Optical Fibers

Photonics
(ELEC-E3240)

Zhipei Sun

Photonics Group
Department of Electronics and Nanoengineering
Aalto University

Lecture Topics

- Course introduction
- Ray optics & optical beams
- Waveguides / optical fibers
- Optical amplifiers
- Fiber optics and applications

Lab work

- Silicon photonics
- Structural coloration
- Plasmonics
- Poster Presentation & discussion

Why Optical Sensors?

- Electromagnetic immunity
- Electrical isolation
- Compact & light
- Both Pint & Distributed sensing configuration
- Wide dynamic range
- Amenable to multiplexing

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Optical sensing parameters

Temperature	Chemical species/Humidity
Pressure	Force/Strain/
Flow	Radiation
Liquid level	pH
Displacement/Vibration/rotation/velocity/acceleration	Magnetic/electric/accoustic fields

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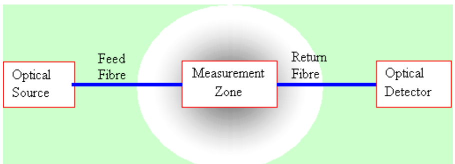
Working principle

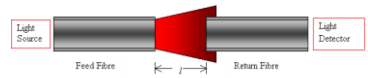


- Light parameter changes by the phenomena that is being measured.

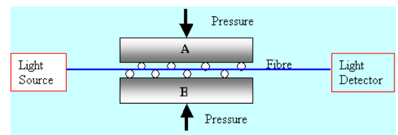
Intensity **Frequency/wavelength, phase, polarization, (mode numbers)**

Classification

Extrinsic sensors



Intrinsic sensors

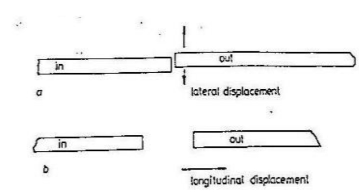


Comparison

Extrinsic	Intrinsic
• Applications: temperature, pressure,liquid,& flow. • Less sensitive • Easily multiplexed • Easier to use • Cost-effective	• Applications: Rotations, acceleration, strain, vibration, pressure. • High sensitive • Difficult to multiplex • Reduces connection problems • Expensive

Examples

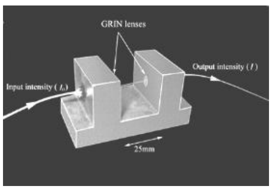
Intensity modulation sensors

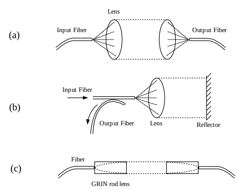


Position dependent coupling between two fibers

Examples

Gas sensor





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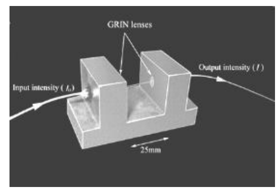
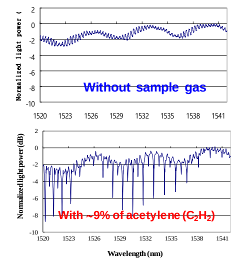
Examples

Gas sensor





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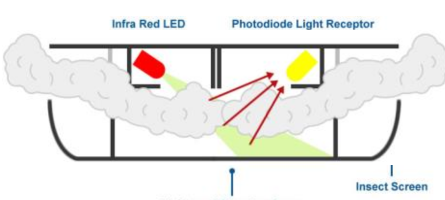
Examples

Optical Smoke Alarms



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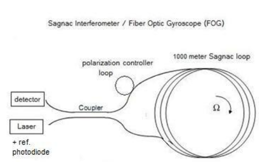
Examples

Interferometric fiber optic gyroscope- Sagnac Interferometer



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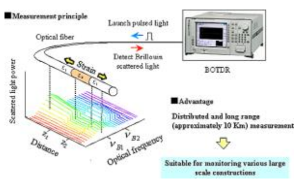
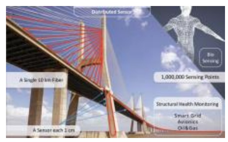
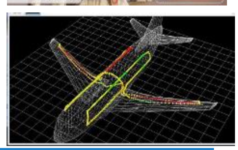
Airbus; Boeing; missile (e.g., ASM-135 US Anti-satellite missile; Shaurya missile)

Examples

Distributed fiber sensors







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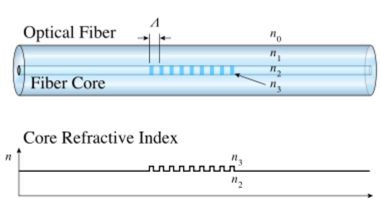
Well, earthquake monitoring, wind energy……

Fiber Bragg grating based devices

Some Applications:

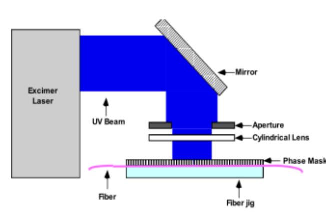
- Wavelength MUX/DEMUX Devices
- Add/Drop Wavelength Filters
- Chromatic Dispersion Compensators
- Gain Flattening Filters

Fiber Bragg Grating

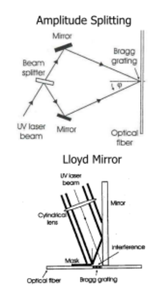


Fiber Bragg Grating Farbrication

Fiber Bragg gratings are written in the fiber by exposure to a UV interference pattern. Due to the dopants, mainly GeO_2 in the core, the photosensitivity is enhanced. The index of refraction increases due to photosensitivity (typically $\Delta n \sim 10^{-3} - 10^{-5}$).



Phase-mask technique

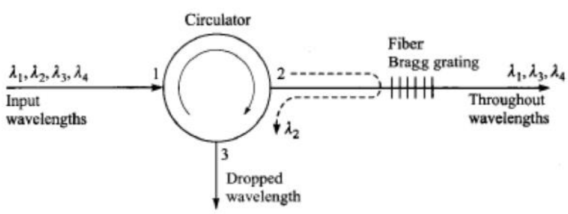


Interferometric photowriting setup

* K.O. Hill et al., "Photosensitivity in optical fiber waveguides: Application to reflection filter fabrication," Appl. Phys. Lett. 32, 647 (1978).

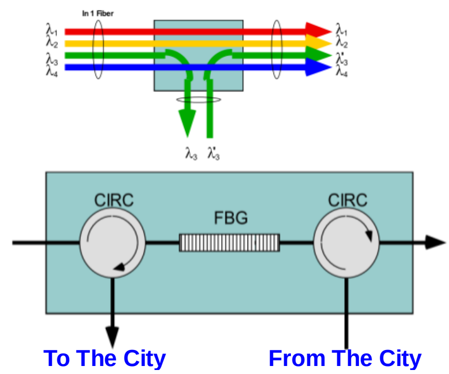
Fiber Bragg Grating Devices

Bandpass Filter



Fiber Bragg Grating Devices

Optical Add/Drop Wavelength Filter



Fiber Bragg Grating Sensors

Bragg wavelength is dependent on strain and temperature:

$$\Delta\lambda_B = 2\left(\Lambda\frac{\partial n_{eff}}{\partial l} + n_{eff}\frac{\partial \Lambda}{\partial l}\right)\Delta l + 2\left(\Lambda\frac{\partial n_{eff}}{\partial T} + n_{eff}\frac{\partial \Lambda}{\partial T}\right)\Delta T$$

strain-optic shift

change in grating spacing

thermo-optic shift

thermal expansion

$$\approx 13.7\,\mathrm{pm}/{\circ}\mathrm{C}$$

- ❖Good for sensors!
- ❖Bad for telecom devices (stability, packaging)
- ❖Good for telecom devices (tuning)

Fiber Bragg Grating Technology

History of Telecommunications

- Telegraph in 1837 by S.B. Morse
- Telephone in 1876 by A.G. Bell
- Electromagnetic waves in late 1800's by Hertz and Marconi
- Wireless telegraphy and radio in 1906
- Practical televisions in 1940
- Digital computer in 1939
- First digitized message in 1941
- Transistors in 1947 by Shockley, Bardeen, and Brittain
- Mainframe computers in 1980s
- Personal computers in 1990s

The first messages in the mid-1800s took two minutes to transmit a single character.


Telegraph Room, White House, 1923

History of Telecommunications

Regulation and Deregulation

- Prior to the early 1900s, there was no regulation of the telecommunications industry.
- The ICC was selected to be the watchdog of the fledgling industry. (At this time, AT&T was the dominant industry.)
- In 1934, the Communications Act established the FCC and charged it with regulation of the telephone and radio broadcasting networks.
- By 1968, private mobile radio systems were allowed to connect to PSTNs.
- By 1976, long-distance services were allowed to be delivered by industries other than AT&T.
- In 1984, AT&T was ordered to get rid of the so-called Baby Bells.
- The Telecommunications Act of 1996 lifted many of the restrictions that had been imposed on the industry and contributed toward the tremendous growth in the telecommunications industry.
- The FCC contributes to the implementation of all types of communications, which not only include terminal equipment and connections but also determine the regions over which the industry can provide services.

Fiber Telecommunications

Optical Sources and Transmitters

- Power
- Size
- Modal characteristics
- Numerical aperture
- Linewidth
- Fiber window
- Wavelength
- Data type

Fiber Telecommunications

Light-Emitting Diode (LED)

Operation:

- When the electron/hole recombine, a photon of light is emitted.
- This is called spontaneous emission.
- The light is emitted in all directions (coherent).
- This light can be focused through a lens to be used for displays.

Performance

- Voltage: 1.5 to 2.5 volts
- Current: 50 to 300 mA
- Couples 10 to 100 μW of power into a fiber
- Fiber window: 850 to 1550 nm
- Linewidth: 15 to 60 nm
- Data rates: 100 Mbps
- Inexpensive
- Rugged
- Used in LANS

Fiber Telecommunications

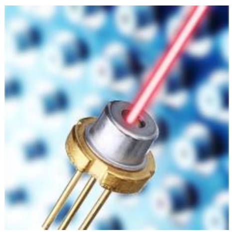
Laser Diode (LD)

Operation:

- Light Amplification by Stimulated Emission of Radiation.
- The light is emitted in one directions (coherent).
- This light can be focused through a lens.

Performance

- High power
- Stable
- Single mode
- Narrow linewidth
- Long-haul and ultra-long-haul communications

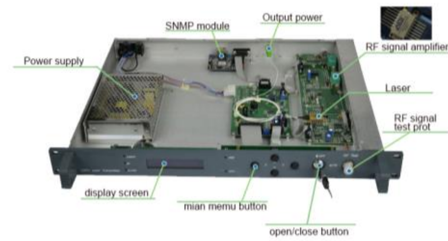


Fiber Telecommunications

Transmitters

The transmitter is a device that converts an electrical communication signal into an optical one, modulates the signal, and couples the modulated signal back into a fiber.

Consists of: Source, modulator, driver, and coupling devices



Fiber Telecommunications

Transmitters

Coupling devices:

- Efficiencies vary from 1% for LEDs to 80% for VCSEL transmitters
- Direct Coupling (Fiber is epoxied to the source)
- Lens Coupling (A lens is used to optimize the process)
- Tapered fiber

Fiber Telecommunications

Modulators

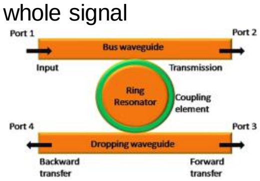
- Direct Modulation: The amount of drive current can be controlled by simply turning it on and off—pulses.
  - Small signal modulation or pulse code modulation is more practical for communications.
  - Limited response time
  - Large wavelength chirp
  - High bias currents

Indirect Modulation: Devices are inserted into the optical path of the source to implement modulation optically.

Major Devices (Electro-optic—process by which the refractive index of a material is changed through the application of an electric field. May be amplitude, phase, or frequency types).

Fiber Telecommunications
Multiplexers and Demultiplexers

- Multiplexers
  - Combine optical signals by wavelength division
  - Add-drop multiplexers may use gratings or filters
- Demultiplexers
  Single wavelengths can be picked off without demultiplexing whole signal



Fiber Telecommunications
Optical Detectors

- Optical Absorption
- Quantum Efficiency
- Responsivity
- Response Time
- Cutoff Frequency

Fiber Telecommunications
Integrated Optical Devices

- Placement of optical communication devices on a single chip
- Will reduce cost
- Will improve system performance
- Will provide versatile modules
- Two methods of connectorization of components
  - Free space
  - Planar

Fiber Telecommunications
System Design Considerations

- Design is based on
  - Application
    - Type of signal
    - Distance from transmitter to detector
    - Performance standards
    - Resource constraints (time, money, etc.)
  - Implementation
    - Components
      - Format, power, bandwidth, dynamic range
    - Amplification, amplitude, and spacing
    - Multiplexing
    - Security requirements
    - Acceptable noise levels

Fiber Telecommunications
System Design Considerations

- System Power Budget
  - Most important parameter is throughput or transfer function.
  - Output power must be greater than the input sensitivity of the receiver.
  - System budget
    (Amount of power lost or gained in each component)
  - System power margin
    (Allows for component tolerances, system degradation, repairs and splices)

Fiber Telecommunications
System Design Considerations

- Power at the Source
  - Transmitter must be appropriate for the application
    - Number of signals
    - Wavelength of signal
    - Type of transmitter device (LED, LDs)
    - Modulation
    - Mode structure
    - Tunability
    - WDM and amplification capability
    - Coupling efficiency

Fiber Telecommunications
System Design Considerations

- Power in the Fiber
  - Matching
    - Source output pattern, core-size, and NA of fiber
    - Coupling is critical
- Power at the Detector
  - Sensitivity is the primary purpose of the detector
  - Minimum sensitivity yet still meets standards
  - Must support the dynamic range of the power levels

Fiber Telecommunications
System Design Considerations

- Fiber Amplification
  - For those fibers that require amplification
  - Two types:
    - Repeaters are rarely used.
    - Optical amplifiers are the preferred amplification.
  - Use manufacturers specifications to ensure optimization of the input signal.

Fiber Telecommunications
System Design Considerations

- Amplifier Placement
  - Depends on
    - Type of amplifier
    - Transmitter
    - Receiver
    - Rise time
    - Noise and error analysis
  - Can be inserted
    - Before regeneration
    - Between regenerators

Fiber Telecommunications
System Design Considerations

- System Rise Time Budget
  - Determines the bandwidth carrying capability
  - Total rises time is the sum of the individual component rise times.
  - Bandwidth is limited by the component with the slowest rise time.

Fiber Telecommunications
System Design Considerations

- Rise Time and Bit Time
  - Rise time is defined as the time it takes for the response to rise from the 10% to 90% of maximum amplitude.
  - Fall time is the time the response needs to fall from 90% to 10% of the maximum.
  - Pulse width is the time between the 50% marks on the rising and falling edges.

Fiber Telecommunications
System Design Considerations

- Transmitters, Receivers, and Rise Time
  - Rise time of transmitter is based on the response time of the LED or laser diode.
  - Rise time of the receiver is primarily based on the semiconductor device used as the detector.
- Fiber Rise Time
  - Comes directly from the total dispersion of the fiber as a result of modal, material, wave guide, and polarization mode dispersion
- Total Rise Time
  - Sum of all the rise times in the system

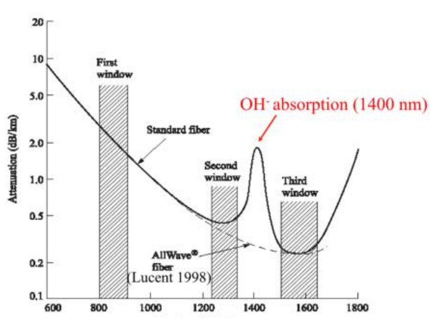
Fiber Telecommunications
System Design Considerations

- Round Trip Delay
  - Time needed for the signal to reach the furthest point of the network and return
- Dispersion Compensation
  - Allows for lowering the fiber dispersion characteristics
  - add fiber with dispersion of the opposite magnitude
  - Only available type: chromatic dispersion

Fiber Telecommunications
System Design Considerations

- Single Channel System Compensation
  - Implementation
    - Long length of small amplitude dispersion fiber
    - Short length of large amplitude dispersion fiber (distributed compensation)
  - Multi-Channel System Compensation
    - Large effective area fibers
    - Reduced dispersion fibers
  - Noise and Error Analysis
    - Determines the type of amplification required
  - Minimizing System Noise
    - Additional Noise Sources
      - Extended pulse width
      - Modal properties of fibers
      - Chirp
      - Fresnel reflection
      - Feedback noise

System Design Considerations
Three Optical Comm Windows



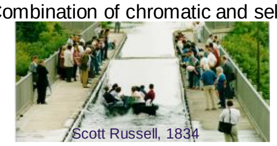
Fiber Telecommunications
From the Global Network to the Business and Home

- Long-Haul Communications
  - Terrestrial cables
    - Telegraph cable across the English Channel in 1850
    - First transatlantic cable in 1866
    - Transatlantic telephone cable in 1957
    - Transatlantic fiber-optic cable in 1988
    - Optical amplifiers replaced repeaters in 1990s
- Undersea Cables
  - Must be capable of low loss and dispersion
  - Must limit optical noise
  - Must have a pressure resistant covering
  - Amplifier gain >10 dB
  - Precise dispersion
  - Repeatered systems has pump lasers and amplifiers
  - Unrepeatered system has optical amplifiers spaced out over the length of the fiber

Fiber Telecommunications

Special Fiber-Optic Communications Systems

- Soliton Communications
  - Form of dispersion compensation
  - Combination of chromatic and self-phase modulation



Scott Russell, 1834

- Coherent Communications Systems
  - Uses WDM bandwidth more efficiently
  - Possible improvement in receiver sensitivity

Fiber Telecommunications

Deadlines

- ~~18th April: Poster topic selection~~
- ~~30th April: Upload home assignments from all groups~~
- 2th May: Lab work
- 7th May: Finish home assignments from other groups
- Morning, 9th May: Evaluate assignment results submitted form other groups
- Afternoon, 9th May: Exercise session from all groups
- 14rd May: PPT submission/print

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Lecture Topics

- Course introduction
- Ray optics & optical beams
- Waveguides / optical fibers
- Optical amplifiers
- Fiber optics and applications
- Lab work
- Silicon photonics
- Structural coloration
- Plasmonics
- Poster Presentation & discussion

Lab work

- Content: optical fiber splicing *(Discuss with Mr.* MD Gius Uddin *if you already know how to splice fibers)*
- Lab room: Lecture room in Micronova
- Assistant: *Mr.* MD Gius Uddin (Office number: 4167; Email: uddinm2@aalto.fi)

2, May: 10:15-10:45 Group 1
2, May: 10:45-11:15 Group 2
2, May: 11:15-11:45 Group 3

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