Efficient Optical Couplings for Fiber-Distributed Solar Lighting

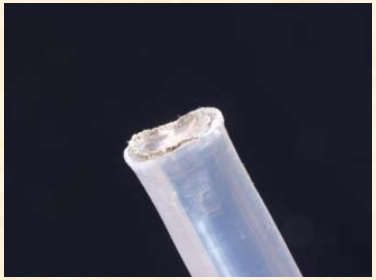
L. Curt Maxey

Oak Ridge National Laboratory

Hybrid Solar Lighting systems transport concentrated (~200X) sunlight

Coupling losses have several unwanted effects

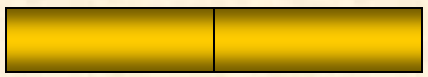
- **Reduced efficiency**
- **Heating**
- **Component degradation**



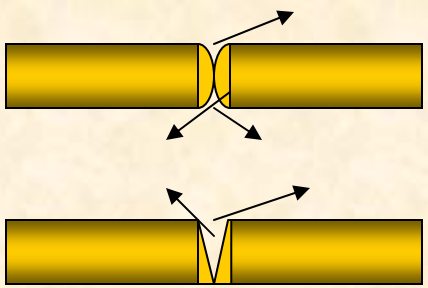
Waveguide coupling losses are dominated by three factors

- Endface geometry
  - controlled during polishing steps
- Alignment
  - determined by connector design
- Fresnel losses
  - mitigated by coupling media

Flat, perpendicular endfaces minimize losses

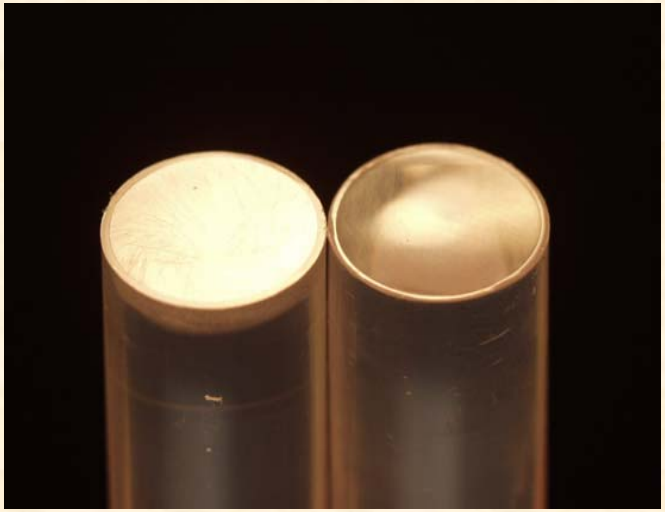


Flat perpendicular endfaces provide core to core coupling

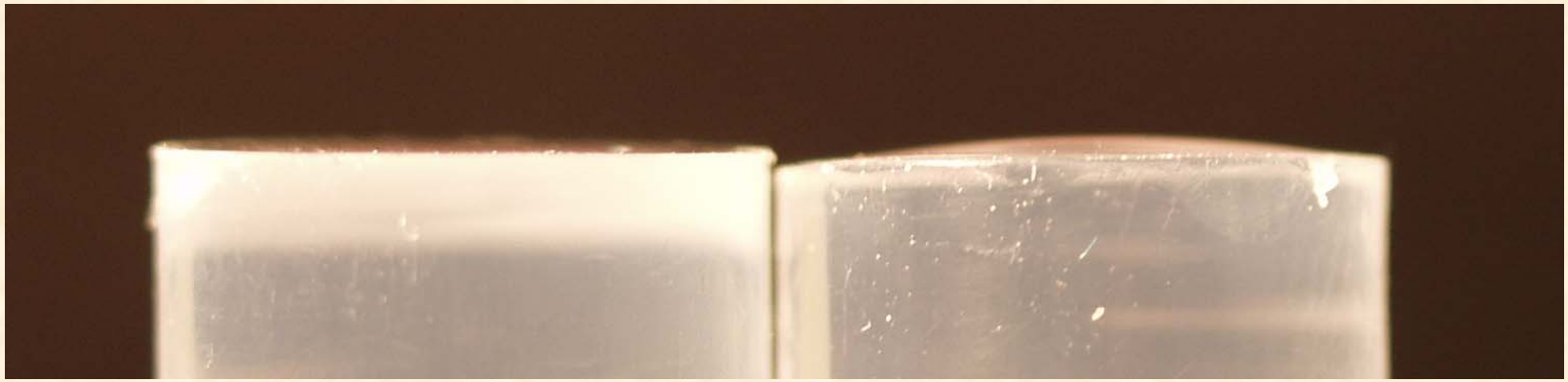


Rounded endfaces and non-perpendicular endfaces produce exit paths for light to escape and may actually refract light out of the fibers

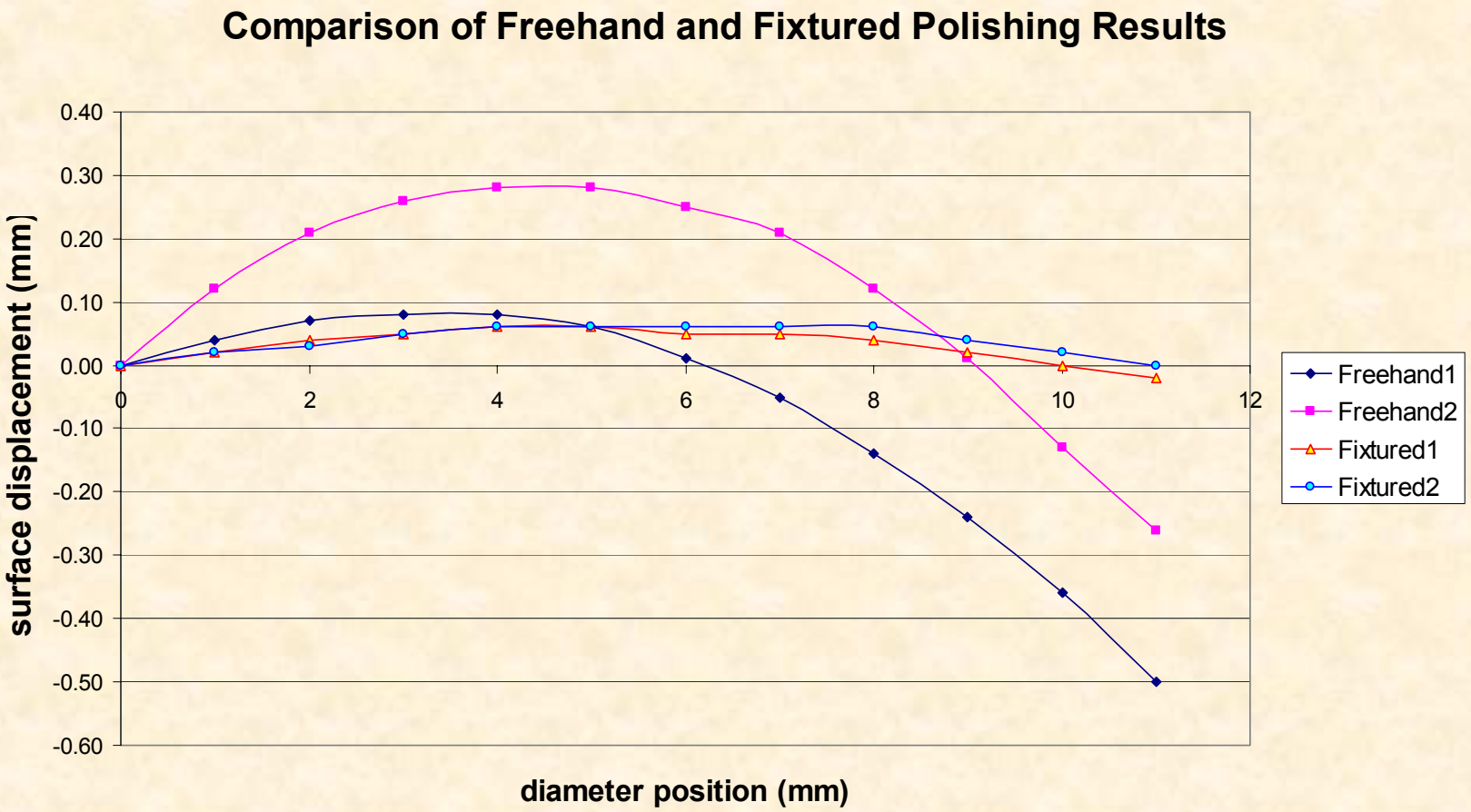
Freehand polishing processes introduce rounding and do not control perpendicularity



Fixture polished endface (left)
Is noticeably flatter than the
Freehand polished surface (right)



Fixtured polishing improves fiber endface flatness, perpendicularity and repeatability



Connector designs must maintain endface contact and alignment

Several factors must be accommodated to maintain good connection integrity under all operating conditions

- variation in fiber diameter
- tensile loads
- bending loads
- connection break and re-make
- thermal stresses

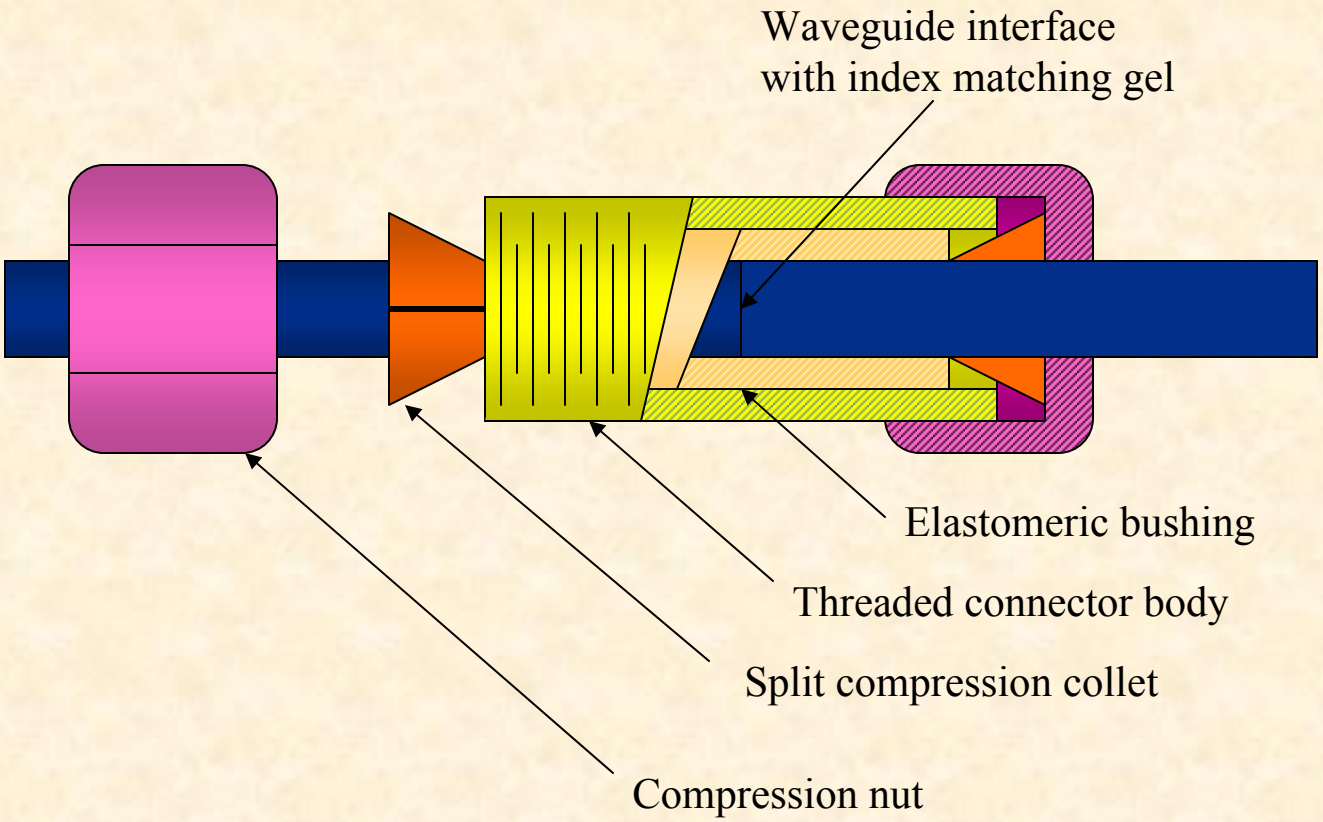
appreciable light loss results from insufficient ability to control any of these factors

We are working on connector prototypes that consistently maintain optimum alignment

Key features of prototype connectors

- Strong axial compression
- Ability to tolerate variations in fiber diameter
- Good coaxial alignment of fiber ends
- Resistance to tensile and bending stresses

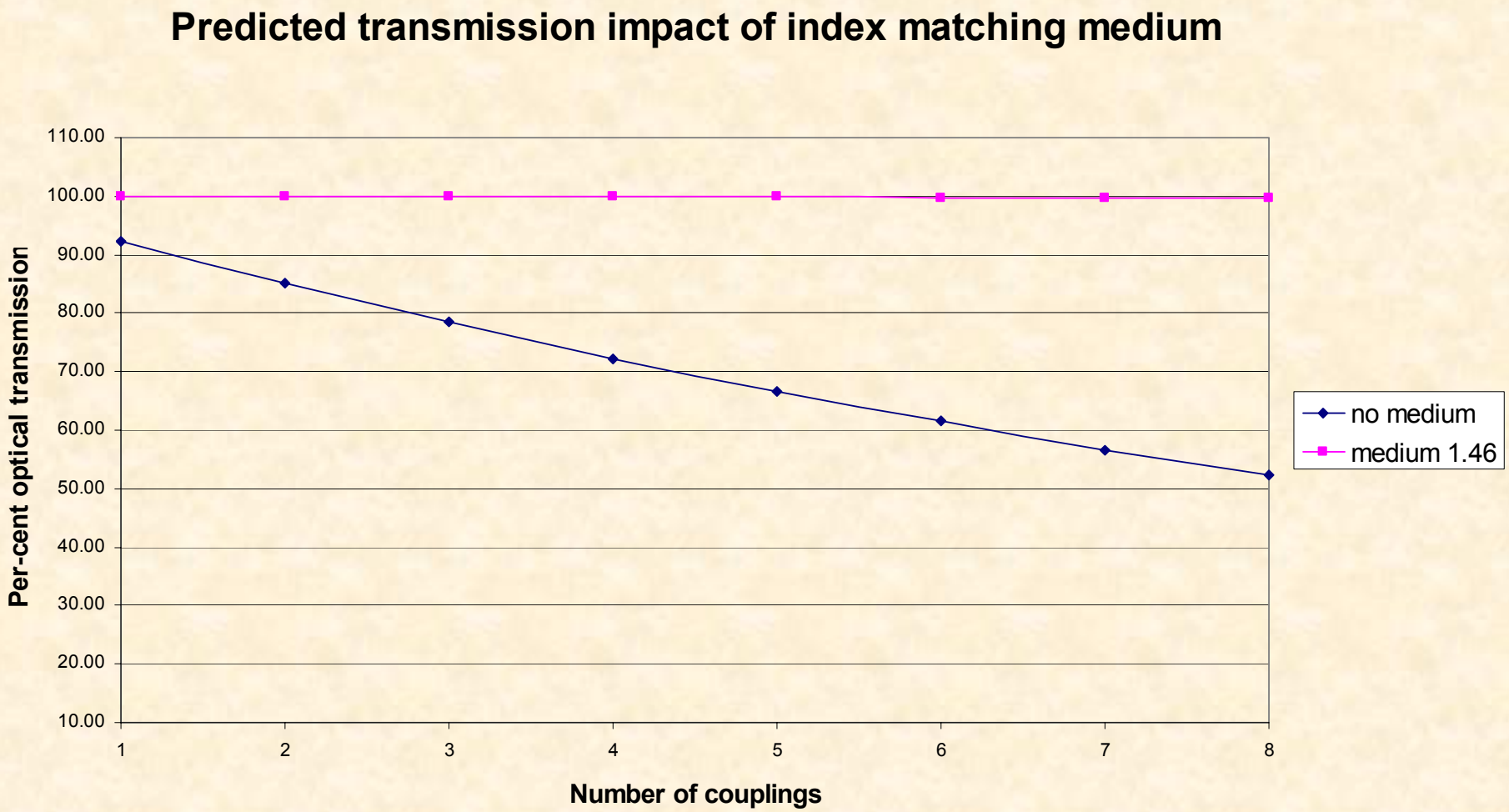
Prototype Connector Diagram with Cutaway Section View



Unmitigated Fresnel reflection creates significant loss at each coupling

- Material dependent phenomenon
  - $R = [(n_2 - n_1)/(n_2 + n_1)]^2$ *(per interface, x2 per coupling)*
- Approximately 8% per coupling with n=1.5 core
- A variety of index matching media can help
  - commercial fluids and gels, glycerin, adhesives etc.
- An exact match is not necessary to achieve results
  - example: core-1.5, medium-1.3, coupling loss-1.2%
- Be attentive to other optical or physical properties that a medium may introduce into the system

Index matching media significantly reduce the fresnel losses at each coupling *(core n=1.5)*



Coupling efficiency can be improved by focusing on the basics

- Good couplings begin with good endfaces
- Connectors must be able to preserve the alignment of the fibers under all operating stresses
- Use index matching media to reduce Fresnel losses

Attention to these details has enabled us to reduce individual connector losses from greater than 15% to less than 5% with typical coupling losses of 2%