Characterization of Carbon Nanotubes by Parallel Plate Waveguide Terahertz Spectroscopy

Daniel K.S. Gilmore,[1,2,3] Razanoelina Manjakavahoaka,[3] Filchito Renee G. Bagisican,[3] Iwao Kawayama,[3] Hironaru Murakami,[3] Weilu Gao,[4] Masayoshi Tonouchi,[3] and Junichiro Kono[2,4]

[1]*Department of Electrical and Computer Engineering, Purdue University, West Lafayette, Indiana, U.S.A.*
[2]*Nakatani Research and International Experiences Program, Rice University, Houston, Texas, U.S.A.*
[3]*Institute of Laser Engineering, Osaka University, Suita, Osaka, Japan*
[4]*Department of Electrical and Computer Engineering Rice University, Houston, Texas, U.S.A.*

Single-wall carbon nanotubes (SWCNTs) are a unique 1-d material with many exciting properties that show promise for various applications. In particular, SWCNTs demonstrate an ultrahigh electron mobility which shows great potential for application in electronic and photonic devices. However, their properties in the terahertz (THz) frequency range are largely unexplored. THz time-domain spectroscopy (THz-TDS) is typically used to characterize electromagnetic properties of materials. However, it is very challenging to use conventional THz-TDS on ultrathin materials such as SWCNT films due to the very short interaction length, typically in the order of nanometers. In this experiment, we use a parallel plate waveguide (PPWG) with the sample layer located halfway between the plates to achieve an increased interaction length that is limited only by the length of the waveguide. We use this setup to measure the THz response and calculate the conductivity of both aligned and unaligned SWCNT films on substrates of both magnesium oxide (MgO) and silicon. Based on other recent research on SWCNT conductivity, we expect very high conductivity from nanotubes aligned parallel to the transverse THz electrical field, lesser conductivity in unaligned nanotubes, and virtually zero conductivity in aligned nanotubes perpendicular to the THz film. The results of this study will provide new insight into the properties of SWCNT films and give us a better understanding of how these films are affected by nanotube alignment and choice of substrate.

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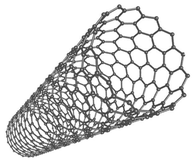
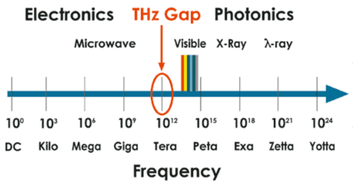
Contact: dgilmor@purdue.edu

Introduction

Carbon Nanotubes

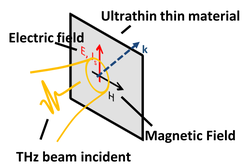
- Very high electron mobility & conductivity
- Film properties vary with alignment and substrate



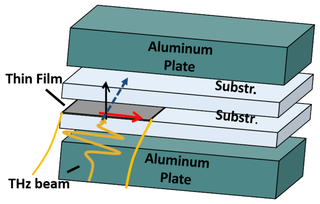


Terahertz Technology Gap

- Frequency range between optics and electronics
- Few current applications



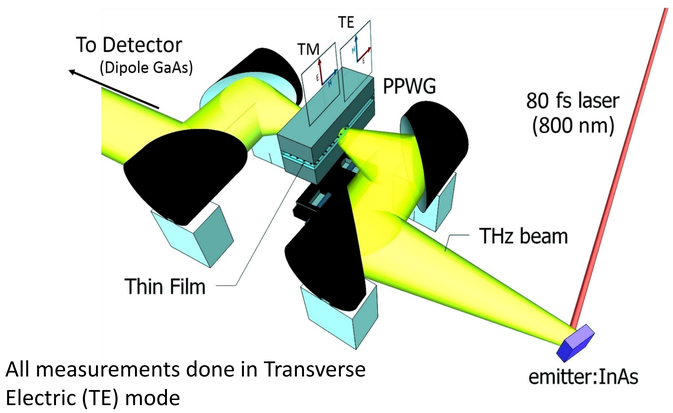
Conventional THz-TDS
-Typically used to find THz conductivity of materials.
-Very short interaction length with ultrathin materials



PPWG THz-TDS
-Greatly increased interaction length, limited only by the length of the waveguide

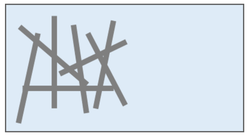
Purpose: Using a parallel plate waveguide (PPWG) THz time domain spectroscopy setup, determine the THz conductivity of SWCNT films with varying alignment and substrates.

Experimental Setup & Method

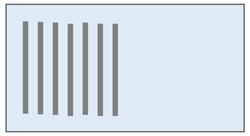


All measurements done in Transverse Electric (TE) mode

Samples

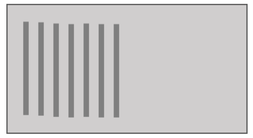


Unaligned CNTs on MgO



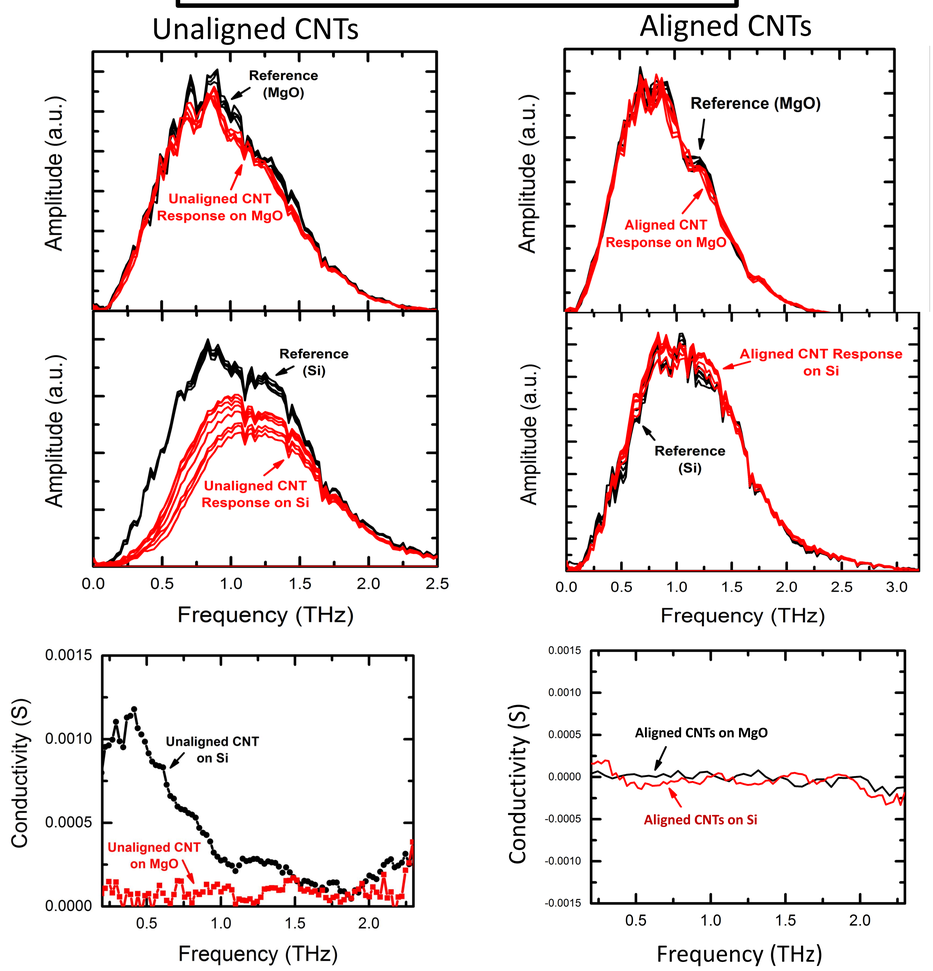
Aligned CNTs on MgO

Unaligned CNTs on Si



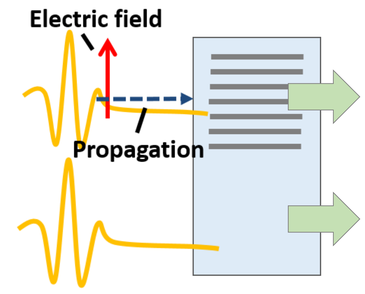
Aligned CNTs on Si

Results



Conclusions

- Unaligned CNTs on a silicon substrate demonstrate **much higher conductivity** than CNTs on a MgO substrate.
- Aligned CNTs exhibit nearly zero conductivity regardless of substrate
  - CNTs aligned perpendicular to electrical field



Same Response

Future Work

- Compare to conventional THz-TDS
- Find conductivity of samples using TM mode
- Aligned CNTs parallel to electrical field

Acknowledgements

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