Dynamic High Repetition Rate Carbon Nanotube Fiber Laser Frequency Comb

Tyler McKean[1,2], Jennifer Schuler[1,3], JinKang Lim[1], Kristan L. Corwin[1], and Brian R. Washburn[1]

[1]116 Cardwell Hall, Department of Physics, Kansas State University, Manhattan, KS 66506, USA
[2]Department of Physics and Optical Engineering, Rose-Hulman Institute of Technology, 5500 Wabash Ave, CM 169, Terre Haute, IN, 47803, USA
[3]Department of Physics, Applied Physics and Astronomy, Rensselaer Polytechnic Institute, Troy, NY 12180, USA

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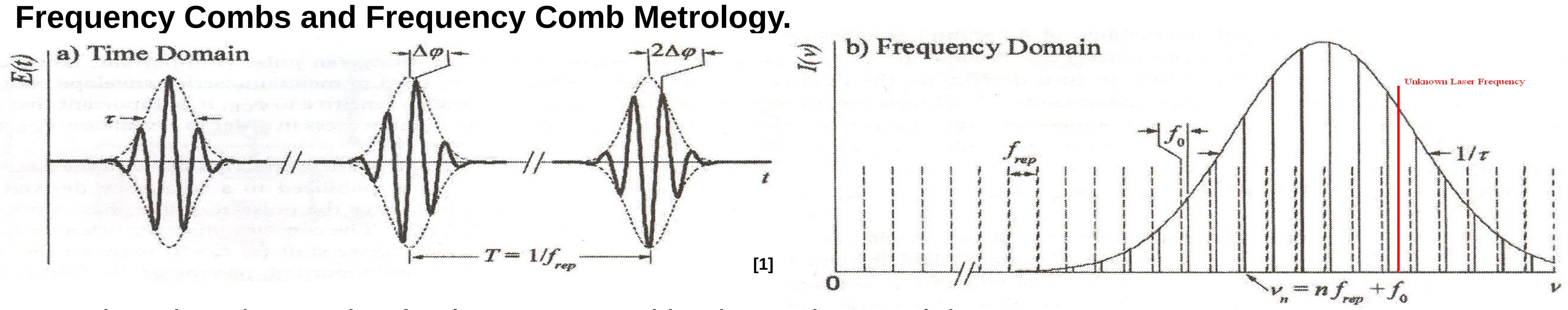
Abstract: Through the use of single wall carbon nanotubes (SWCNT) and their saturable absorption properties, it is possible to create a very stable mode-locked fiber laser. In turn, a very stable frequency comb can be generated by this type of laser. One of the main applications of this resulting frequency comb would be frequency comb metrology. Through which, it is possible to characterize the unknown frequency of a laser by referencing it to this stabilized frequency comb. By being able to dynamically control the properties of this frequency comb it is possible to make this process much more accurate.

Frequency combs and metrology applications

Frequency Combs and Frequency Comb Metrology.



- In time domain, a train of pulses separated by the cavity travel time.
- In frequency domain, a series of Dirac delta functions (referred to as teeth of the comb) separated by repetition rate of the laser.
- By beating an unknown laser with our known frequency comb reference we can use the resulting beat note to match the laser to a specific tooth and find the repetition frequency of the laser.

What is required for this?

- A very stable mode-locked laser (to generate the frequency comb).
- High repetition rate laser.
  - Requires minimizing the length of fiber in cavity.
  - Increases the spacing between teeth of the comb.
  - Makes is easier to match the unknown laser to the correct tooth of the comb.
- Dynamic control over the frequency comb.
  - Allowing for more accurate/Vernier determination of mode number *n* .
  - Each individual tooth moves by n (~10^6) times the repetition rate of the laser.
  - Small changes in repetition rate result in large changes of tooth location.

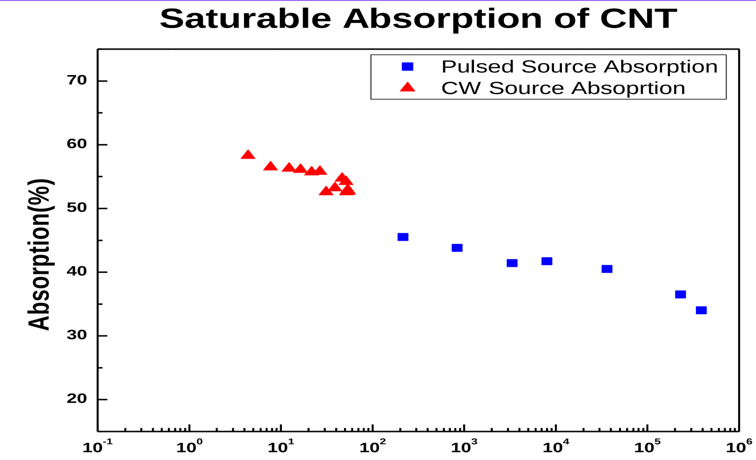
Designing and building a mode-locked carbon nanotube fiber laser

Using single wall carbon nanotubes (SWCNT) to make a mode-locked laser.

- The saturable absorption properties of the SWCNT cause mode-locking.
  - Act like a semi-conductor
  - Absorption decreases as intensity of light increases.
  - High intensity fluctuations of pump laser pass through CNT with low absorption
  - Fluctuations amplified with each cavity trip and result in mode-locking.

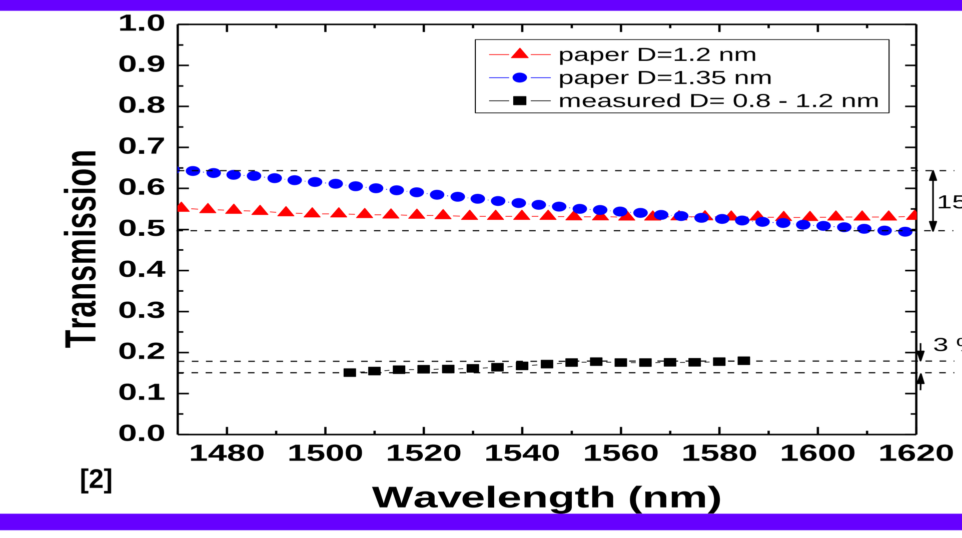
Characterized saturable absorption properties.

- Absorption decreased as intensity increased, as expected.
- Unintentionally found SWCNT to have a damage threshold of 40-50mW of CW light.



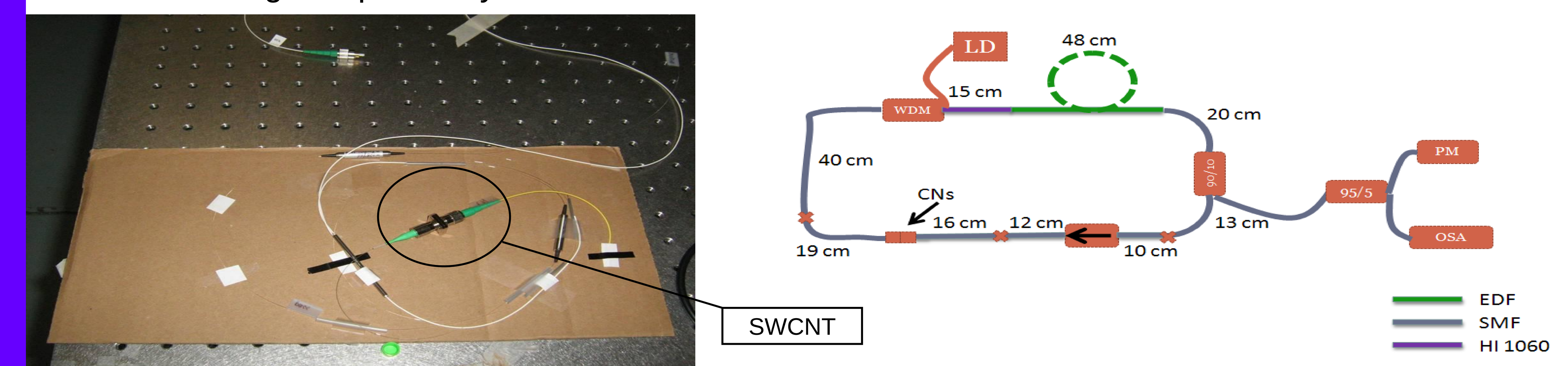
Characterized wavelength dependant absorption

- Found SWCNT to have very little wavelength dependant absorption.
- Absorption properties change with diameter.



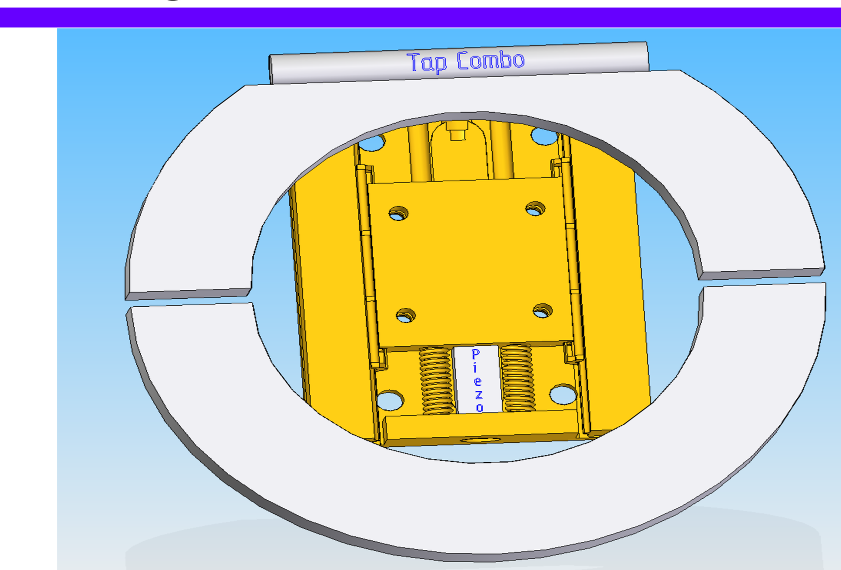
Properties of finished carbon nanotube fiber laser (CNFL).

- Repetition rate: 100.5 MHz.
- Bandwidth ranging between 5-8 nm.
- Total cavity length: 2 m
- Self starting and passively mode-locked.



Dynamic high repetition rate laser design

How the design works.



- Fiber laser is wrapped around metal ring.
  - Outer Radius: 2 in
  - Inner Radius: 1.3 in
- Using Newport translation stage as base.
  - Upper ring is attached to stage (moving)
  - Lower ring is attached to sides (stationary)
- Tap combo is WDM/Splitter/Isolator component
  - Shortens cavity length, increasing repetition rate
- Piezoelectric transducer used to stretch fiber.
  - Transducer displacement length: 17.4 μm
  - When electricity is applied the transducer pushes the ring halves apart.
  - Stretches fiber, changing the repetition frequency of the laser.
- Design allows cavity length to change by up to 34.8 μm.
- Change in repetition rate for our pre-existing CNFL:

$$\Delta f = \frac{2\,\Delta \cdot f_1}{d_1}$$

$$\Delta f = \frac{2 \cdot (17.4\ \mu m) \cdot (100\ MHz)}{2\ m} = 1740\ Hz$$

- Able to change optical frequency of specific comb tooth by ~ 2 GHz

Piezoelectric Transducer

Acknowledgements: I would like to thank Kevin Knabe, Shun Wu, Chenchen Wang, Karl Tillman, Andrew Jones, Larry Weaver for their help. I would also like to thank the NSF and all other parties who made this opportunity possible. This work was partially funded under NSF grant number PHY-0851599.

References

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