Exploring Advanced Methods for Deposition of Carbon Nanotubes on Photonic Bandgap Fiber for Improved Laser Design

Jennifer Schuler

Rensselaer Polytechnic Institute, Troy, NY

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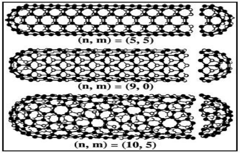

Fig. 2.16. Single-walled carbon nanotubes.[1308]

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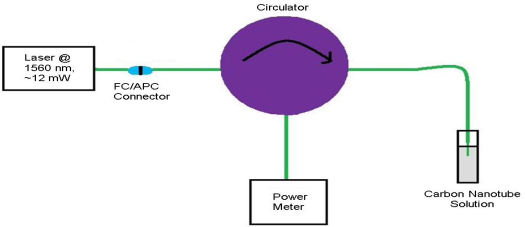
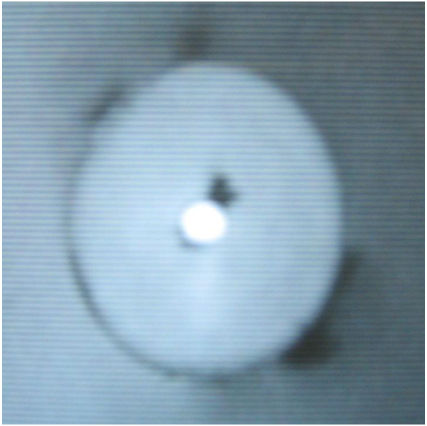
The Deposition Process

- Step index single mode fiber (SMF) is attached to a circulator and dipped in a solution of single-walled carbon nanotubes and ethanol (2).
- Laser light is then pumped through the fiber for $\sim$ 15 minutes to generate the deposition.
- Pump laser is set at $\lambda \approx$ 1560 nm with power $\approx$ 12 mW

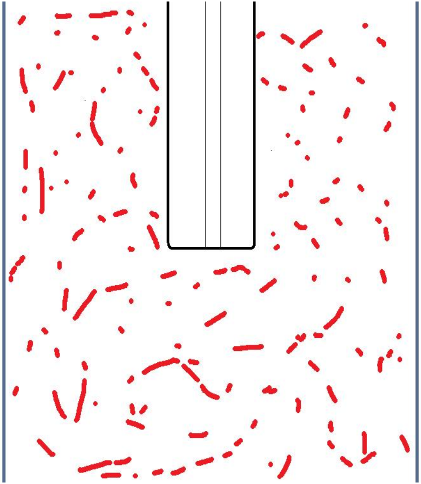


- Solution must be mixed VERY well

Deposition on Single Mode Fiber (SMF) Tip



Physics of the Deposition Process



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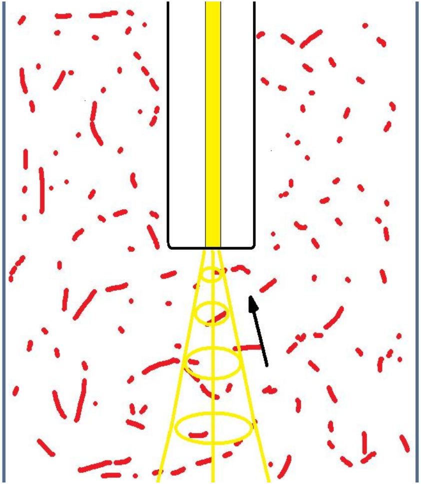

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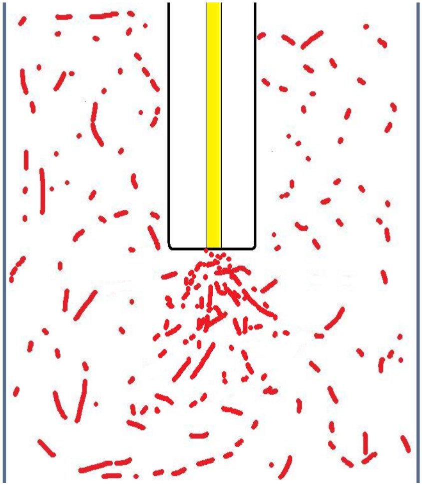

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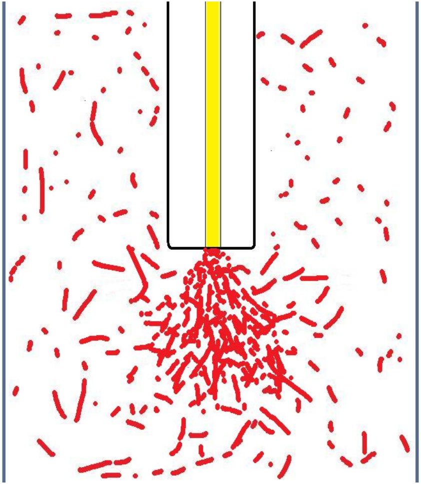

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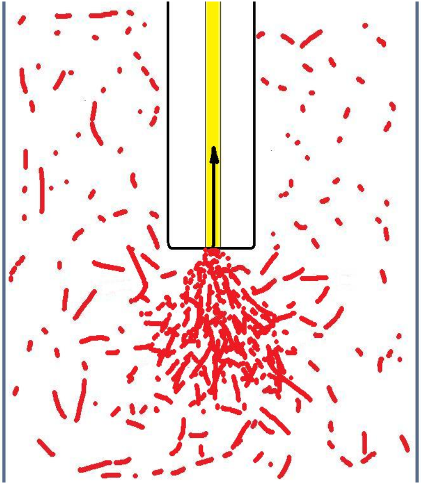
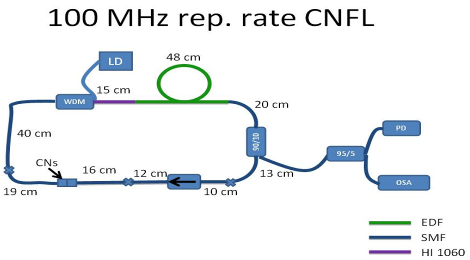
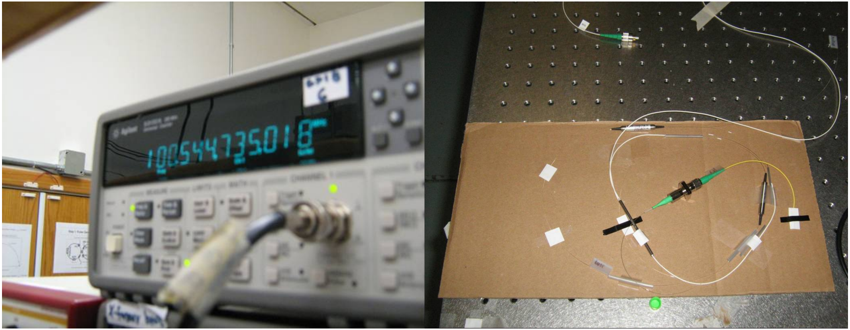
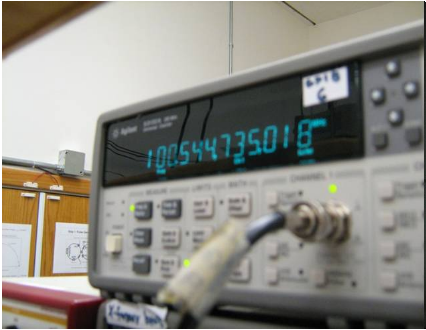


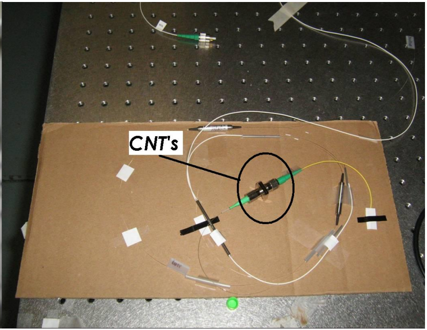
Building the Carbon Nanotube Fiber Laser

- The components of the laser include a wavelength division multiplexer (WDM),erbium doped fiber (EDF), isolator, 90/10 splitter and the CNT connector.
- In order to build the laser, we put all of the components together and then proceeded to cut back fiber until the desired repetition rate of 100 MHz was reached. We began with about 4 m of fiber, and cut back to 2 m. In the end 48 cm of EDF were used.








CNT's

Breaking the Carbon Nanotube Fiber Laser

Characterizing the Carbon Nanotubes

- Laser bandwidth was abnormally small at $\sim$ 6 nm.
- We hoped that cutting back fiber would increase the bandwidth, but no relation was seen.
- We decided to characterize the carbon nanotubes to measure their effect on the laser cavity

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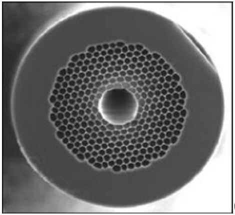
A Broken Laser

- In the characterization process too much power was put through the laser.
- The carbon nanotubes burned and the fiber was damaged.
- Damage threshold of carbon nanotubes is $\sim$ 50 mW

Photonic Bandgap Fiber (PBGF) Instead of Single Mode Fiber (SMF)

What is PBGF?

- Photonic bandgap fiber has a honeycomb of holes surrounding a hollow core (3).
- Photonic bandgap fiber guides light through interference.
- Carbon nanotube deposition in photonic bandgap fiber can help make a higher repetition rate laser.



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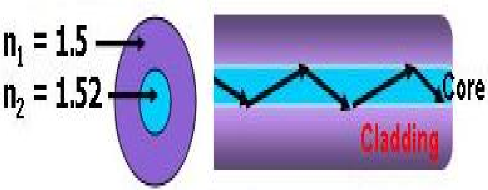

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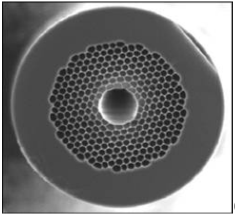

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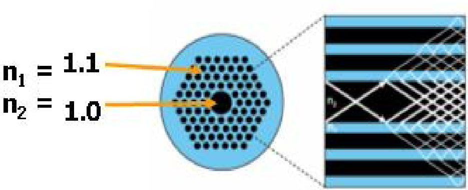
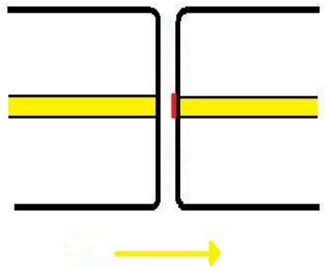


Why Do We Want to Use Photonic Bandgap Fiber?

First Motivation

- Evanescent coupling to the carbon nanotubes in the cladding would increase the damage threshold.



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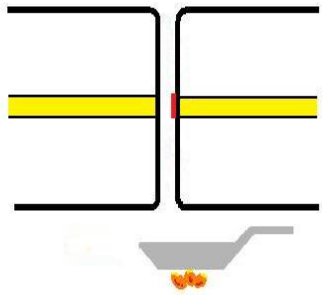

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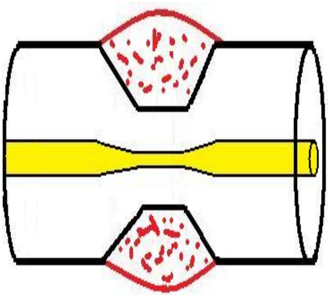

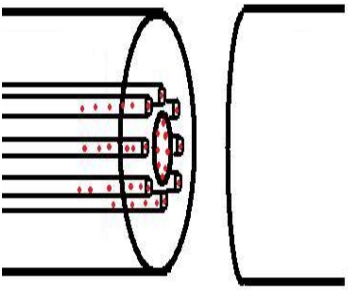

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Photonic bandgap fiber has a larger negative group velocity dispersion, β_2,than single mode fiber, meaning a smaller length is needed to minimize net laser cavity dispersion.

Equation used to determine net cavity dispersion

$$\beta_{2(HI1060)} L_{HI1060} + \beta_{2(EDF)} L_{EDF} + \beta_{2(?)} L_{?} = \text{net cavity dispersion}$$

$$\beta_{2(HI1060)} = -0.45 \cdot 10^{-5}\ \text{fs}^2/\text{nm}$$

$$\beta_{2(EDF)} = 1.12 \cdot 10^{-5}\ \text{fs}^2/\text{nm}$$

$$\beta_{2(SMF)} = -2.315 \cdot 10^{-5}\ \text{fs}^2/\text{nm}$$

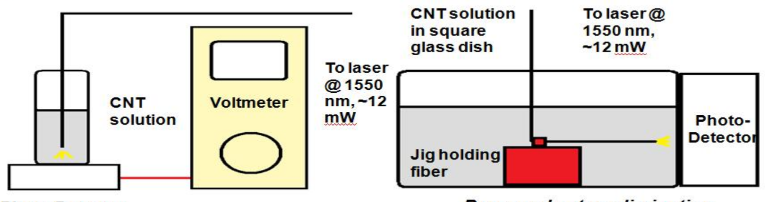
$$\beta_{2(PBGF)} = -11.05 \cdot 10^{-5}\ \text{fs}^2/\text{nm}$$

$$L_{HI1060} = 0.15\ \text{m}$$

$$L_{EDF} = 0.48\ \text{m}$$

Attempting to Do the Deposition

- Due to the splice between single mode fiber and photonic bandgap fiber, the reflected light from the splice overshadowed any change in reflected light.
- Instead of looking at the reflected light, a photo-detector with a voltmeter was placed directly underneath the solution to measure the transmitted light.
- The new setup also allows deposition to be measured on an angled cleave.



Setup eliminating circulator

Proposed setup eliminating problem of settling CNT's

Conclusion

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- Work still needs to be done to determine deposition in photonic bandgap fiber
  - The new setup needs to be refined
  - Progress can still be made in determining deposition on an angled cleave
- Carbon nanotube deposition in photonic bandgap fiber is still a viable option for improved laser design and frequency metrology

Acknowledgments and References

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- (1) `www.nanomedicine.com/NMI/Figures/2.16.jpg`
- (2) ”Optically driven deposition of single-walled carbon-nanotube saturable absorbers on optical fiber end-faces” by: Nicholson, Windeler and DiGiovanni
- (3) ”Photonic band gap guidance in optical fibers” by: Knight, Broeng, Birks, Russel
- (4) `www.rdmag.com/images/0407/RD47FE_PH1.jpg`