation.

- For example, amorphous films of silicon can be pyrolytically deposited from SiH_4 vapour onto quartz or various other surfaces irradiated by 10.59 μm radiation from a carbon dioxide laser.

Photolytic deposition *(photodeposition),* by contrast, results directly from the absorption of laser light by molecules of the vapour.

Example : possibility of laying down an InP layer by co-deposition of indium and phosphorus from a mixture of $(CH_3)_3InP(CH_3)_3$ and $P(CH_3)_3$

In this case, using 193 nm radiation from an ArF excimer laser, the photodecomposition reactions are:

$$(\mathrm{CH_3})_3\mathrm{InP}(\mathrm{CH_3})_3 + 2h\nu \rightarrow \mathrm{In}^* + 3\mathrm{CH_3} + \mathrm{P}(\mathrm{CH_3})_3$$

$$\mathrm{P}(\mathrm{CH_3})_3 + 3h\nu \rightarrow \mathrm{P}^* + 3\mathrm{CH_3}$$

Purification of Materials

- The underlying principle is the specific excitation of a single chemical component in a mixture, in this case usually the impurity.

- The removal of contaminants from silane, SiH_4 can be done by using an ArF laser operating at 193 nm, it has been shown that impurities of arsine AsH_3 , phosphine PH_3 , and diborane B_2H_6 can all be photolysed and so removed from silane gas very effectively.

- Another example based on the argon fluoride laser is the removal of H_2S from synthesis gas. This is particularly significant since H_2S readily poisons the catalysts used for hydrocarbon synthesis.

- The removal from BCl_3 of carbonyl chloride, $COCl_2$, which is often a fairly troublesome contaminant, can be done by using the CO_2 laser.

Laser-Initiated Polymerisation

- It is primarily pulsed UV radiation that is employed to produce radicals for the process initiation.

- It generally proves that there are substantial differences in the character of polymers obtained with laser radiation, compared to those produced with radiation of the same wavelength and total energy from other sources.

- One reason is that the high intensities associated with laser radiation can, by increasing the transient concentrations of radical intermediates, substantially increase the extent to which sequential absorption processes enter into the reaction. A second reason is more directly connected with the pulsed nature of the radiation.

- The mean chain length in the laser-produced polymer is then directly proportional to the 'dark time' between pulses. So, the product is characterised by a molecular weight distribution more directly amenable to control and generally quite different from the polymer produced using conventional photo initiation.

Lasers in communications

- Laser communications systems are wireless connections through the atmosphere.
- Use Laser Beams to transmit information between two locations
- No fibers need, a wireless technology
- Communication over long distances, e.g. between planets
- Laser Communication Terminals (LCTs) transmit a laser beam and are capable of receiving laser beams.

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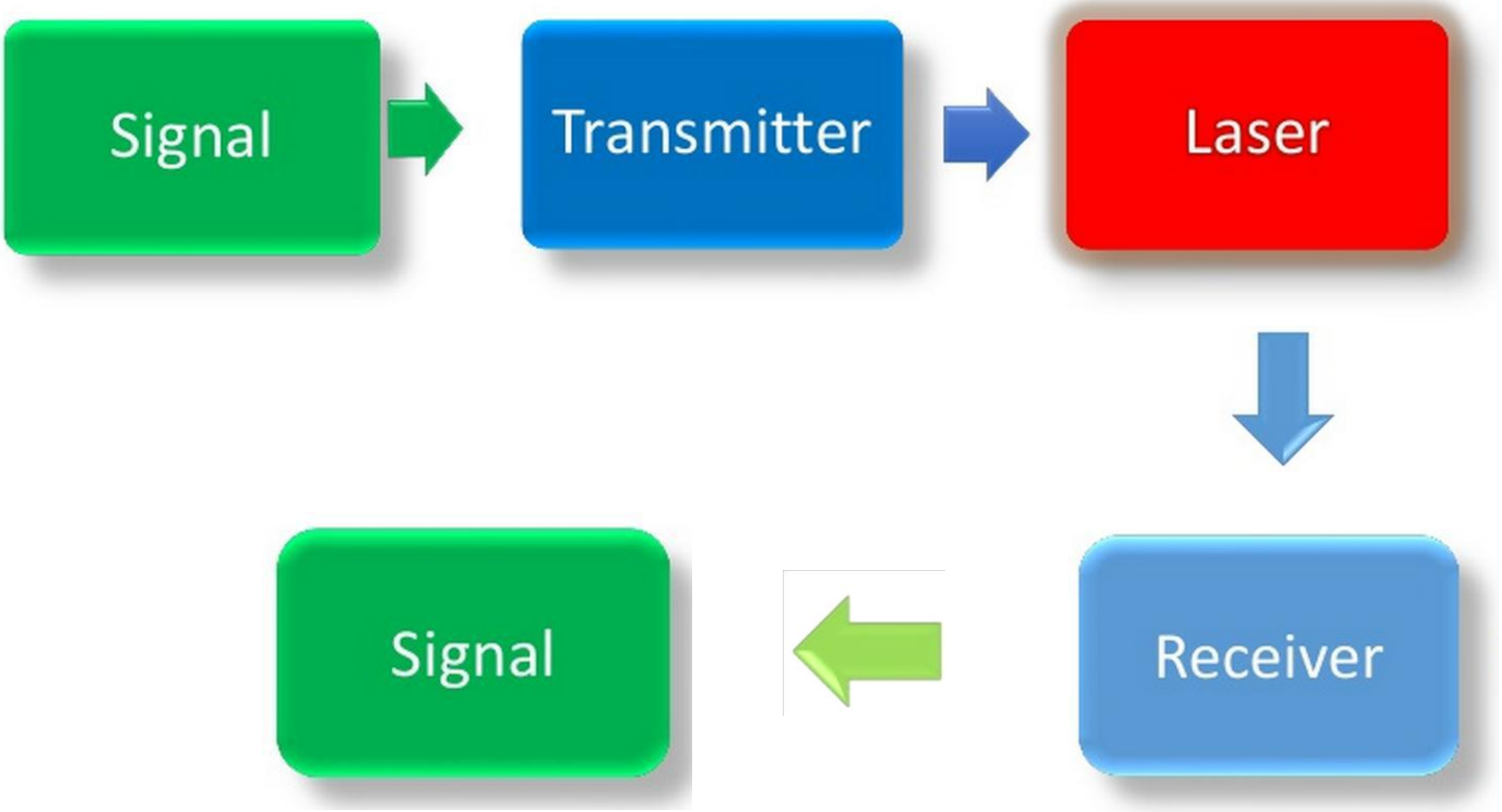
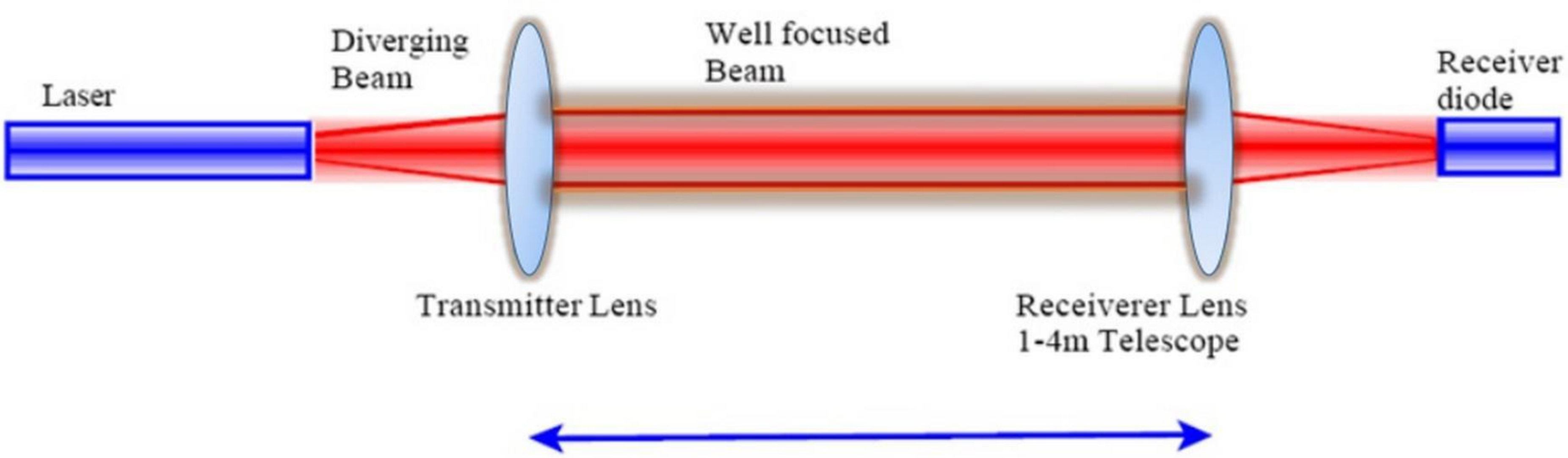
How does it Work ?



One-way Laser communication system



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Laser Transmitter

- The Transmitter involves a signal processing circuit, and a laser.

- A laser diode is used to create the laser signal.

Receiver

The receiver involves:

- Telescope('antenna')
- Signal processor
- Detector
  - PIN diodes
  - Avalanche Photo Diodes(APD)
  - Single or multiple detectors

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Why not Fiber Optics?

- Not always possible to lay fiber lines
  - Satellites
  - Combat zones
  - Physically / Economically not practical
  - Emergencies

- Laser Communication being incorporated into fiber optic networks when fiber is not practical.

Why not RF?

- **Bandwidth**
  - for Laser Communication (LC) is 100 times greater than for RF.
- **Power**
  - in LC is directed at target, so much less transmission power required.
  - Also the power loss is less.
- **Size / Weight**
  - LC antenna is much smaller than RF.
- **Security**
  - Due to low divergence of laser beam, LC is more secure than RF.

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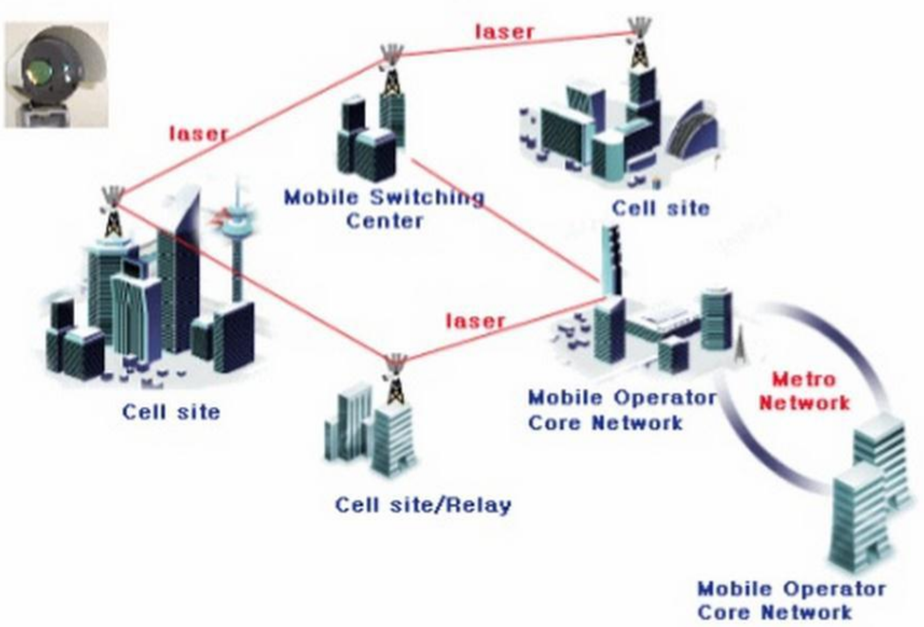
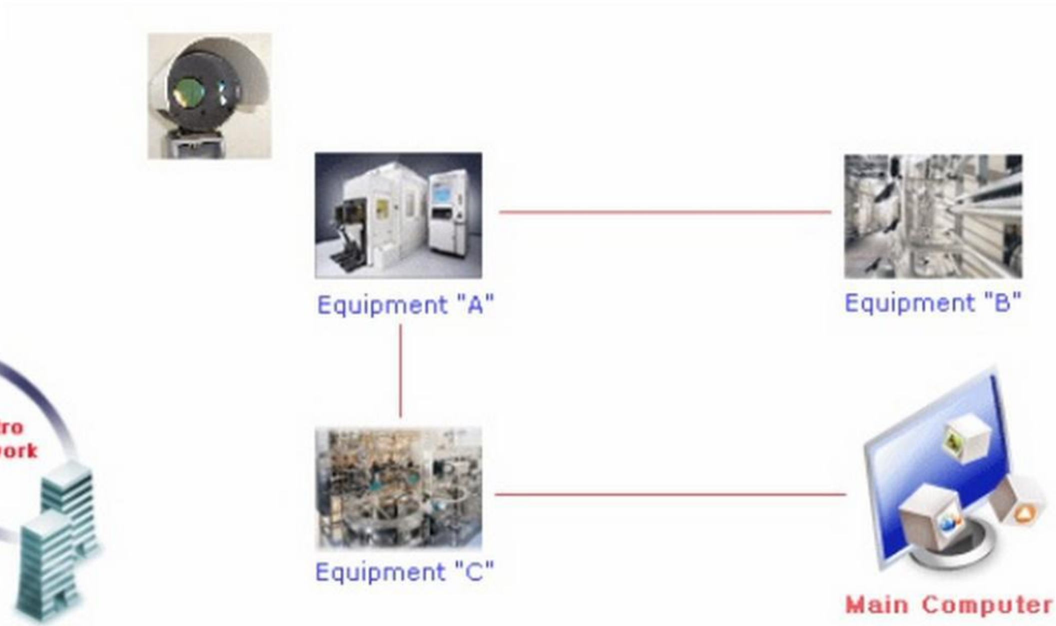
Applications

ISP (Internet Service Provider)



Industrial Use



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Applications

- Defense and sensitive areas.
- At airports for communication across the runways.
- Mass communication
- Free-space optical communication
- Space probe are being designed to use optical rather than radio communication.
- Laser communication has also been demonstrated on aircraft and high altitude platforms.

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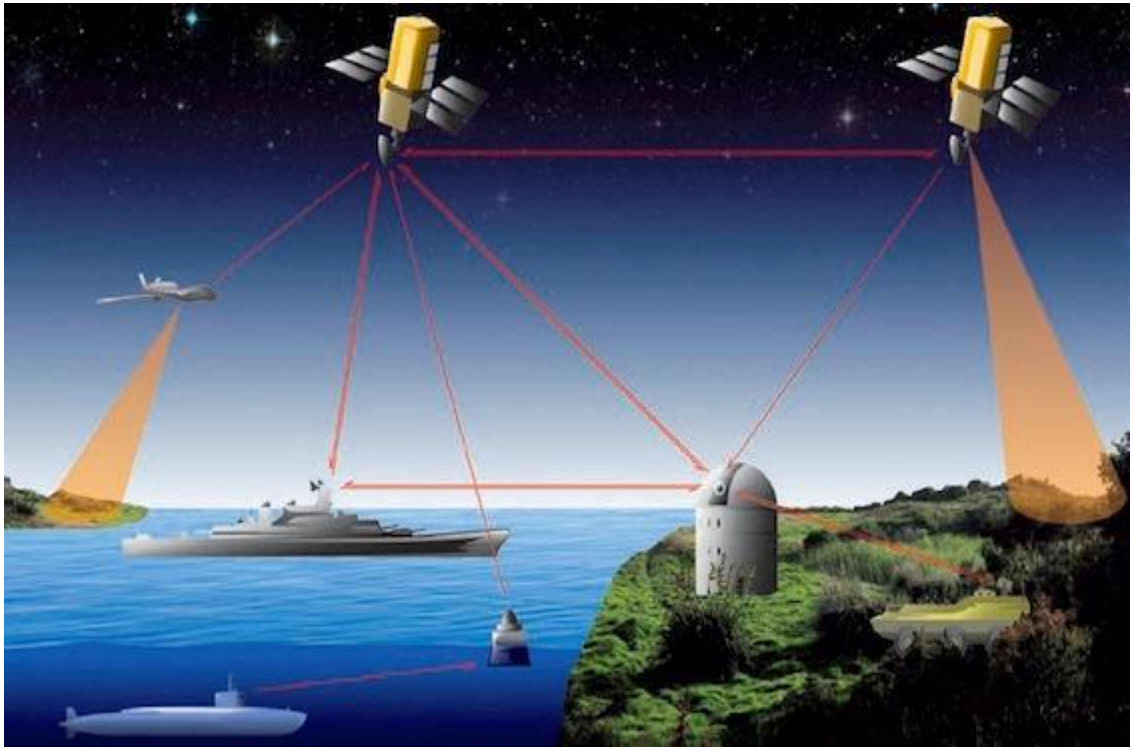

Security Aspects

- Free space laser communications systems have narrow optical beam paths, which are not accessible unless viewing directly into the transmitter path.
- Any potential eavesdropping will result in an interruption of the data transmission.
- The existence of laser beams cannot be detected with spectrum analyzers.

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Advantages

- Ease of deployment
- Can be used to power devices
- License-free long-range operation (in contrast with radio communication)
- High bit rates
- Low bit error rates
- Immunity to electromagnetic interference
- Full duplex operation
- Protocol transparency
- Increased security when working with narrow beam(s)[citation needed]
- No Fresnel zone necessary

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Disadvantages

- For terrestrial applications, the principal limiting factors are:
- Beam dispersion
- Atmospheric absorption
- Rain
- Fog (10..~100 dB/km attenuation)
- Snow
- Scintillation
- Interference from background light sources (including the Sun)
- Shadowing
- Pointing stability in wind
- Pollution / smog

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