OPTICAL FIBER - FABRICATION & CABLELING

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Out line of Talk

- Optical Fiber – Basics
- Journey of Optical Fiber
- Why Fiber Optics
- Fabrication of Communication Fiber
- Fabrication of Glass/Plastic Fibers
- Fiber Cabling
**OPTICAL FIBER**

An Optical Fiber is a Flexible, Thin and Transparent Fiber made by Drawing Glass/Silica or Plastic to a Diameter slightly Thicker than that of a Human Hair. This is a Cylindrical Waveguides, which include a Core surrounded by a Cladding material with a lower R.I.

![Optical Fiber Diagram]

Typical dimensions

- Core diameter: $2a = 9 \text{ to } 62.5 \mu m$
- Cladding diameter: $2b = 125 \mu m$

Typical values of refractive indices

- Core: $n_1 = 1.461$
- Cladding: $n_2 = 1.460$
Optical Fiber Cable

- The Core is the light carrying element at the center of the optical fiber.
  - Commonly made from a combination of silica and germanium.

- Surrounding the Core is the Cladding.
  - Made of pure silica.
  - The difference in materials between Core and Cladding is important.

- Buffer Material helps shield the core and cladding from damage (Acrylic, Polyimide).

- Strength Material helps prevent stretch problems when the fiber cable is being pulled (Kevlar, Aluminum).

- Outer Jacket protects against abrasion, solvents, and other contaminants (Polyethylene).
WHY FIBER OPTICS?

- **EFFICIENT TRANSMISSION** *(LOW LOSS FIBERS)*
  Optical Fibers: 0.2 dB/Km at 1.55 µm; Window glass: 1000dB/Km
  Improvement of at least 3 order of magnitude over Coaxial Cables

- **LARGE BANDWIDTH**
  Optical Frequencies: $\sim 10^{14}$ Hz; Radio waves: $\sim 10^{6}$ Hz; Microwaves: $\sim 10^{10}$ Hz
  BWs are 4 order of magnitude larger than usable BWs of Coaxial Cables
  Achievable Data Rate Increases as the usable Bandwidth Increases

- **IMMUNITY TO EMI/RFI/EMP**
  Optical signal confined in the Core of the Carrier (Optical Glass Fiber - a Dielectric material), Non-Inductive and Non-Conductive Nature of the material

- **SECURITY OF INFORMATION**

- **HIGH BEAM ANGLES**
  Large NAs Good for Endoscopic Applications
WHY FIBER OPTICS? Contd.

- **GEOMETRIC VERSATILITY**
  Good for Endoscopic Applications

- **SMALL SIZE AND LIGHTWEIGHT**

- **FLEXIBILITY**

- **RESISTANT TO HOSTILE ENVIRONMENTS**

- **FREEDOM FROM CROSS-TALKS**

- **NO SPARKING AND FIRE HAZARDS**

- **RAW MATERIAL (SILICA) ABUNDANTLY AVAILABLE IN NATURE**
1840  First Laboratory Demonstration of Principles of Total Internal Reflection (TIR) by Daniel Colladon and Jacques Babinet at University of Genava.

1852  First Public Demonstration of TIR by John Tyndall in London


1930  Image Transmission by Tubes used First Time for Internal Medical Examination by Heinrich Lamm

1952  First Experiment that led to Invention of Optical Fibers by N S Kapany & later Practical Fibers were Produced where Glass Fibers are Coated with Transparent Material to offer a more suitable cladding
1956 Development of Fiber Bundles for Image Transmission; First Fiber Optic Semi Flexible Gastroscope by Lawrence E Curtiss at Michigan Uni.


1966 Charles K Kao & George A Hockham of STC London First to Proposed Optical Fiber as a Practical Medium to Communicate only If their Attenuation/Loss Could be Reduced to 20dB/Km

1970 First Demo. of Optical Fiber with Loss of 17dB/Km by Robert D Maurer, Donald Keck, Peter C Schultz & Frank Zimar at Corning Glass, USA by Dopping Silica with Titanium. Later Dopped Silica with Ge to Produce Fiber with Losses as Low as 4dB/Km

2000 Optical Fibers with Losses much below 1dB/Km Theoretically Loss Cannot be Reduced Below the Rayleigh Limit of 0.156dB/Km.
Types of Fibers

1. **Step Index Multimode Fibers**

2. **Graded Index Multimode Fibers**

3. **Step Index Single Mode Fibers**
Graded Index Fiber

$n$ Varies Quadratically
Graded Index Fiber
Refractive Index Profiles of Optical Fiber

\[ n^2(r) = n_1^2 \left[ 1 - 2\Delta \left( \frac{r}{a}\right)^q \right] \quad 0 < r < a \quad \text{Core} \]

\[ = n_2^2 = n_1^2 \left[ 1 - 2\Delta \right] \quad r > a \quad \text{Cladding} \]
Numerical Aperture of a Fiber (N.A)

Numerical Aperture defines a Cone of Acceptance for Light that will be Guided by the Fiber

\[ \theta_{\text{max}} \]

\[ NA = n_{\text{outside}} \sin(\theta_{\text{max}}) \]

\[ NA = \sqrt{n_{\text{core}}^2 - n_{\text{clad}}^2} \]
NUMERICAL APERTURE

Light inside the Acceptance Cone can only be Coupled into the Fiber
The V Parameter

- An Important Parameter that Governs the Number of Modes that can Travel in Fibers
- For \( V \leq 2.405 \), Fiber supports only one Mode which is Fundamental Mode and hence the name Single Mode Fiber.

\[
V = 2\pi \frac{a}{\lambda_o} NA
\]

\( a = \text{Fiber Radius} \)
\( \lambda_o = \text{Incident Wavelength} \)
DESIGNER’S PARAMETERS

Numerical Aperture (NA): 

\[ NA = \sin \theta_a = \left[ (n_1)^2 - (n_2)^2 \right]^{1/2} \]

N.A : 0.12 - 0.15 for SMF; 0.15 - 0.25 for MMF

Relative Refractive Index Difference (\( \Delta \)): 

\[ \Delta = \frac{n_1 - n_2}{n} \quad n - \text{the average refractive index} \]

\( \Delta \) : <0.4% for SMF; > 1% for MMF

Normalized Frequency or V-Number: 

\[ V = \left( \frac{2\pi a}{\lambda} \right) NA \]

V : \( \leq 2.405 \) for SMF; \( \geq 10 \) for MMF
BROAD APPLICATION AREAS

- FIBER OPTIC INSTRUMENTATION
- FIBER OPTICS COMMUNICATION
- FIBER OPTIC SENSORS
Fabrication Techniques Varies for Different Types and Applications of Optical Fibers

• Communication Fibers
• Glass Fibers
• Plastic Fibers
How are Communication Optical Fibers made?

Three Steps are Involved

- Making a Preform Glass Cylinder
- Drawing the Fibers from the Preform
- Testing the Fiber
PREFORM FABRICATION PROCESS

• Choosing Required Pure Raw Materials
• Transport of Reactants to Heat Source
• Chemical Reactions and Particle Formation
• Particle Collection
• Drying and Sintering
• Preform Design
# TYPICAL MATERIAL COMBINATIONS FOR OPTICAL FIBERS

<table>
<thead>
<tr>
<th>CORE</th>
<th>DEPOSITED CLAD</th>
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<tbody>
<tr>
<td>• GeO$_2$.B$_2$O$_3$.SiO$_2$</td>
<td>• B$_2$O$_3$.P$_2$O$_5$.SiO$_2$</td>
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MOD. CHEMICAL VAPOUR DEPOSITION (MCVD)

OUTSIDE VAPOUR DEPOSITION (OVD)

VAPOUR AXIAL DEPOSITION (VAD)
MODIFIED CHEMICAL VAPOUR DEPOSITION (MCVD) PROCESS

It involves depositing high purity material on the inner surface of a tube, collapsing this composite to form a preform rod comprising the core/clad structure and drawing this preform into controlled diameter light guide fiber.

- First described by MacChesney et al. in 1974 at AT &T Bell Labs.
- Most simple, versatile, flexible & widely used.
- Used for drawing both S.M fibers (2 - 5 layers) and M.M fibers (30 - 70 layers).
MODIFIED CHEMICAL VAPOUR DEPOSITION (MCVD) PROCESS (contd.)

- Germanium Dioxide as Dopant to Increase R.I
- Fluorine to Decrease R.I
- \( \text{B}_2\text{O}_3 \) and \( \text{P}_2\text{O}_5 \) to Decrease the Processing Temp.
- Typical Core \( \text{GeO}_2 - \text{P}_2\text{O}_5 - \text{SiO}_2 \)
- Cladding Barrier \( \text{P}_2\text{O}_5 - \text{B}_2\text{O}_3 - \text{SiO}_2 / \text{P}_2\text{O}_5 - \text{F} - \text{SiO}_2 \)
- Substrate Cladding \( \text{SiO}_2 \)
- Diffusion of Ge to Surface During Collapse gives Centre Dip in RIP which is Removed by Flowing Small Quantity of \( \text{GeCl}_4 \) During Collapse
MODIFIED CHEMICAL VAPOUR DEPOSITION (MCVD) PROCESS - SCHEMATIC

The Deposition Phase of the Process is Based on the High Temperature Oxidation of SiCl$_4$ and other Dopant Halides to Form High Silica Glass Compositions.
Steps for Making Fiber Preform using MCVD Method

- Prepare a Silica Tube.
- Heat the tube
- Inject SiCl$_4$ and O$_2$ into the Tube
- At the Heated Portion, the SiCl$_4$ is Oxidized
  \[ SiCl_4 + O_2 \xrightarrow{\text{heat}} SiO_2 + 2Cl_2 \]
- Ultra pure SiO$_2$ is Deposited on the Inner Walls of the Tube
- Draw the Tube through the Furnace, continuously Coating the Inner Walls with SiO$_2$ Particles deposit
- Sinter along the Tube
CHEMICAL REACTIONS AND PARTICLE FORMATION

\[
\begin{align*}
\text{SiCl}_4 + O_2 & \rightarrow \text{SiO}_2 + 2\text{Cl}_2 \\
\text{GeCl}_4 + O_2 & \rightarrow \text{GeO}_2 + 2\text{Cl}_2 \\
2\text{H}_2\text{O} + 2\text{Cl}_2 & \rightarrow 4\text{HCl} + O_2 \\
\text{GeO}_2(s) & \rightarrow \text{GeO} (g) + \frac{1}{2} O_2(g)
\end{align*}
\]
MODIFIED CHEMICAL VAPOUR DEPOSITION (MCVD) PROCESS
PREFORM MAKING BY MCVD PROCESS
Temperature Field within an MCVD Substrate Tube Relative to Torch Position
Particle Trajectories Resulting from Temperature Field
Particle Growth Trajectories in MCVD
SEM Micrograph of Consolidation of a Particular Layer Showing Surface (Top View) and Cross-Section (Bottom View)
Transparent Preform Containing Bubbles
MCVD PRODUCTION LATHE UNIT

PREFORM PRODUCTION AREA AT AT&T TECH. USA
OUTSIDE VAPOUR DEPOSITION (OVD) PROCESS

- Invented by Keck and Schultz at CORNING GLASS WORK, USA in 1973

- Both Step Index and Graded Index Fiber Designs can be Achieved.

- Complexity and Custom Designed Equipment have caused Restricted use of the Process.
OUTSIDE VAPOUR DEPOSITION (OVD) PROCESS

a) Soot Deposition
b) Sintering
c) Fiber Drawing
VAPOUR PHASE AXIAL DEPOSITION (VAD) PROCESS

- First Described by IZAWA et. al at NTT, Japan in 1977
- Continuous Fabrication Process of Fiber Preform in Axial Direction and is Preferred for Mass Production
- Deposition & Consolidation Steps arranged in Sequence
- Long and Large Diameter Preform can be Produced, thereby, Reducing Significant Cost in Fiber Production
- Raw Materials such as SiCl$_4$, GeCl$_4$, PoCl$_3$ and BBr$_3$ are Fed from the Bottom into Oxyhydro Flame
- Porous Preform Produced by Depositing Glass Particles by Flame Hydrolysis Reaction and is Consolidated by Zone Melting in Carbon Ring Heater.
VAPOUR PHASE AXIAL DEPOSITION (VAD) PROCESS
VAPOUR PHASE AXIAL DEPOSITION (VAD) PROCESS
STAGES OF PREFOM MAKING
CROSS-SECTIONAL STRUCTURE OF FIBER PREFORM AND RESULTING POLARISATION-MAINTAINING FIBERS

Rod-in-jacket

Pit-in-jacket
SIMPLE

TRIANGLE

GRADED

DEPRESSED CLAD

DOUBLE CLAD(W)

QUADRUPLE CLAD

DESIGN FLEXIBILITY

WIDEBAND

SINGLE MODE FIBER DESIGNS
OPTICAL FIBER DRAWING MECHANISM
- Fibers are Drawn at 30 to 60 ft/s
- Multiple Polymer Coatings may be Applied
  - Thermoplastic (Buffer)
  - PVC of Fluoride as Co-Polymer
- Spools up to several km are wound.
OPTICAL FIBER DRAWING AREA
## FACTORS AFFECTING THE MECHANICAL STRENGTH OF FIBERS PULLED IN GRAPHITE FURNACE

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>MAJOR FACTOR</th>
<th>MINOR FACTOR</th>
<th>NO OBSERVABLE INFLUENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Preform Quality</strong></td>
<td><strong>MATERIAL GRADE:</strong> Synthetic silica has higher strength than natural quartz.</td>
<td><strong>Residual strain/small surface marks:</strong> Eliminate by flame polishing and annealing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Preform cleanliness: Ideal clean: HF wash and flame polish</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Furnace Environment</strong></td>
<td><strong>Contamination by graphite dust and impurities:</strong> Reduced by: 1. High grade graphite.</td>
<td><strong>Abrasion of preform at top seal:</strong> Eliminate top seal</td>
<td><strong>Furnace preheating:</strong> Preheat for several hours before fiber pulling</td>
</tr>
<tr>
<td></td>
<td>2. Prolonged burn-in period. 3. Optimize gas-flow pattern</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Fiber-forming Process</strong></td>
<td><strong>Temperature/pulling tension:</strong> Control by optimizing furnace temperature and pulling speed</td>
<td><strong>Temperature profile:</strong> Alter hot zone profile by heating element arrangement</td>
<td><strong>Fiber cooling rate:</strong> Use forced gas cooler to accelerate cooling rate</td>
</tr>
<tr>
<td>PROPERTY</td>
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<tr>
<td>------------------</td>
<td>------------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------------</td>
</tr>
</tbody>
</table>
| Primary coating  | *Decentered coating:* Crucible alignment to < 1mm  
*Coating thickness:* Minimum thickness for soft silicone coat >30mm  
*Polymer cleanliness:* Filter to eliminate dust and impurities | *Irregular coating:* Vibration. Fiber temperature too high at crucible.  
*Crucible design:* 1. Tapered tip gives lower eccentricity.  
2. Flexible tip gives a thicker coating | *Fiber-polymer attenuation:* Optical attenuation of fiber polymer coat unrelated to strength  
*Pulling speed:* No effect on coating quality |
| Fiber handling   | *Surface damage:* Use Teflon-coated pulling drum/expanded polystyrene storage drums | *Thermal expansion differences:* cool fiber before winding on drum | |
Plastic/Glass Fiber Fabrication Techniques

- EXTRUSION TECHNIQUE
- DOUBLE CRUCIBLE METHOD
- ROD - IN - TUBE METHOD
Glass Fiber Drawing by Double Crucible Method

- This Method has become Important in the Production of Inexpensive Fibers by a Continuous Process.

- The Starting Materials may be Fed in either Powdered Form or by Means of High Purity Preformed Rods.
Double Crucible Mounted inside a Vertical, Silica Lined Muffle Furnace capable of Raising the Melt Temp between 1000-1200°C.

An Inert Gas Atmosphere is Maintained inside the Furnace.

Control of the Core and Cladding Diameters are Maintained by the Fiber Pulling Speed and the Head of Molten Glass in each Crucible.

With a Suitable Choice of Materials and Control of the Melt Temperature at the Nozzle, Index Grading can be obtained by Ionic Diffusion.
DIMENSIONS OF TYPICAL DOUBLE CRUCIBLE

\[ R_1 = 0.5-1.5\text{mm} \]
\[ R_2 = 2-3\text{mm} \]
\[ A_1 = 5-15\text{mm} \]
\[ A_2 = 40-50\text{mm} \]
\[ H_1 = 30-80\text{mm} \]
\[ H_2 = 30-80\text{mm} \]
\[ H_3 = 40-100\text{mm} \]
\[ I_1 = 8-24\text{mm} \]
\[ I_2 = 15-30\text{mm} \]
\[ I_3 = 10-30\text{mm} \]
GLASS FIBER DRAWING WITH ROD - IN - TUBE METHOD

Core

Cladding

Heater
Fiber Drawing Machine Developed at CSIO
WHY CABLING?

- EASE OF HANDLING THE FRIGILE FIBER
- PROTECTION FROM DAMAGING FORCES
- ENVIRONMENTAL PROTECTION
OPTICAL FIBER CABLE DESIGN

- **Fiber Protection**: Protect against fiber damage and breakage both during installation and throughout the life of the fiber.

- **Stability of Fiber Transmission Characteristics (T.C.)**: Must be designed so that the T.C. of the fiber are maintained after the cabling process and cable installation.

- **Cable Strength**: High mechanical properties (tension, compression, bending, squeezing and vibrations) – need for strength members and thick outer sheath.

- **Identification and Jointing of fibers within the cable**: Cables with large number of fibers; fibers to be arranged in suitable geometry.
FIBER OPTIC CABLE JACKET COLOR

For **Outdoor Aerial and Burial type Cables**, the Jacket Color is usually Black Polyethelene for both MM and SM Cables to prevent UV Radiation Damage. For **Indoor Cables**, the outer most Fiber Cable Jacket may be of any color but the de facto Industry Standard is:

- **Orange** for Multimode Fibers
- **Yellow** for Singlemode Fibers

Fiber Color Codes are Specified by TIA/EIA 598-A. In Loose Tube Cables, this Color Code will be used for Tubes as well as Fibers within the Tubes and Subgroups.
FIBER CABLE
Cross - Sectional View of Six Fiber Telecommunication Cable
Fiber Cable View

- Outer Jacket Polyethylene
- Aramid Strength Elements
- Flooded Core
- Central E-Glass Strength Member
- Thermoplastic Tube
- Moisture Blocking Gel
- Multiple 250 Micron Fibers

- .9" diameter
- High-density polyethylene jacket
- Metal armor
- Rip cord
- Inner sheath
- Dielectric strength member
- Water-blocking tape
- Core tube
- Each of the 12 ribbons has 24 fibers
Various Fiber Cable Designs
Fiber Cable Manufacturing Process
Fiber Cabling Machine
Fiber Cabling Machine
Cabled Fiber Rolls/Spools
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Thank you