New Applications for Graphene Electronics

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What is the best application for graphene?

Transport properties are not what make this material unique…

- Electron mobility?
  - \( \mu_{\text{graphene}} = 200,000 \text{ cm}^2/\text{Vs} \)
- Carrier velocity?
  - \( v_{e,\text{GNT}} = 5 \times 10^7 \text{ cm/s} \)

- Ballistic transport?

\[ \mu_{\text{InSb}} = 80,000 \text{ cm}^2/\text{Vs} \]
Unique properties of graphene

- **Ambipolar transport** with very high mobility
- **Bandgap control through etching** → lateral bandgap engineering
- **Flexible and transparent material**
- **Excellent electrostatic control**
  - Improved transport properties.
New graphene devices: Frequency doublers

- Full wave rectification using a single graphene device
- No bandgap required
- Field effect transistor: Signal amplification possible
- Much higher efficiency than conventional diode or FET frequency doublers

Holes
Electrons

Graphene Ambipolar FET

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Fabrication of Graphene Frequency Multipliers

Optical Interference Image of graphene flakes

Final Device

Schematic Structure

Experimental results...

Graphene frequency doubler

• First demonstration of frequency doubling

• Excellent spectral purity → high conversion efficiency

• High frequency operation

• Large gain possible

• No bandgap required

Graphene is the an excellent material for high performance frequency multipliers

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Conclusion and Future Work

- Ambipolar frequency multipliers based on graphene demonstrated.
- Excellent spectral purity with 94% of the output power at useful frequency.
- No filtering elements are needed at the output.
- Signal amplification possible.

Many other new devices/applications are possible:
- Analog to digital converters
- Energy harvesting devices
- Advanced photodetectors
- …


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Ambipolar Frequency Multipliers

Conventional FET Frequency Multipliers

I-V Characteristics

Circuit and Output Waveform

Output Power Spectrum

Ambipolar Frequency Multipliers

I-V Characteristics

Circuit and Output Waveform

Output Power Spectrum

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Why is spectral purity so high at the output?

Sub-linear $I_{ds}-V_{gs}$ characteristics in fabricated GFETs

Parabolic component of $I_{ds}-V_{gs}$ much larger in fabricated GFETs

Less higher order harmonics, hence higher spectrum purity

GFET with Ideal Graphene

GFET with Graphene containing Impurities