LASER PRINCIPLES AND PRINCIPLES OF LASER INDUCED BREAKDOWEN SPCTROSCOPY (LIBS)

BY
Dr. Tarek Atwee

QUESTIONS

1. what is laser?
2. What is laser wavelength?
3. What is a laser diod?
4. What is a gas laser?

INTRODUCTION

LASER is an acronym for **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation which describes the theory of laser operation. Albert Einstein published the theoretical basis for the laser in 1917, but it was only in 1960 that the first functioning laser was constructed by Theodore Maiman in California, using a ruby crystal to produce laser light. An extract from the newspaper article following a public demonstration of the laser, read:
"*Suddenly a light from hell appeared in the middle of the ruby. Then, from the end of a cylinder, a hundred thousand times brighter than the sun, burst forth a thin red light, a perfectly parallel monochromatic beam.*
Maiman and his assistants were silent for some time, enthralled by the beauty of this spectacle… 'Einstein was right' he murmured, 'light can be concentrated and coherent."

The device produces a beam of coherent light with a specific wavelength in the infrared, visible or ultraviolet regions of the electromagnetic spectrum. Further development of this technology led to lasers becoming widely used in medical practice.

LASER PHYSICS

Properties of laser light

Unlike other forms of light, laser light has special properties which make it significantly more effective and dangerous than conventional light of the same power. The laser light particles (photons) are usually:

Monochromatic: consisting of a single wavelength or colour

Coherent: photons are in phase (like marching soldiers)

Collimated: photons are almost in parallel (aligned), with little divergence from the point of origin

Components of a laser

A laser consists of 3 basic components:

1. A lasing medium or "gain medium":

May be a solid (crystals, glasses), liquid (dyes or organic solvents), gas (helium, CO_2) or semiconductors

2. An energy source or "pump":

May be a high voltage discharge, a chemical reaction, diode, flash lamp or another laser

3. An optical resonator or "optical cavity":

Consists of a cavity containing the lasing medium, with 2 parallel mirrors on either side. One mirror is highly reflective and the other mirror is partially reflective, allowing some of the light to leave the cavity to produce the laser's output beam – this is called the output coupler.

The laser is usually named according to the type of lasing medium. This also determines the type of pump required and the wavelength of the laser light which is produced.

Principle of operation at atomic level (Figures 2 and 3)

One model in atomic physics describes an atom as a central nucleus of protons and neutrons, surrounded by a cloud of electrons which encircle the nucleus in different orbitals. When appropriate energy is supplied to the atom, electrons can jump from low-energy orbitals (ground state) near the nucleus to high-energy orbitals further away, leading to atomic excitation by the process of energy **absorption**.

Some of the electrons in the high-energy orbit spontaneously return to the ground state, releasing the difference in energy in the form of a photon, with a wavelength which depends exactly upon the difference in energy of the 2 states and has a random phase and direction. This process is called **spontaneous emission** and forms the basis of light emitted by a neon sign, fluorescent light bulb and television tube. This emitted photon can collide with one of the mirrors in the resonating cavity and reflect back into the lasing medium causing further collision with some of the already excited atoms. If an excited atom is struck, it can be stimulated to decay back to the ground state, releasing 2 photons identical in direction, phase, polarization and energy (wavelength). This process is termed **stimulated emission**.

A cascade effect of stimulated emission of photons occurs, resulting in further amplification (optical gain) and soon many of the atoms emit light along the same axis. For a laser to sustain function, the majority of the atoms must be maintained in the excited state, hence called "**population inversion**". This is achieved by the continuous input from the energy pump (continuous wave laser) or by intermittent pumping resulting in a pulsed wave laser.

A small number of photons are allowed to escape from the lasing medium though the partially reflective mirror of the output coupler. This is the usable laser light and may be in the visible spectrum or beyond (infrared or ultraviolet). It is directed to the target via a **delivery system** which consists of fibre-optic light guides for visible light or a series of mirrors for infrared.

PRINCIPLES OF LASER ACTION

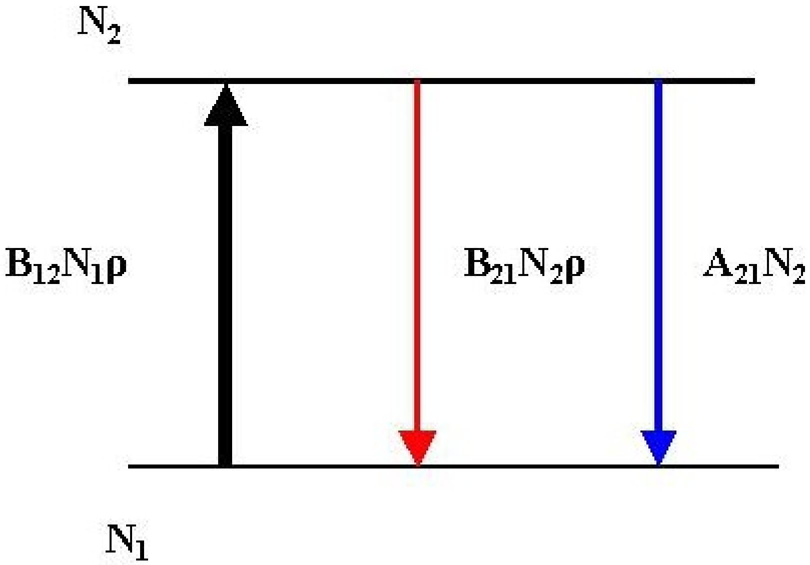


Fig 1: ***Spontaneous and stimulated processes in a two-level system***

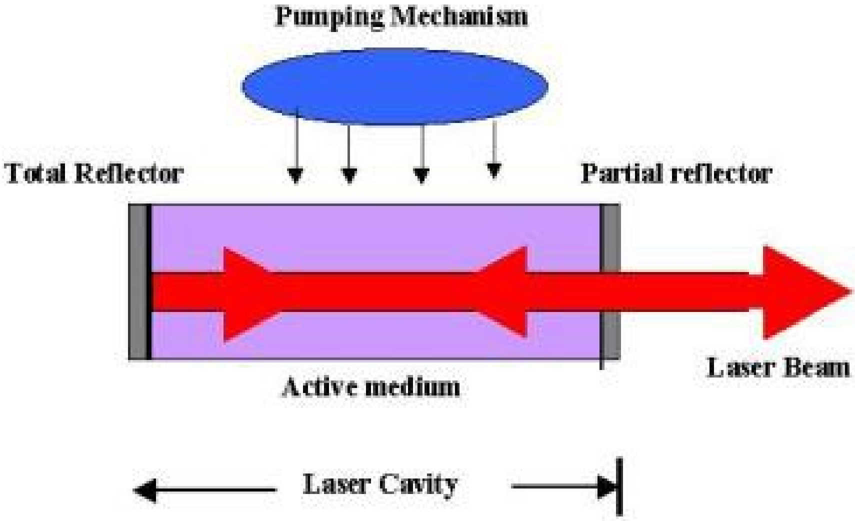


Fig. 2: ***Basic Laser System***

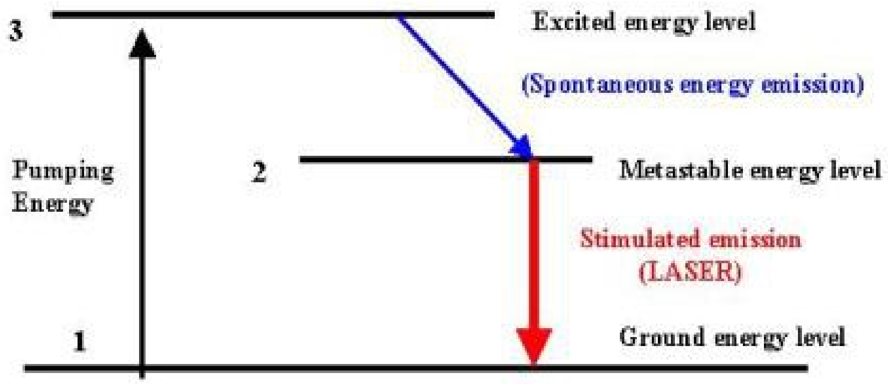


Fig. 3a: ***Energy States of Three – level Active Medium***

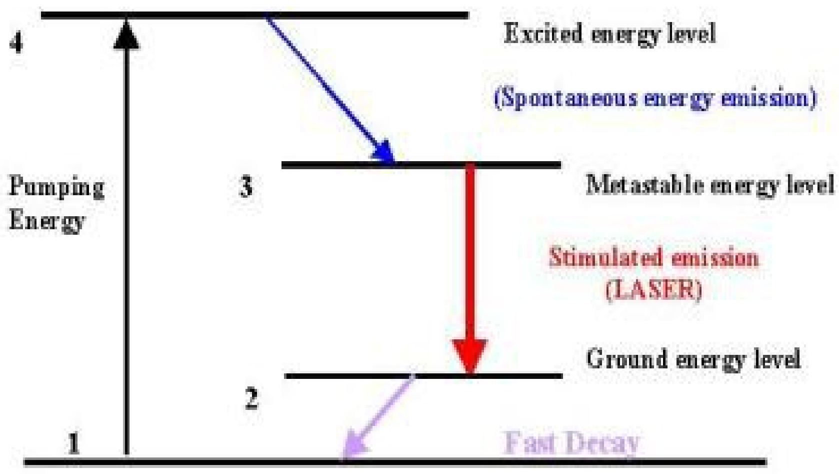
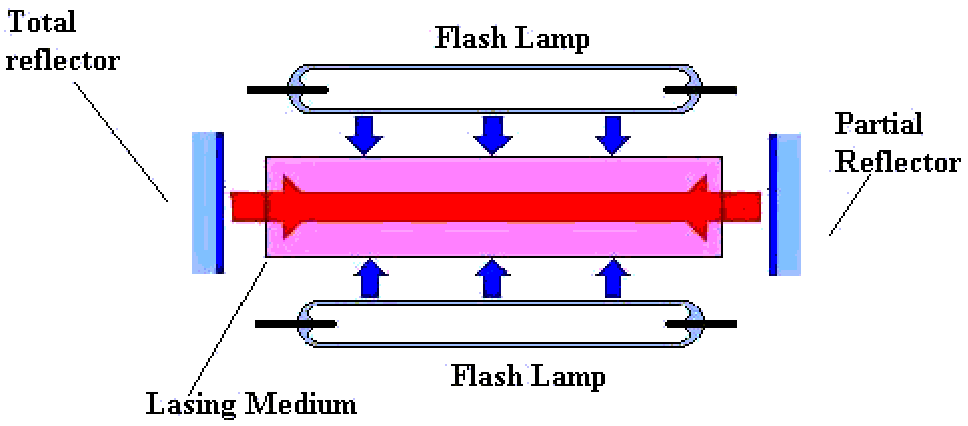
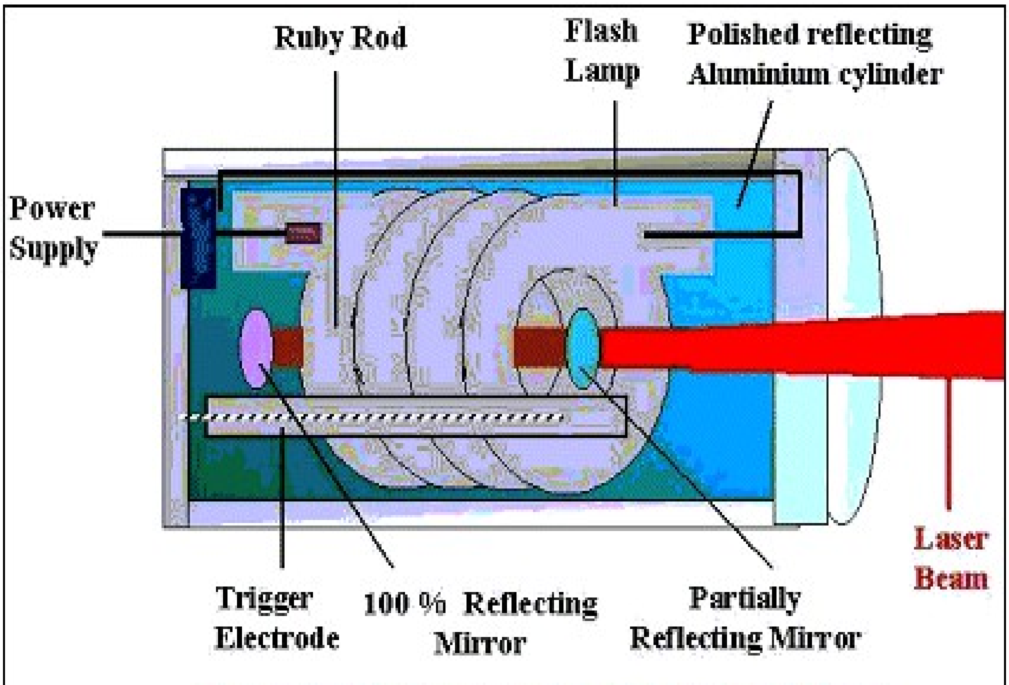


Fig. 3b: ***Energy States of Four – level Active Medium***

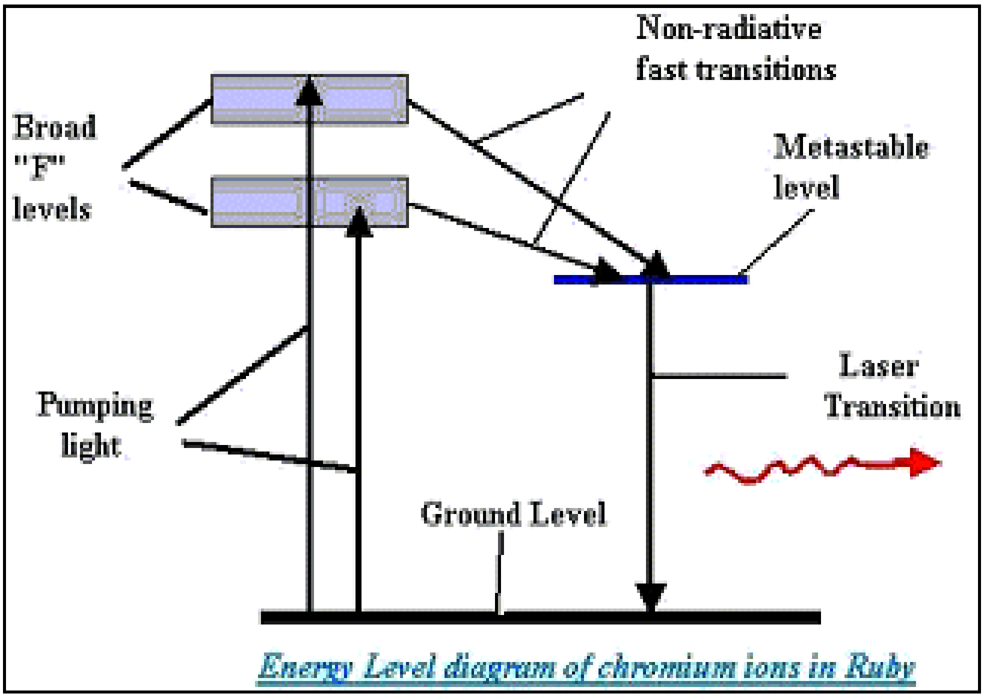


Basic Parts of a Solid State Laser System

(A) Ruby Laser System



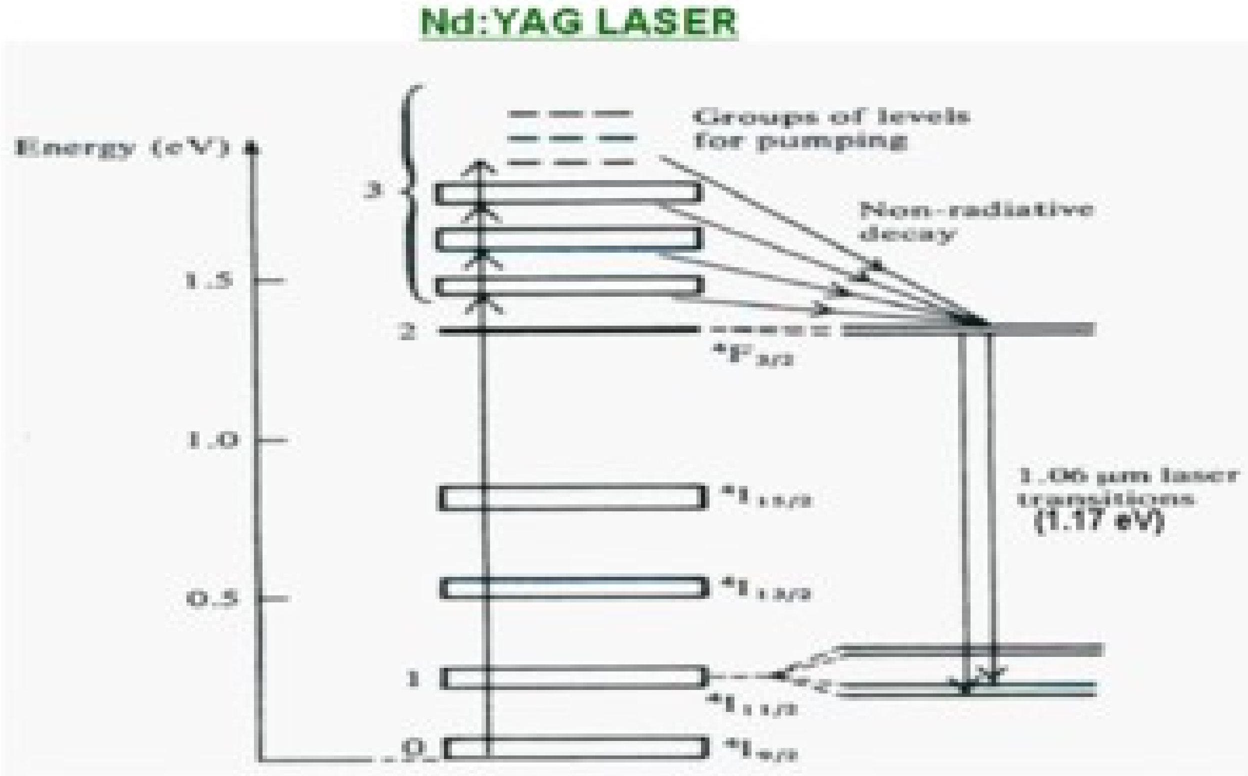
Concept and Basic Components of First Ruby Laser By Maiman



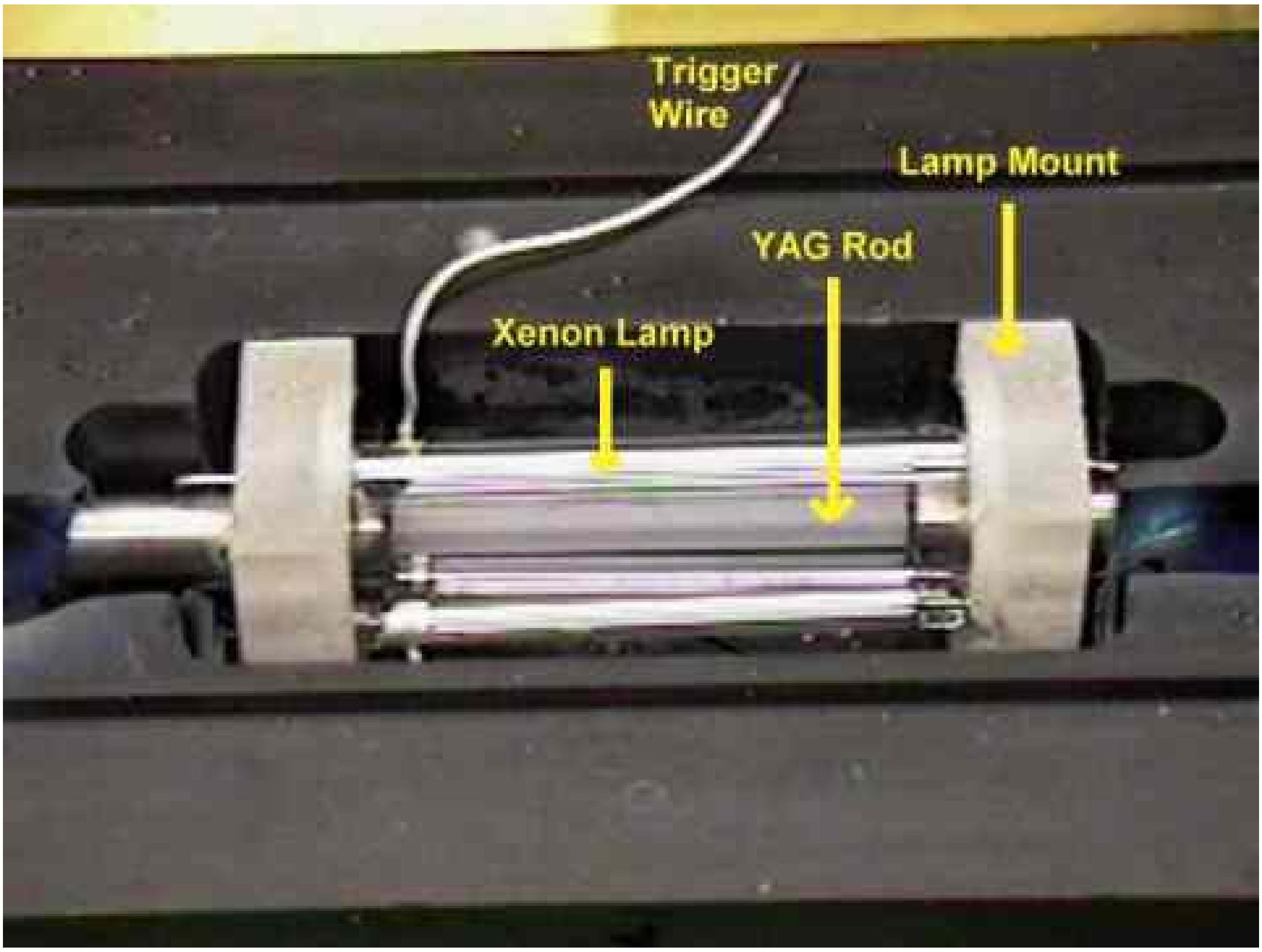
Energy Level diagram of chromium ions in Ruby

(B) Nd: YAG laser System

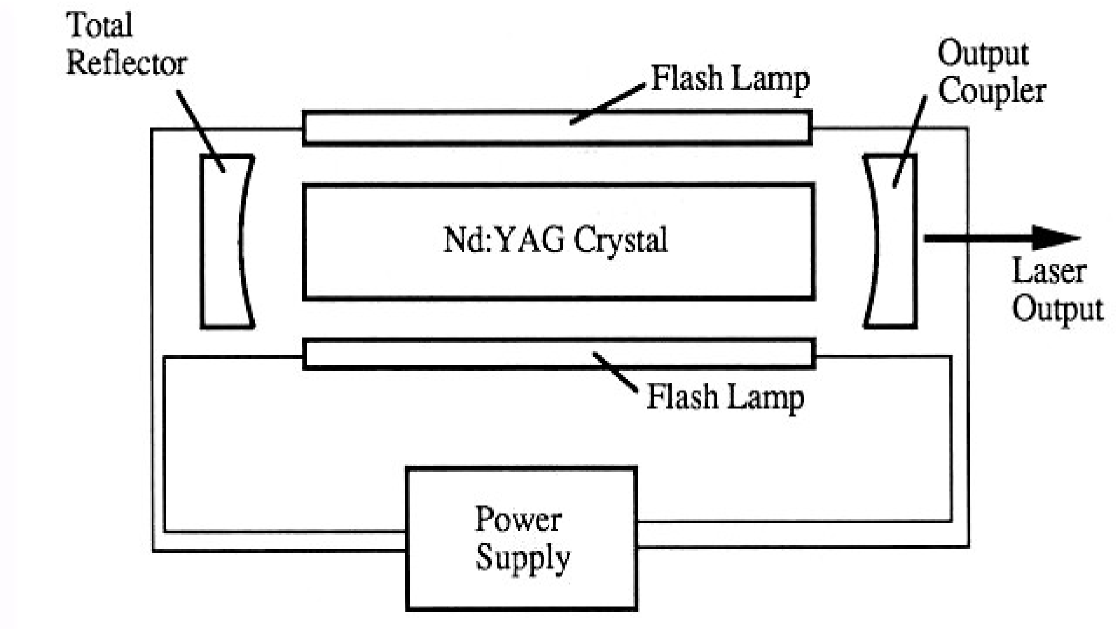
Nd: YAG Laser System



Energy levels of Nd: YAG Laser System



The Laser Cavity of Nd:YAG Laser System



Principles of Laser Induced Breakdown Spectroscopy (LIBS)

What is LIBS?

Laser Induced Breakdown Spectroscopy (LIBS) is a rapid chemical analysis technology that uses a short laser pulse to create a micro-plasma on the sample surface. This analytical technique offers many compelling advantages compared to other elemental analysis techniques. These include:

A sample preparation-free measurement experience

Extremely fast measurement time, usually a few seconds, for a single spot analysis

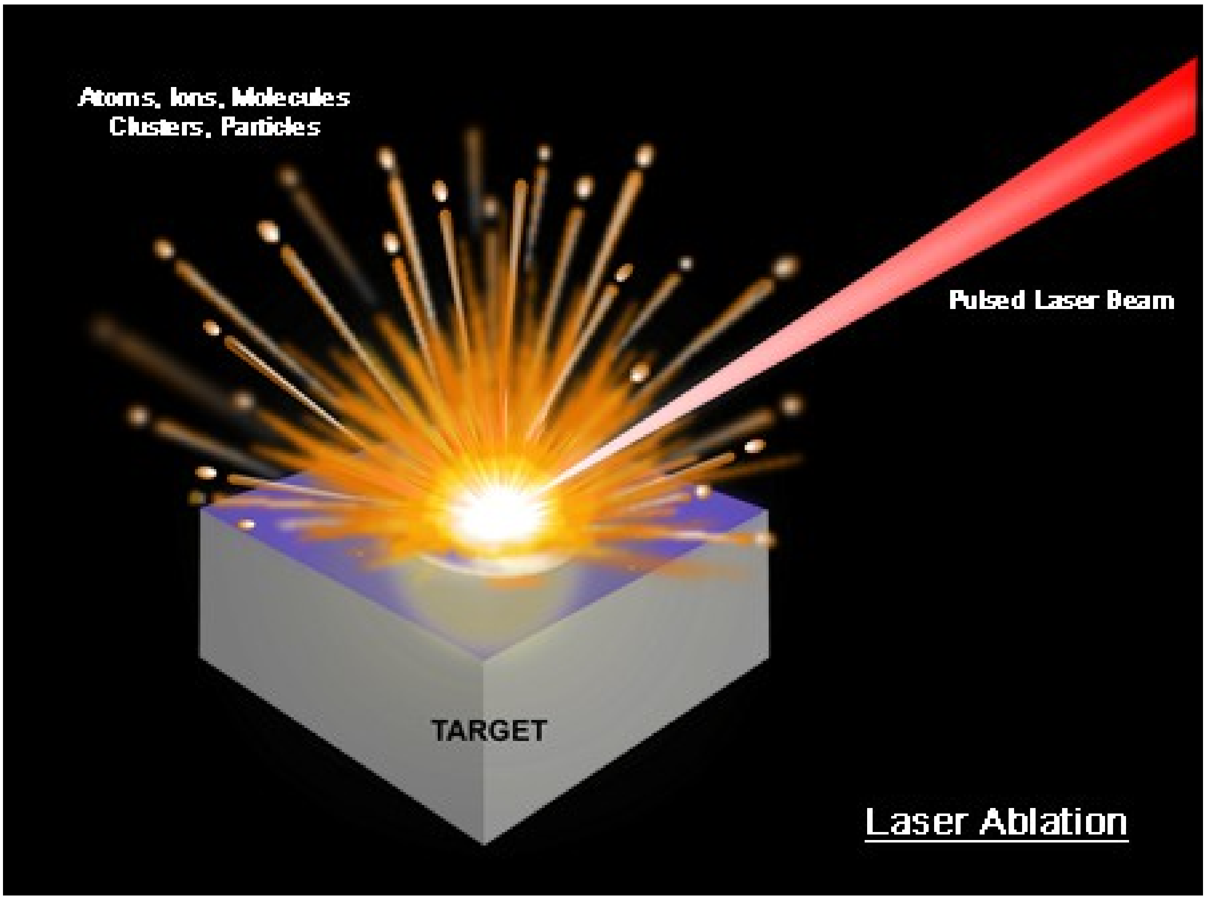
Broad elemental coverage, including lighter elements, such as H, Be, Li, C, N, O, Na, and Mg

Versatile sampling protocols that include fast raster of the sample surface and depth profiling

Thin-sample analysis without the worry of the substrate interference

So how does LIBS work?

The main physical process that forms the essence of LIBS technology is the formation of high-temperature plasma, induced by a short laser pulse. When the short-pulse laser beam is focused onto the sample surface, a small volume of the sample mass is ablated (i.e. removed via both thermal and non-thermal mechanisms) — in a process known a Laser Ablation. This ablated mass further interacts with a trailing portion of the laser pulse to form a highly energetic plasma that contains free electronics, excited atoms and

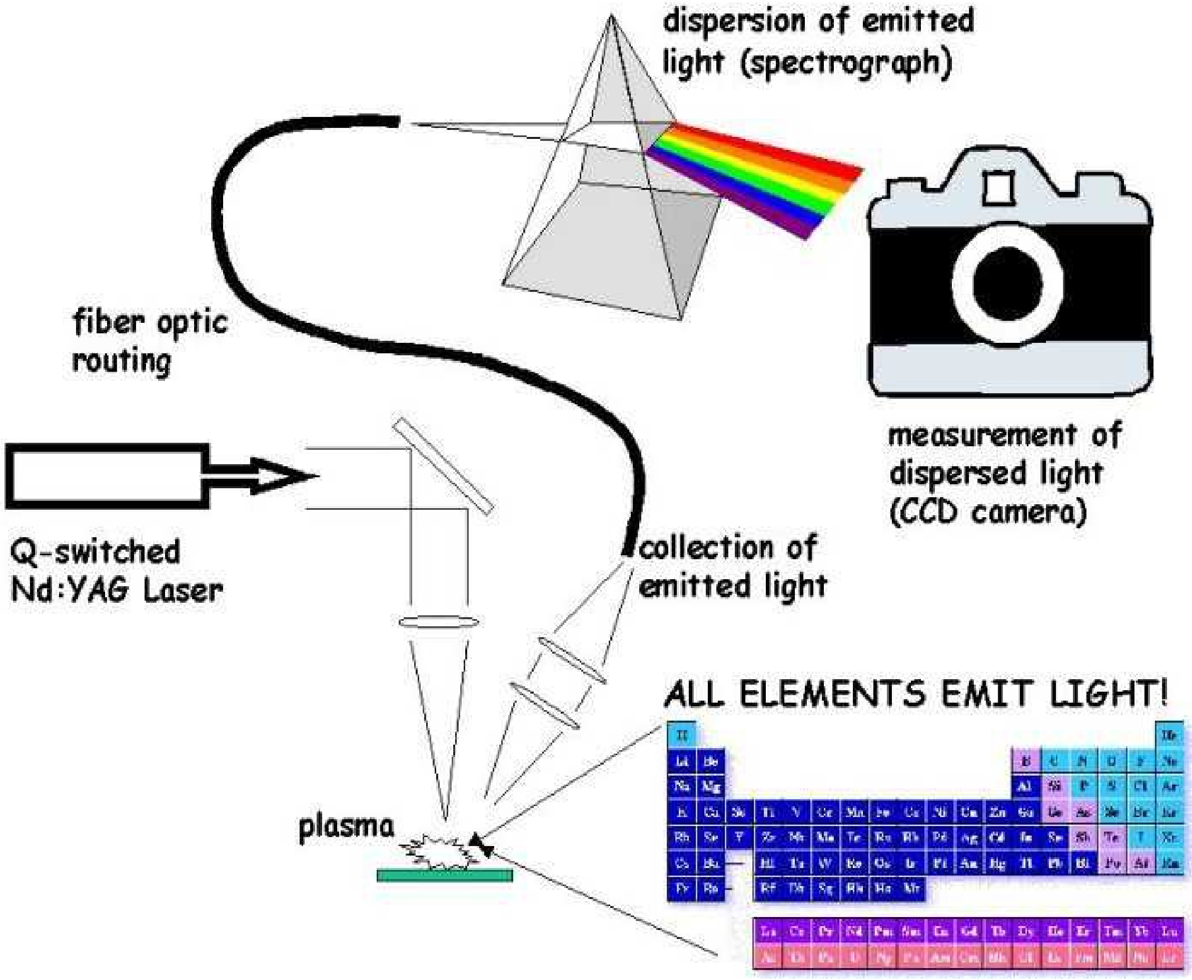


Laser Ablation: The removal of a small quantity of mass from a sample's surface using a focused, pulsed laser beam.

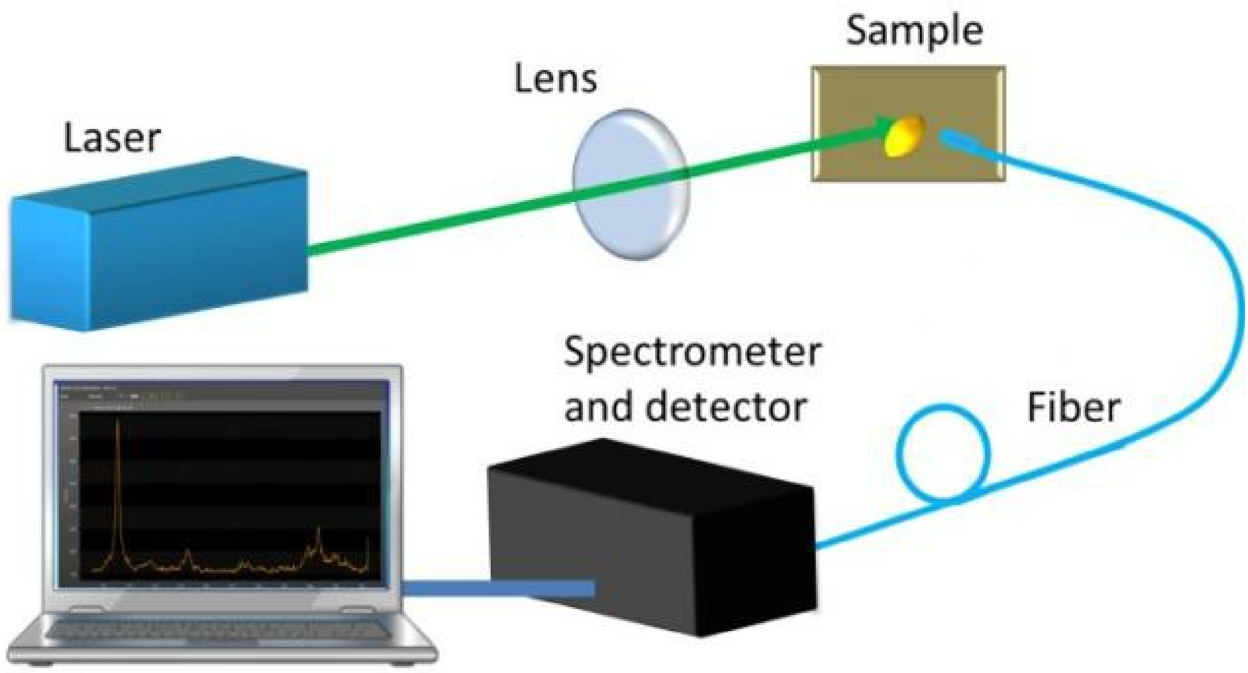
ions. Many fundamental research projects have shown that the plasma temperature can exceed 30,000K in its early life time phase.

When the laser pulse terminates, the plasma starts to cool. During the plasma cooling process, the electrons of the atoms and ions at the excited electronic states fall down into natural ground states, causing the plasma to emit light with discrete spectral peaks. The emitted light from the plasma is collected and coupled with an ICCD/spectrograph detector module for LIBS spectral analysis. Each element in the periodic table is associated with unique LIBS spectral peaks. By identifying different peaks for the analyzed samples, its chemical composition can be rapidly determined. Often, information on LIBS peak intensities can be used to quantify the concentration of trace and major elements in the sample.

With the advancement of powerful chemometric software for LIBS data analysis, and with steady progress in understanding laser ablation fundamentals, today's analytical researchers are applying LIBS effectively for both quantitative and material discriminatory analysis for a wide range of sample matrices.

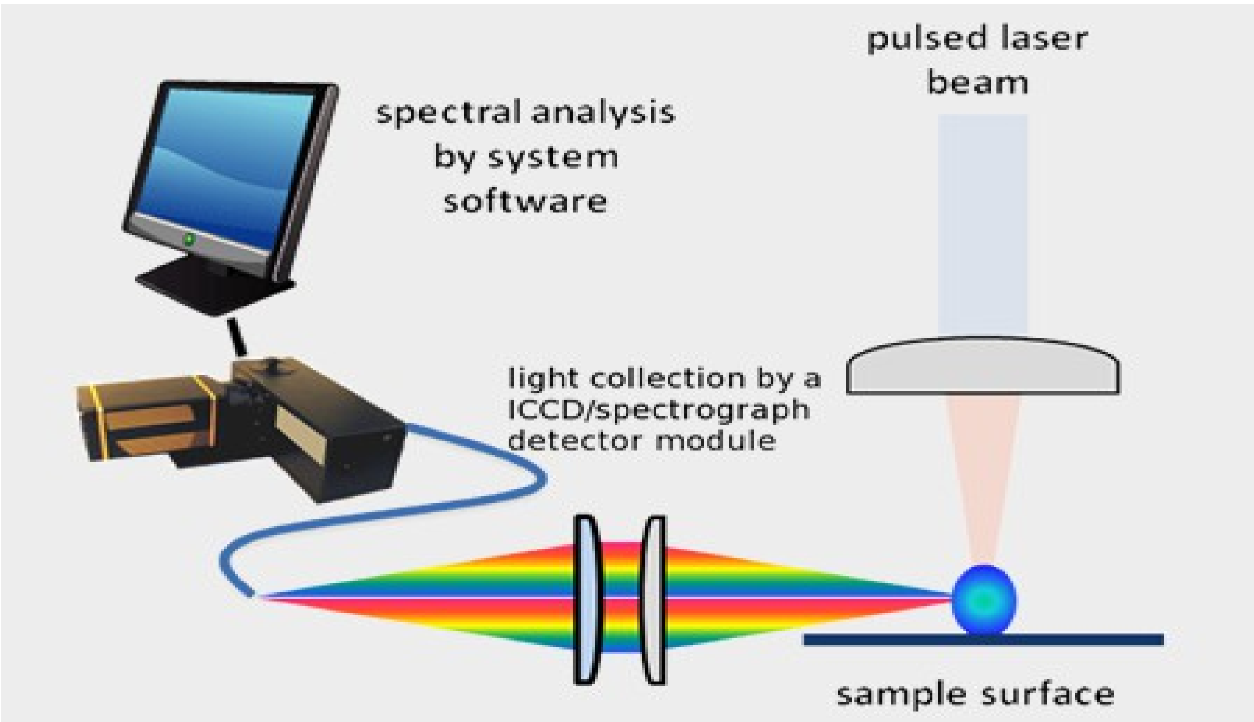


The Basics of Laser Induced Breakdown Spectroscopy (LIBS)

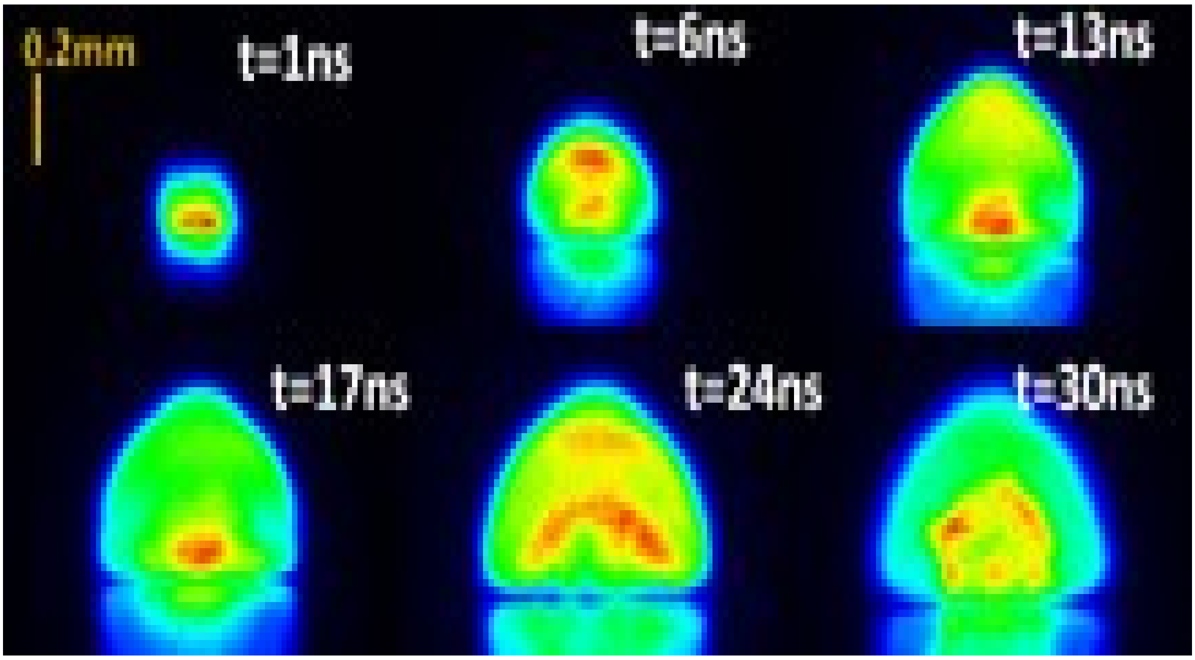


(a)

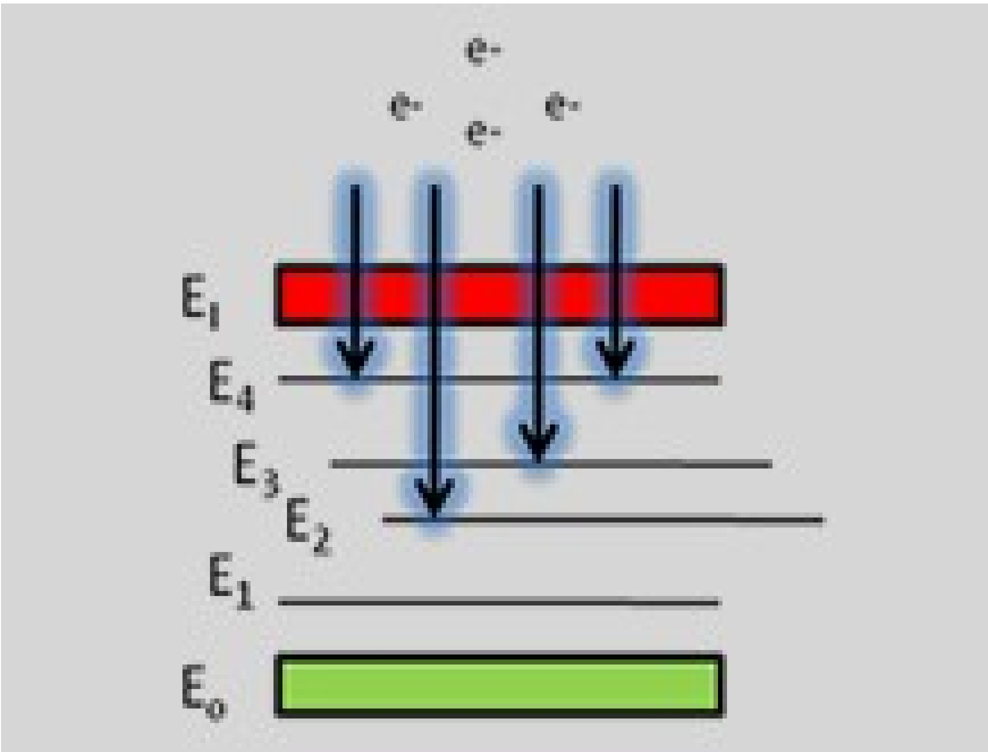
Block Diagram for a typical LIBS System for a local chemical Analysis or for laser cleanning.



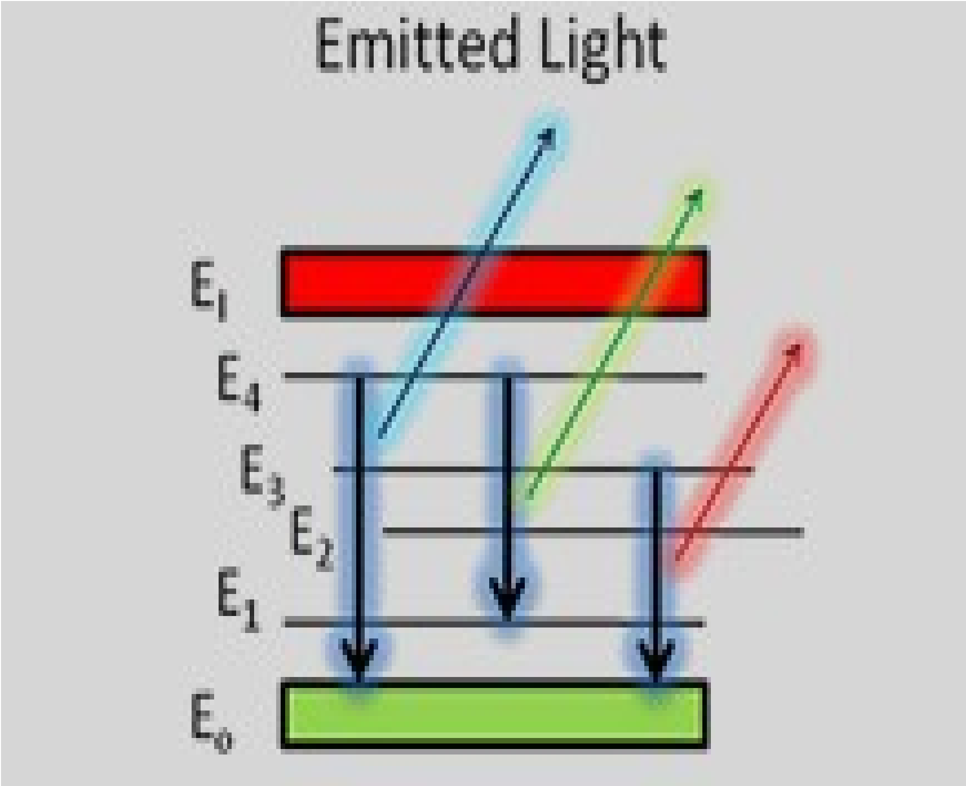
(b)



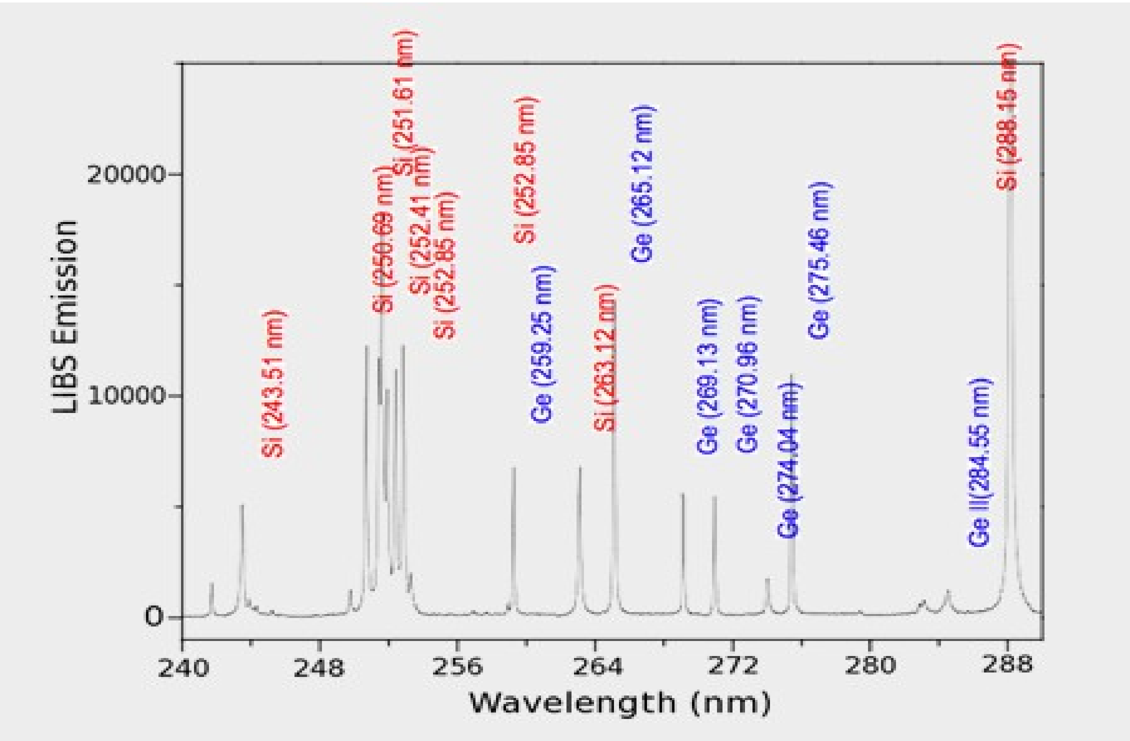
Initiation of a high-temperature (>15,000K) plasma above the sample surface and a rapid expansion of the plasma into the ambient medium.



Emission of continuum light during early stage (< 200 ~ 300 nsec) of plasma cooling process.

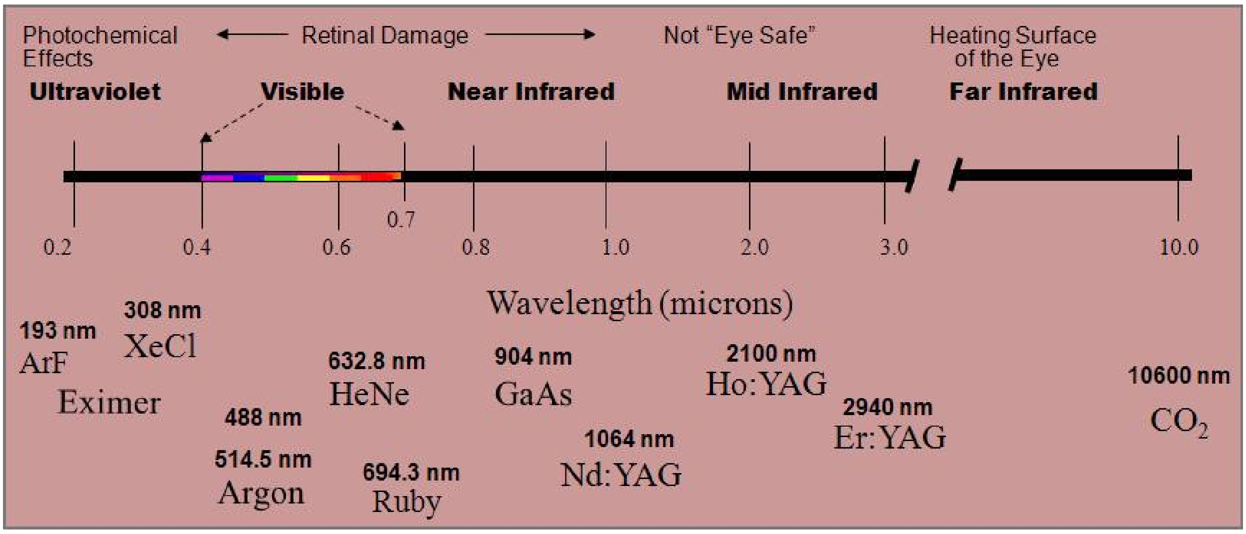


Emission of discrete atomic lines at later times (> 1 μsec)



Display of LIBS spectra and their subsequent analysis by the system software for both qualitative and quantitative elemental analysis

Summary for all laser systems



Laser Terminology

*Maximum Permissible Exposure (MPE) is the level of laser radiation to which a person may be exposed without hazardous effect or adverse biological changes in the eye or skin.

*Nominal Hazard Zone (NHZ) The space within which the irradiance or radiant exposure exceeds the appropriate MPE.

*Optical Density (OD) is the approximate order of magnitude of transmittance (T) at a given wavelength. OD is determined by log10 (1/T). For example an OD of 1 reduces transmission by 10 and an OD of 3 reduces the transmission by 1000.

*Accessible Emission Limit (AEL) is the allowed emission within a certain laser hazard class.

*Laser Output is the maximum energy associated with the laser usually measured in Watts (W) or milliwatts (mW).

*Pulse energy is the amount of laser energy per pulse usually measured in Joule/pulse.

*Irradiance is the amount of continuous laser light energy per unit area usually measured in Watt/cm2.

*Radiant exposure is the amount of laser light per pulse per unit area usually measured in Joule/cm2.