Nonlinear ultrafast fiber optic devices based on Carbon Nanotubes

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Outline

- Introduction
- CNT-coated TFBG
- Nanotube deposition
- Nonlinear experiment
- Conclusion
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Introduction

- Use of nonlinear materials for optical applications
  - Second harmonic generation
  - Optical parametric amplification
  - Four wave mixing
  - Saturable absorbance
  - Wavelength conversion
  - ... (omitted)

- Ultrafast response, large bandwidth, high damage threshold, fiber compatibility
Carbon nanotubes

- Single Walled CNT
- Double Walled CNT
- Multiple Walled CNT

Diameter ~ few nm  
length ~ hundreds µm  

Unidimensional system
Introduction

- Interesting optical properties
- Depending on the chirality, CNTs can behave as conductor or semiconductor in optical frequencies
- The absorption band is related to the tube diameter

- This absorption is saturable
Introduction

- CNT-based Mode-locked fiber lasers approaches

CNT composite polymers

- CNT deposited on D-shaped fiber
- Fiber microchannel filled with CNT
- Selective CNT deposition on fiber end
- CNT deposition in hollow fiber
- CNT deposition on tapered fiber

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CNT-coated TFBG

- CNT for mode locked fiber lasers: Interest in all-fiber solutions
- Damage threshold of CNTs not high: distributed interaction desired
- Avoid delicate fiber structures

Use of tilted fiber Bragg grating (TFBG)
Tilted fiber Bragg Gratings

- Higher coupling of light to counter-propagating cladding modes
- Cladding mode resonance frequencies depend on, among other factors, the external refractive index $n_{\text{ext}}$
CNT-coated TFBG

- Light coupled to a cladding mode interacts with the outer medium
- Cladding mode resonance frequency shifts as $n_{\text{ext}}$ varies
- Nonlinear external layer $\rightarrow n_{\text{ext}}(I_{\text{cladding}})$

Nonlinear transmittance response $T(I)$
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Nanotube deposition

1) Dipping method

- Fiber 3min immersion in 3-aminopropyltriethoxysilane (APTES) solution, COOH-SWNT/DMF dispersion and pure water sequentially
- 10 steps process → coating thickness progressive growth
- Measurements of optical transmittance each step
Nanotube deposition

2) Wrapping method

- Preparation of SWNT film floating in water:
  - CNT film implemented by vacuum filtration
  - Easy detachment from the filter membrane in water
- Manual wrapping of SWNT film on the fiber

- Thicker coating compared to dipping method is obtained
Nanotube deposition

Dipping

Wrapping
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Nonlinear experiment

- TFBG response sensible to temperature

- In addition to SWNT thermal conductivity → slow (CW) switching effect

- Looking for SWNT ultrafast effects

Pump-probe pulse set-up
Nonlinear experiment

○○ Pump-probe phase sensitive set-up

-1ps
20MHz rep.
Pulsed laser
Coupler
90%
10%
Coupler
AOM 1
Coupler
AOM 2
Coupler
Sample
Motorized delay line
80 MHz RF
40 kHz Ref
Mixer + filter
80.04 MHz RF
Lock-in
PD
Coupler
Coupler
Coupler
Coupler
10ns
10ns
pump
probe
ref

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Temporal resolution limited by pulse width (1ps)
Amplitude modulation of 6% (12% in intensity)
Different configurations in source wavelength and polarization of pump and probe pulses
Not straightforward effect in pulse transmission
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Conclusion

- SWNTs constitute an efficient nonlinear material for optics
- Interest in approaches for integrating SWNTs in fiber devices
- A solution based on a SWNT-coated TFBG-written optical fiber is presented
- Two different deposition techniques have been carried out:
  - Dipping: high layer uniformity, thickness controlled
  - Wrapping: thicker SWNT coating, simple implementation
- Ultrafast nonlinear effects have been demonstrated by pulse-probe experiment
Thank you for your attention