Enhancing Biotech and Advanced Manufacturing Programs
by Infusing Cutting-Edge Laser and Optics Curricula

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LASER – THE NEW TOOL OF ALL INDUSTRIES

- LASER was invented in 1960 but it had not become economically viable for common industrial use until the 2000’s
- Today we read about a new applications of Lasers every day
- Because of economies of scale Lasers are becoming cheaper, smaller and more energy efficient
- Lasers enable us to do things that we could have not done before because of their unique characteristics
1. High energy beam can be focused with optics into a small spot with energy densities never possible in the past.
   ex. 1.3 PW (1.3×10^{15} W) – world's most powerful laser at LLNL

2. Different laser wavelengths that have different effects when interacting with matter
   ex1. Copper or brass are cut with laser light of 1,070 nm (fiber laser)
   ex2. Cutting iron 10,600 nm (CO_2 laser)
   ex3. Laser hair removal 1,064 nm (Nd:YAG Laser)

This beam can be focused with optics as close or as far away we desire.

3. Laser energy and wavelength can be customized to achieve different effects on organic and inorganic substances.
Cutting metal with CO₂ laser $\lambda=10.6 \, \mu\text{m}$

Beam spot size diameter = 0.001 inches (0.025 mm) [$A=4.9 \times 10^{-10} \text{m}^2$]

<table>
<thead>
<tr>
<th>Material (1mm thick)</th>
<th>Laser Power [Watts]</th>
<th>Energy at the beam spot $E= P/A$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stainless steel</td>
<td>1000</td>
<td>$2.04 \times 10^{12} \text{ w/m}^2$</td>
</tr>
<tr>
<td>Aluminum</td>
<td>1000</td>
<td>$2.04 \times 10^{12} \text{ w/m}^2$</td>
</tr>
<tr>
<td>Mild steel</td>
<td>400</td>
<td>$8.2 \times 10^{11} \text{ w/m}^2$</td>
</tr>
<tr>
<td>Titanium</td>
<td>210</td>
<td>$4.3 \times 10^{11} \text{ w/m}^2$</td>
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</tbody>
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Market of Laser Enabled Technologies

PHOTONICS-ENABLED INDUSTRIES
US GDP $7.5 TRILLION; 7 MILLION JOBS

- Biomedical, Medical Imaging, Healthcare
- Consumer & Entertainment
- Solar PV & Alternative Energy
- Defense, Security, Law Enforcement
- Lighting & Displays
- Communication, Information Processing, & Storage
- Semiconductor Processing, Manufacturing
- Sensing, Monitoring, Measurement & Control

Sources: the National Academy of Science & the National Photonics Initiative
DNA sequencing based on laser-excited fluorescence is characterized by dramatic increases in throughput, equally impressive reductions in cost, and diverse technological innovations.

In the Past:
The entire human genome was read by multiple labs, each operating multiple sequencers—with a total cost of around $3 billion over 10 years.

Today:
With massive parallelism, a complete human genome sequencing is done under $1,000 in one hour.
Proteins must fold into compact and unique three-dimensional structures to carry out their specific functions. If folding goes wrong, proteins become useless and often toxic molecules for living cells. Millions of people around the world suffer from diseases caused by protein misfolding, such as Gaucher’s disease, Alzheimer’s disease and Parkinson’s disease.
Laser microdissection is a highly selective process for preparing samples for DNA, RNA and protein analysis. It is a microscope-controlled manipulation technique for the precise separation of samples and tissue using a focused laser beam.
LASERS in BIOTECHNOLOGY

OPTOGENETICS

A rapidly growing field combining molecular biology with optical stimulation of light-sensitive proteins to target specific regions of a single cell or a group of cells within the brain.
LASERS in BIOTECHNOLOGY

Multiphoton Excitation (MPE) Microscopy

In-vivo imaging technique. A fluorescent molecule – attached to the specimen or naturally present – is excited by two or three photon of infrared light.
LASERS in BIOTECHNOLOGY

Flow Cytometry

In-vivo imaging technique. A fluorescent molecule – attached to the specimen or naturally present – is excited by two or three photon of infrared light.
What is Spectroscopy?

The non destructive study of the molecular structure and dynamics of matter through the absorption, emission, and scattering of light.
Applications of Spectroscopy

Agricultural measurements and monitoring

Food and beverage quality control
Applications of Spectroscopy

Characterization of fluid substances

Protein and nucleic acid analysis
Applications of Spectroscopy

Water and air analysis

Environmental monitoring
Applications of Spectroscopy

- Fuel Authentication
- Food Safety
- Explosives Detection
- Value Validation & Brand Protection
Applications of Spectroscopy

- Polymer Analysis
- Metallurgical Analysis
- Thickness Measurement
- Plasma Monitoring
Raman Spectroscopy

Able to detect brain, lung, colon, and skin cancers *in situ*, during surgery to with astonishing performance: 97% accuracy, a full 100% sensitivity, and 93% specificity.
Lasers in Advanced Manufacturing

- Cutting
- Drilling
- Welding
- Brazing
- Cladding
- Engraving
- Polymer Marking
- Polymer Welding
- Micro cutting
- Micro Patterning
Lasers in Automotive and Aerospace Industries
With LAM we can create complicated metal parts that cannot be manufactured with traditional technologies.
Laser Additive Manufacturing

Overcome via Outside Engineering

- Low risk
  - disclose minimal loading
- High payback
- Leverage to in-house design teams
- Potential “circle of friends”

Crowd Sourcing for Additive to Spur Internal Creativity
Laser Additive Manufacturing

GEA Leap Fuel Nozzle: 1st GE DMLM Production Part

- Combine 20 parts into 1 monolithic body
- 5x Life improvement
- 25% weight reduction
- BoM for AETD/other military devel and all commercial

**FETT parts running now,**

*Leap Fuel Nozzle > 40,000 / year in 2018*
Laser Additive Manufacturing

Candidate AM Applications

- **Combustion**
  - Liners
  - Fuel nozzles

- **HPT/LPT**
  - Blades
  - Vanes
  - Shrouds

- **Booster/Compressor**
  - Blades
  - Vane Segments

- **Fan**
  - Metal Leading Edge
  - Blisk

- **Installations**
  - VSV bushing
  - Heat shield
  - Tubes & brackets
  - Assemblies

- **Structures (New Make Repair)**
  - Compressor case
  - Combustion case
  - HPT case
  - LPT case
Alloys used in LAM

Titanium Alloys
TiAl6V4, Ti Gd II - Tensile strength: 1,200 MPa

Aluminum Alloys
AlSi10Mg, AlSi12, AlSi7MG – Tensile strength 400 MPa

Steel
316L, H11, MS1 – Tensile strength 1,600 MPa

Nickel Based

1 MPa = 145 psi = 1 newton/millimeter²
Other Applications
Laser Development History

Ruby Laser Invented in 1960
A SOLUTION LOOKING FOR A PROBLEM

Gas Lasers - HeNe, CO₂

Semiconductor Laser
Vertical-cavity surface-emitting laser

VCSEL

Fiber Laser
Basic Laser Theory
Laser Resonator

What is a Laser?

Resonator + Gain Medium

- pump energy
- gain g
- output beam
- total losses $I = I_c + I_{out}$
- output coupling $I_{out}$
- cavity losses $I_c$

$g > 1$
$g = 1$
$g < 1$
$t$

Bern University of Applied Sciences
Engineering and Information Technology
Basic Laser Theory
Population Inversion and Stimulated Emission
When matter is exposed to electromagnetic radiation, e.g. infrared light, the radiation can be absorbed, transmitted, reflected, scattered or undergo photoluminescence. Photoluminescence is a term used to designate a number of effects, including fluorescence, phosphorescence, and Raman scattering.
Types of Spectroscopy

Absorption Spectroscopy
Emission Spectroscopy
Scattering Spectroscopy

Visible light
UV Ultra violet
IR Infra red
NMR Nuclear Magnetic Resonance
Electromagnetic Spectrum
Example of Absorption Spectrometer
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Lasers in Health Science Applications

Vision

Vision Correction

Glaucoma Pressure Correction

Cataract Surgery

Lasik surgery

Diabetic Retinopathy
Lasers in Health Science Applications

Lasers are more precise than standard surgical tools (scalpels), so they do less damage to normal tissues. As a result, patients usually have less pain, bleeding, swelling, and scarring. With laser therapy, operations are usually shorter.
Lasers in Health Science Applications

- Prostate surgery
- Tattoo removal
- Pain therapy
Lasers in Health Science Applications

Arthrosis of the knee

Tissue healing using laser light
no needles and stitches
Lasers in Health Science Applications

Chronic spinal illnesses, spinal stenosis, bulged disks

Treatment of psoriasis, eczema, acne and other dermatological problems

Intravenous laser therapy
Lasers in Health Science Applications

Dentistry

Sterilization for root canal

HOW THE LASER WORKS

1. The laser is directed at the rotten area, which contains more water molecules than the rest of the tooth.

2. Water molecules in the decay are heated rapidly. Pressure increases and the rotten area "explodes", making a popping sound.

3. The laser kills any bacteria in the area so the tooth is sterilised.

Removal of decay and damaged gums
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