Fiber Lasers: Fundamentals and Applications

Lecture 1

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Personal Background

Indian Institute of Science (Aug 2014 - )
Assistant Professor, Centre for Nano Science and Engineering
Research: Fiber Lasers, Silicon Photonics, Optical Communications

OFS Laboratories (Feb 2011 – July 2014)
Optical Fiber Solutions division of Bell laboratories spun off in 2002 into a separate R&D center
Research Scientist
Research: Fiber Lasers, Nonlinear Fiber Optics

Purdue University (Aug 2006 – Jan 2011)
PhD in Electrical and Computer Engineering
Research: Optical signal processing and characterization, Microwave Photonics, Frequency Combs and Metrology (Advisor: Prof Andrew M. Weiner, dept of ECE)
A Laser is basically an optical feedback oscillator
Spontaneous and Stimulated Emission

absorption

Upper level $E_2$

Photon

Lower level $E_1$

atom

$\Delta E = \nu$

Spontaneous emission

E2

Photon Random direction

E1

Stimulated emission

E2

Photon Same direction

E1
Feedback

Various other types of feedback possible
A brief history of lasers

Albert Einstein – 1917 (Stimulated Emission)
• Laid the foundation for lasers

Charles Townes, Jim Gordon, Arthur Shawlow (Columbia)
• Laser theory, Masers, credited for invention of masers

Gordon Gould (1959)
• Patent on fabry – perot resonator for lasers, came up with the word laser

Ted Maiman (1960) – First Laser (Ruby)
High Power Laser Technologies

Solid State Lasers

- Thermal limitations – causes beam degradation
- Efficiency

Carbon-di-oxide Laser

- Low efficiency
- Continuous Maintenance
- Large form factor

Fiber Lasers

From encyclopedia of laser physics and technology
Fiber Lasers

![Graph showing the power trend of Fiber Lasers from 1996 to 2012. The graph indicates a long-term trend of 2.0 dB/year.](image-url)
Why High Power (Fiber) Lasers?

**Defence**
- LIDAR
- Directed Energy
- And many more

**Industrial**
- Material Processing
  - From automobiles to semiconductors

**Medical**
- Laser surgery
Fiber Lasers in Action

Our Sun ~ 100 W per sq ft (0.1 square meter)

This Laser transmits light in an area of $10^{-11}$ square meter

What does this mean? This source is just a little brighter than our sun – by $10000000000$ times!

In a camera sensitive to IR wavelengths
High Power Rare-earth doped fiber lasers

The rare-earth doped core absorbs and reemits the pump light into a high brightness beam (multimode to singlemode conversion)
Why Fiber Lasers?

Distributed heat load

- Bulk
- Fiber

For a long cylinder – Area/Volume ~ (r/L)

Waveguiding

- Bulk
- Fiber
Single Mode or Multimode

Single Mode Light

Focussed spot

Propagation

Highly Multimode Light
High Power Fiber Lasers as Brightness Convertors

A 1W laser which can only be focused to 1mm beams
• More of a heater than anything else

A 1W laser which can be focused to a 1micron spot
• Can cut metal

Fundamentally, fiber lasers or most optically pumped high power lasers are brightness convertors.
Characterizing the brightness of a beam

How do we characterize the true brightness of a beam?

A Gaussian beam is optimal for free space propagation, diffraction limited.

Brightness is characterized by how Gaussian like the beam is.

\[ M^2 \text{ value characterizes the beam} \]

\[ \theta = M^2 \frac{\lambda}{\pi W_0} \]
A brief history of fiber lasers

Ted Maiman (1960)
• First laser

Elias Snitzer (1961)
• First fiber laser, 30micron core, 300 micron cladding

However, after this it went no where for a long time ... why?
What happened to Fiber Lasers after their invention?

No important application

Optical communications, laser material processing were all at their infancy

Problems with pumping

Fiber lasers require pumping with other (albeit lower quality) lasers. Diode lasers were not there.

Flash lamp pumped solid state lasers were much better
What happened to Fiber Lasers after their invention?

High Loss in fibers

Fibers had very high loss (15dB/m). Not sustainable

Problems with pump coupling
Invention of the EDFA

Powered the tremendous growth of internet

Advances made in amplifier development, components, doped fibers etc applied well to high power fiber lasers
Low Loss Fibers

![Graph showing optical loss vs. wavelength for different fiber types and windows.]

- **First Window**
- **Second Window**
- **Early 1980’s**
- **Late 1980’s**
- **Modern Fiber**
- **Third Window (The “C”-Band)**
- **Fourth Window (The “L”-Band)**
Development of high power pump diodes

This was also applicable to solid state lasers

Over 100W modules routinely available in the market today
Better pump coupling

All fiber architectures – compact, robust, fiber delivery
Schematic of a Modern High Power CW Fiber Laser

Diagram showing the components of a modern high power CW fiber laser, including laser diodes, pump combiner, gain fiber, high reflectivity fiber mirror, lower reflectivity fiber mirror, and pump dump. The laser output is directed through these components to generate high power laser emission.
Classes of High Power/Intensity Fiber Lasers

- **Continuous Wave**
  - High average power
  - Lower light intensity

- **Pulsed (ns-ps)**
  - medium average power
  - higher light intensity

- **Ultrafast (fs)**
  - Low average power
  - Extreme light intensity
Classes of High Power/Intensity Fiber Lasers

Ultrafast
- Athermal processing
- Fundamental Physics
- Nuclear fusion

Pulsed
- Thermal (fine features)
- Tissue ablation
- LIDAR

Continuous wave
- Thermal material processing
- Defense
- Pump laser sources