Temperature Dependent Time-Domain Terahertz Spectroscopy of Pure and Nitrogen-Doped Graphene

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Graphene Background

- Graphene Characteristics:
  - Single layer of carbon atoms
  - Zero-gap semiconductor
  - Exceptional ballistic transport properties
  - High strength
  - High thermal conductivity

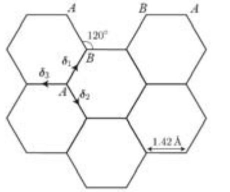


Fig 1: Graphene's hexagonal crystal lattice of carbon atoms

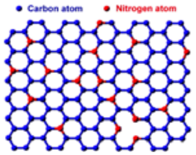


Fig 2: Vacancies and substitutions in the crystal lattice from doping

- Controlled doping is an essential tool in the path to semiconductor applications
  - N-doping: n-type semiconductor
  - B-doping: p-type semiconductor

Purpose

- Observe the low energy carrier dynamics of graphene
  - Understand the effects of doping on the transmittance
  - Understand the effects of temperature on the transmittance
- Explain transmission trends within the Mikhailov theoretical model

Methods

- Terahertz Time-Domain Spectroscopy (THz-TDS) is a method of determining a number of material properties including:
  - refractive index
  - dielectric constant
  - complex conductivity
  - Transmission coefficient
- Production of samples
  - CVD on Copper film
  - N-doped produced by introducing ammonia
  - Transferred to sapphire substrate
- Measurement and Analysis
  - Used THz-TDS to get waveforms
  - Compared substrate and sample
  - Applied FFT to find transmittance

Fig 3: Specimens used in this experiment

Experimental Setup: THz-TDS

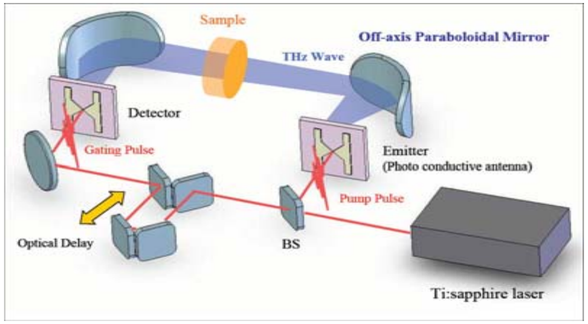
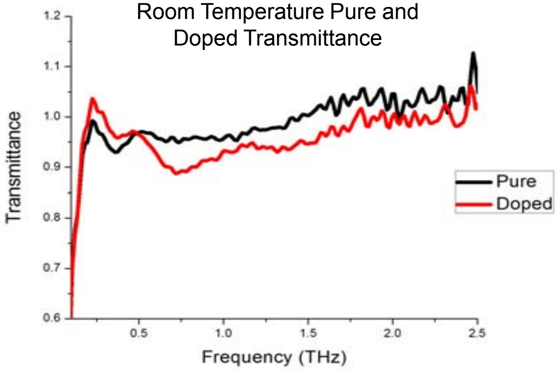


Fig 4: An example room temperature THz-TDS set up

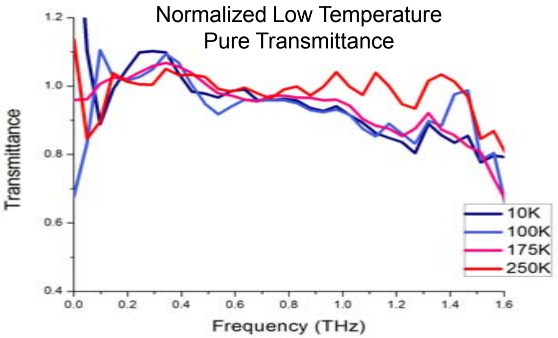
- Two methods of reducing relative humidity
  - Nitrogen purging
  - Vacuum pumping
- Two different emitters
  - Low Temperature grown Gallium Arsenide (LT GaAs)
  - 4-dimethylamino-N-methyl-4-stilbazolium-tosylate (DAST)
- Measurements taken from 10K-300K
  - Used Helium to lower the temperature of the cryostat
- Data averaged over at least 3 readings

Pure and Doped Graphene



- Pure graphene has a higher transmittance than doped graphene in the range of .5 – 2.5 THz
- Around .7 THz, there is a peak that may be attributed to absorbance
- Both pure and doped have very high transmittance

Temperature Dependence



- Positive correlation between temperature and transmittance
- Scattering can be observed in higher energy regions
- Gap suggests a critical temperature between 175K and 250K

Discussion

- Reasons for high transmittance:
  - Both graphene samples had low absorbance or high reflection
  - Different substrate sample thicknesses
- Doping and Temperature Effects
  - Doping increases intraband absorbance
  - Temperature broadens the zero-frequency peak of the intraband conductivity

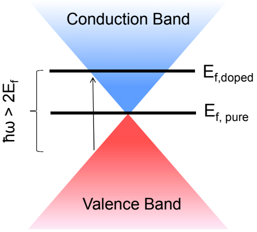


Fig 5: Doping Effects on Fermi Energy due to carrier densities

Conclusions

- Monolayer graphene has either a low absorbance or high reflection
- Doping is observed to decrease transmittance
- Increasing temperature is observed to increase transmittance

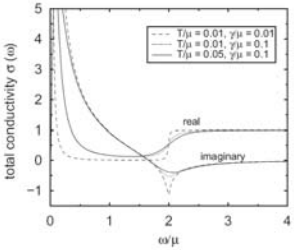


Fig 6: Conductivity according to the Mikhailov theoretical model

Sources:
Fig 2: Dacheng Wei, *Nano Letters* **2009** *9* (5), 1752-1758
Fig 4: http://www.riken.jp/lab-www/THz-img/English/annual_gas.htm
Fig 6: S. A. Mikhailov, Microelectronics Journal 40, 712 (2009)

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