Terahertz Detection at Room Temperature with Wafer-Scale Films of Highly-Aligned Single-Wall Carbon Nanotubes

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Terahertz (THz) imaging and spectroscopy could be used for the detection of cancer cells, various drugs, and even bacterial infections [1]. Carbon nanotubes (CNTs) promise to eliminate the bulkiness and low-temperature restrictions of previous THz detectors. CNTs exhibit ultra-broadband absorption [2] and aligned CNT films have shown high sensitivity to polarization changes of radiation even at room temperature [3]. However, current CNT-based detectors utilize a chemical vapor deposition and wet transfer fabrication process [4] that is unsuitable for application integration. We aim to develop a wafer-scale THz detector, with arc-discharge-grown aligned CNTs, that functions at room temperature, is polarization-sensitive, and is compatible for device integration.

We characterized the THz response of a highly dense film of aligned single walled CNTs (SWNTs) using THz-time domain spectroscopy (THz-TDS) and near-field scanning optical microscopy (SNOM). When radiation (0.1 to 7 THz) polarization was parallel to CNT alignment, absorption was 10 times higher than in the perpendicular case. It was also found that absorption peaked around 4.1 THz, where the CNTs exhibit a phonon resonance effect. We also discovered that on a nanometer spatial scale (analyzed with SNOM) similar polarization dependence exists. We have deposited gold electrodes onto the sample and completed fabricating the detector. We are measuring the photothermoelectric response of the device in response to polarization, temperature, and magnetic field dependence. The ultimate goal of this research is to develop a high-resolution array of THz detectors from such a wafer-scale SWNT film to create a THz camera capable of macro-scale real-time imaging.

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[2] Nanot, S.; et al. *Advanced Materials* 2012, *24*, 4977−4994.
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[4] Xiaowei, H.; et al. *Nano Letters* 2014, *14*, 3953-3958.

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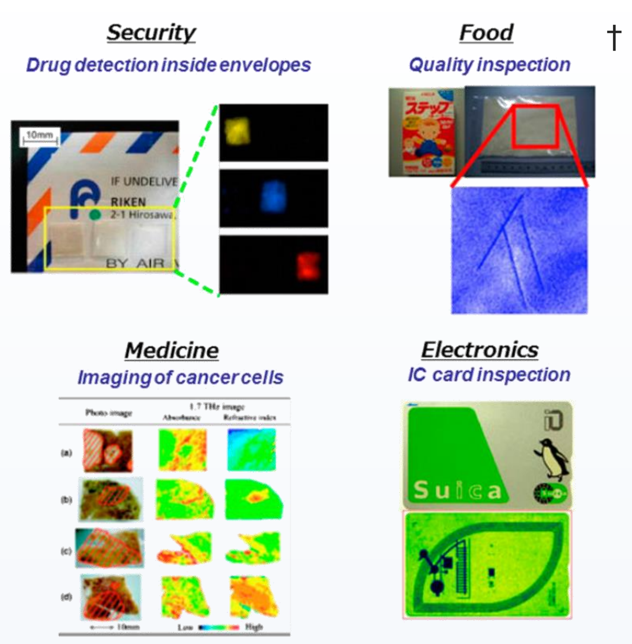
Introduction

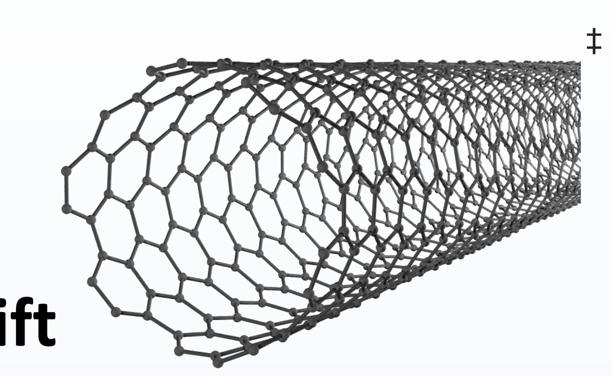
Terahertz (THz) Radiation

- Underutilized but with huge potential in security, medicine, and astronomy
- **Need to develop means for THz imaging and spectroscopy**



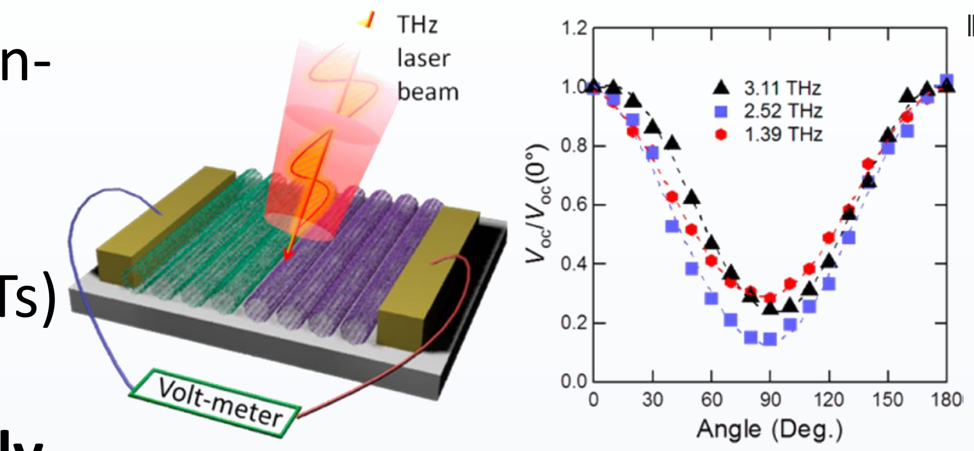
Carbon Nanotubes (CNTs)

- Exhibit ultra broadband absorption when using mixed chiralities
- **Electrical properties shift when exposed to THz radiation**



Previous Work

- Room temperature, polarization-sensitive THz detection via a photothermoelectric effect across single-wall CNTs (SWCNTs)
- **Not suitable for integration. Fabrication method not friendly for application purposes.**



Purpose

Characterize a wafer-scale THz detector

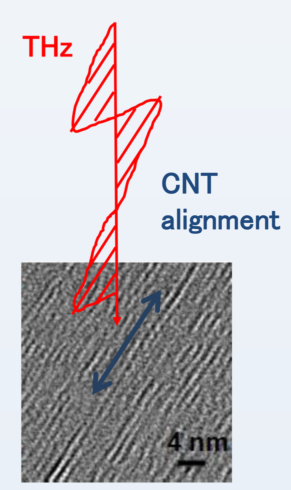
- Vacuum filtration sample more suitable for standard device fabrication technology
- High sensitivity and polarization-dependent THz response at room temperature

To advance development of a macro-scale, real-time THz camera

Experimental Setups

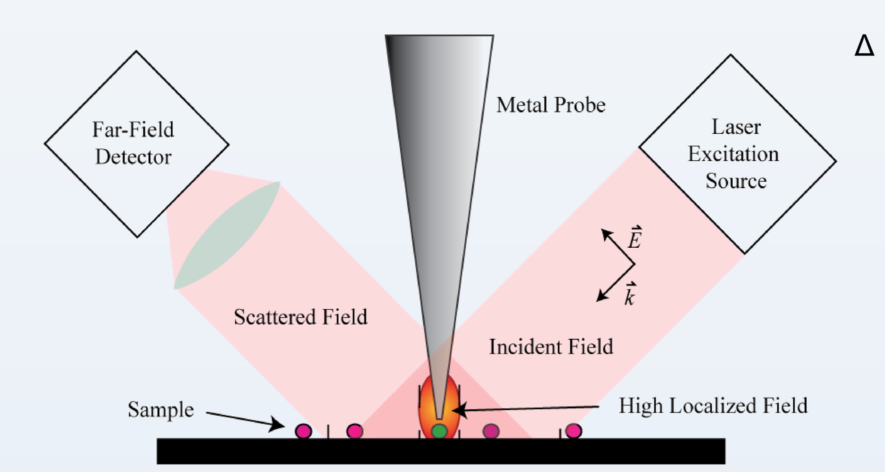
THz-Time Domain Spectroscopy (TDS)

- Analyze frequency dependence of THz absorption
- Can see polarization sensitivity



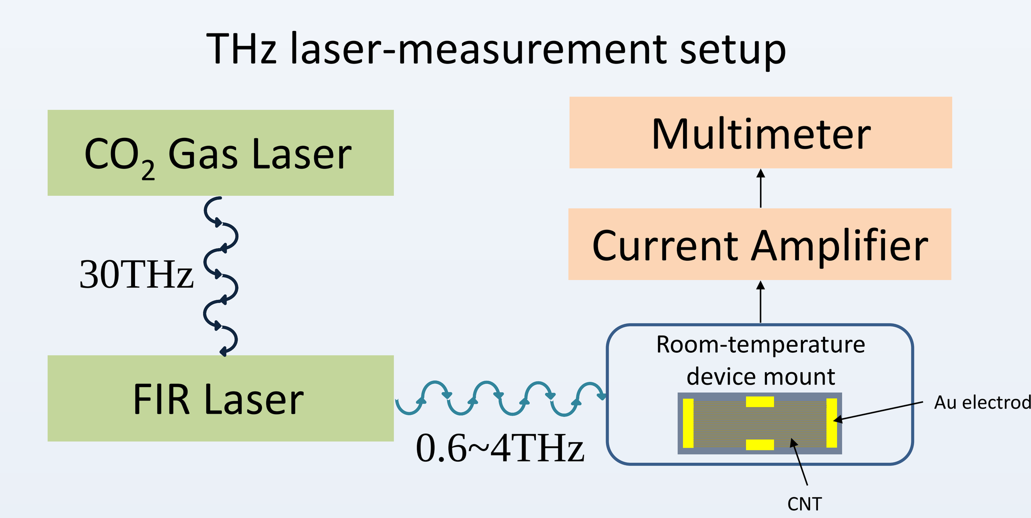
Near-field Scanning Optical Microscopy (SNOM)

- Analyze spatial dependence of THz absorption
- Can see polarization sensitivity



THz Response (IV characteristic)

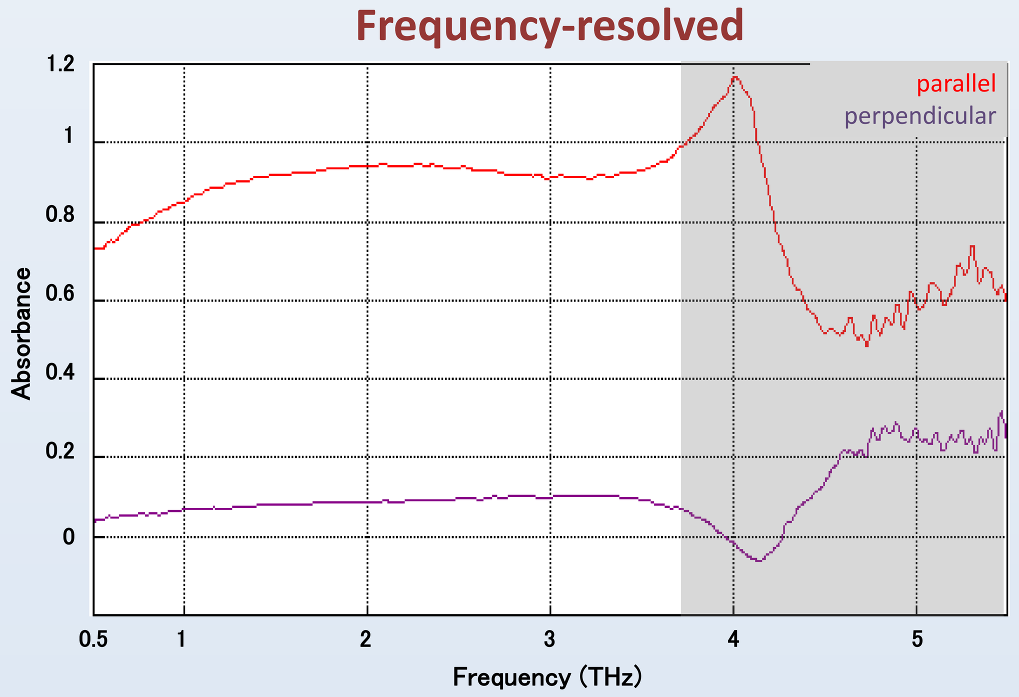
- Directly measures sensitivity of THz detector



Results

THz-TDS

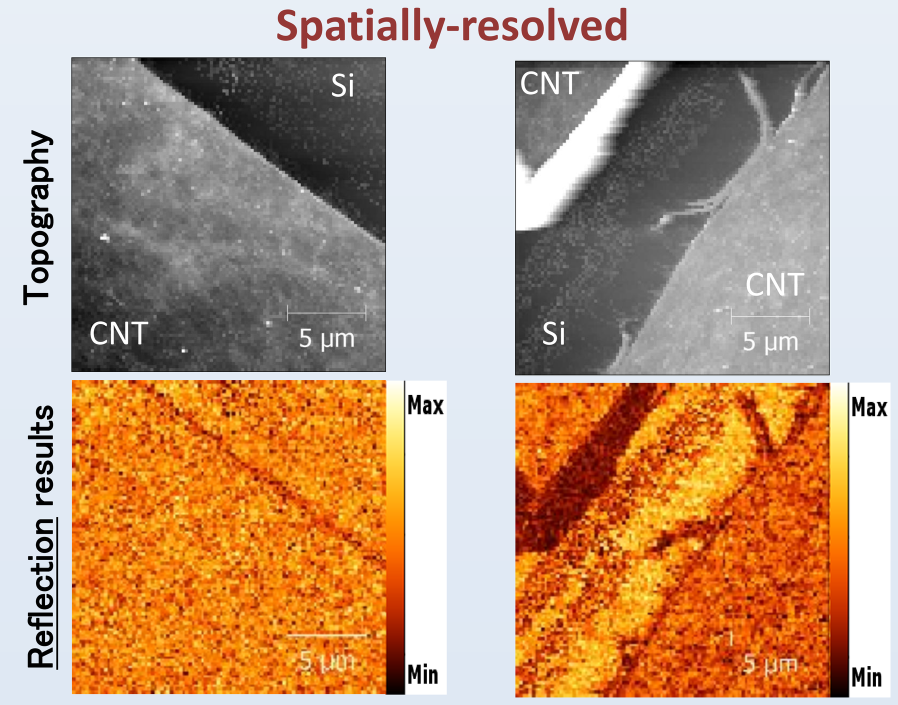
Frequency-resolved



- Data represents SWCNT absorption as a percentage of the silicon reference absorption
- Abnormal results at >3.7 THz
  Must repeat experiment.

SNOM

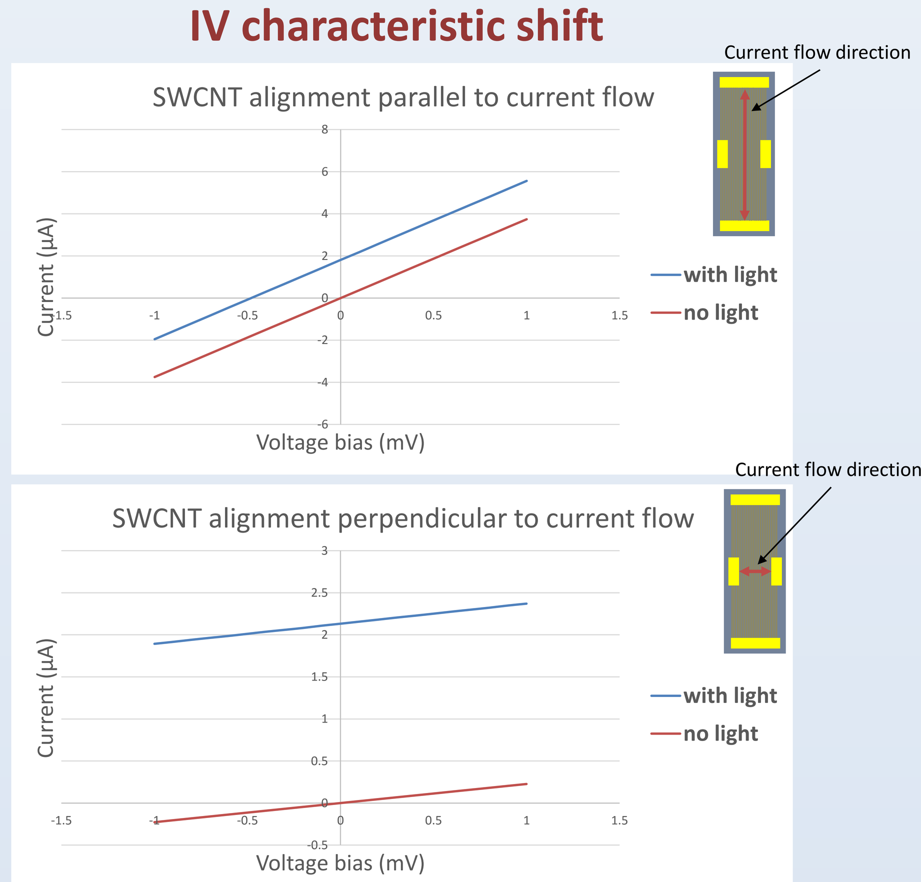
Spatially-resolved



- Scanned edges and cracks in sample
- Color represents amount of radiation reflected (low reflection implies high absorption)

Ambient Light Response

IV characteristic shift



- Resistance effects from large electrode distance overruled by effects of CNT alignment

Conclusions

THz-TDS and SNOM

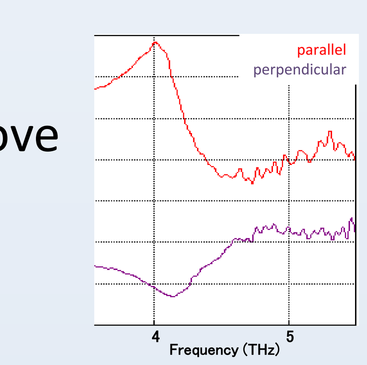
- **Very strong polarization-dependence THz absorption**
- **Spatially-consistent THz absorption across cracks and edges in the CNT film**
- **Very high CNT density yields much higher current response than previous samples**

Ambient Light Response

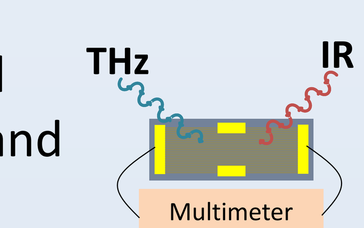
- **Resistance much lower when CNT alignment and current flow are parallel**
- **Device shows strong photothermoelectric response to ambient (visible) light**

Future Work

Confirm THz-TDS data above ~3.7 THz frequency



Measure THz and infrared (IR) response to thermal and magnetic field variation



Optimize detector fabrication
(and device shape / electrode configuration)

Substrate material	Electrode material
• Silicon	• Gold
• Sapphire	• Platinum
----- etc -----	• Silver
	----- etc -----

References

† Kawase et al., Opt. Express 11 (2003), 2549 for security, Nakajima et al., Appl. Phys. Lett. 90 (2007), 041102 for medicine, Ariyoshi et al., Appl. Phys. Lett. 88 (2006), 203503 for food, and Dobroiu et al., Appl. Opt. 43 (2004), 5367 for electronics.

‡ "Carbon nanotubes better carbon-fibre by being even lighter and stronger" <http://www.motoroids.com/>

‖ He, Xiaowei, et al. "Carbon nanotube terahertz detector." Nano letters 14.7 (2014): 3953-3958.

Δ "TENOM Tip Enhanced Near-field Optical Microscopy" < https://www.pdx.edu/>

Acknowledgements

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