New Applications for Graphene Electronics

Han Wang, Daniel Nezich, Jing Kong
and Tomas Palacios

Department of Electrical Engineering and Computer Science
Massachusetts Institute of Technology
tpalacios@mit.edu

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What is the best application for graphene?

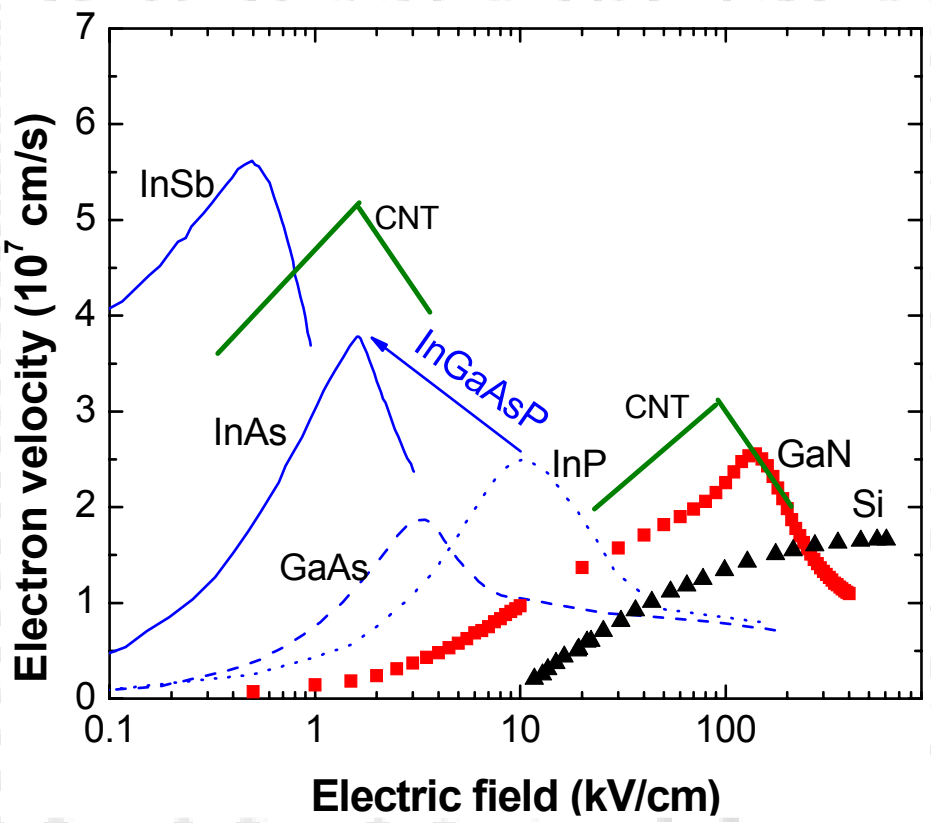
Transport properties are not what make this material unique…

- Electron mobility?
  - $\mu_{graphene} = 200{,}000\ cm^2/Vs$

$\mu_{InSb} = 80{,}000\ cm^2/Vs$

- Carrier velocity?
  - $v_{e,GNT} = 5\times10^7\ cm/s$

- Ballistic transport?



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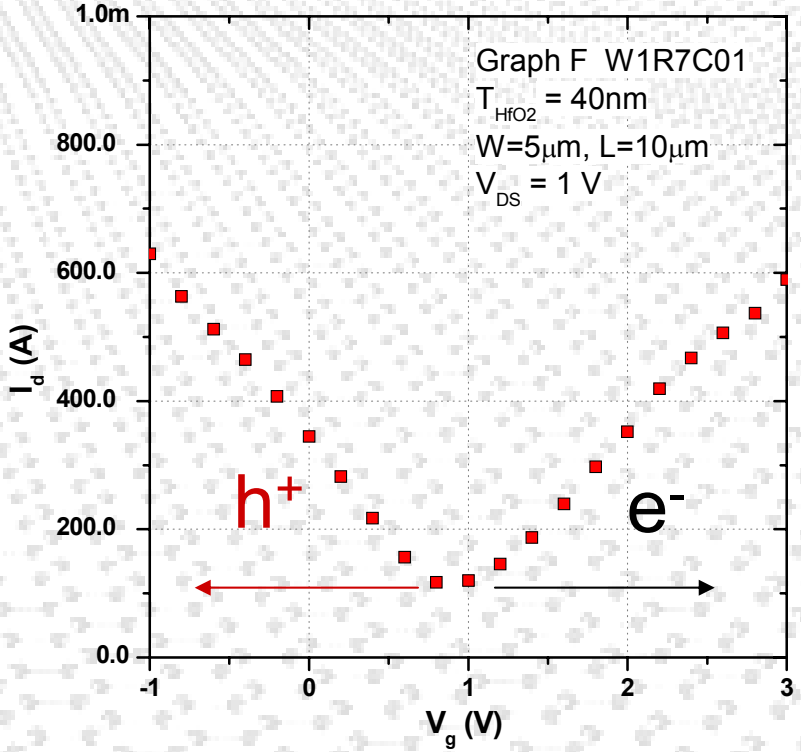
Unique properties of graphene

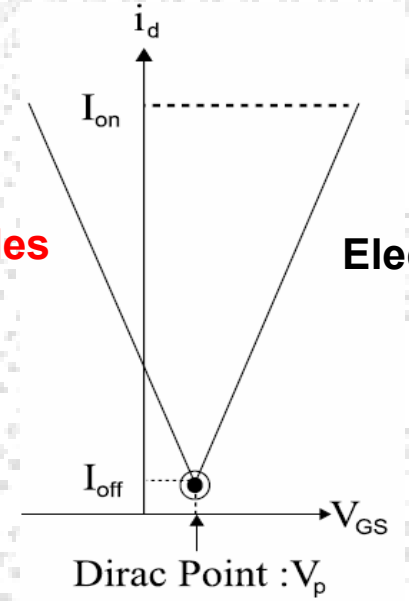
- *Ambipolar transport* with very high mobility
- *Bandgap control through etching* → lateral bandgap engineering
- *Flexible and transparent material*
- *Excellent electrostatic control*

+

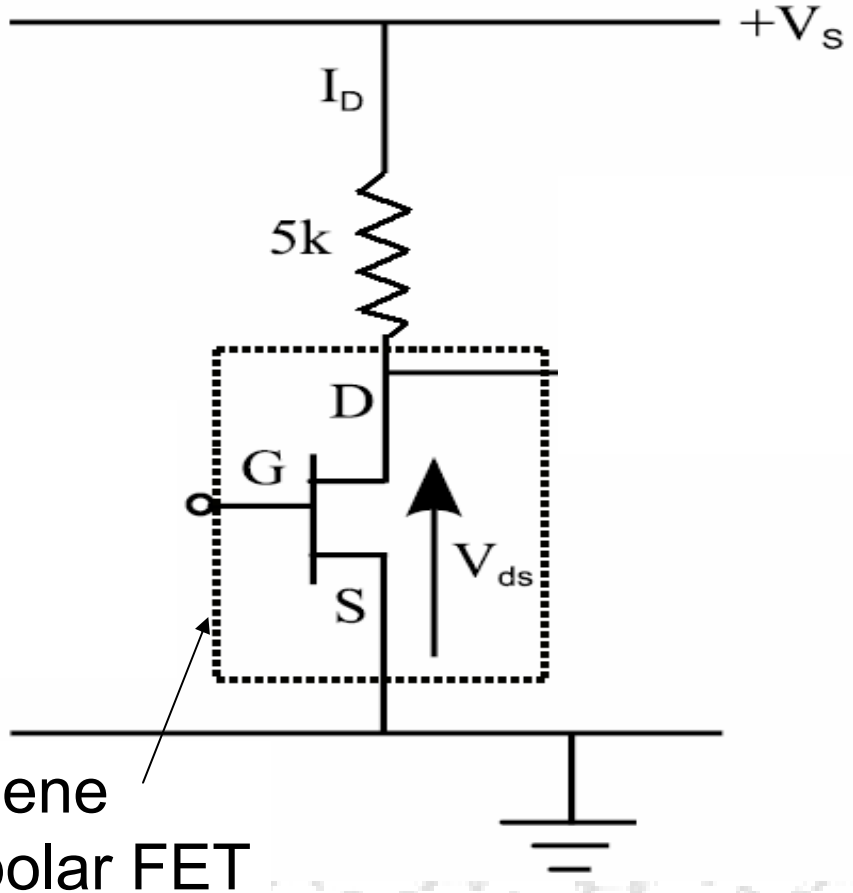
- Improved transport properties.



New graphene devices:
Frequency doublers



Holes **Electrons**



Graphene
Ambipolar FET

- 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

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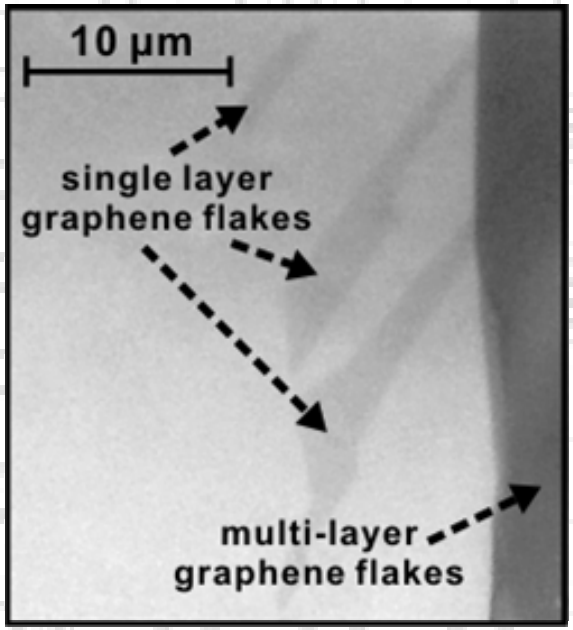
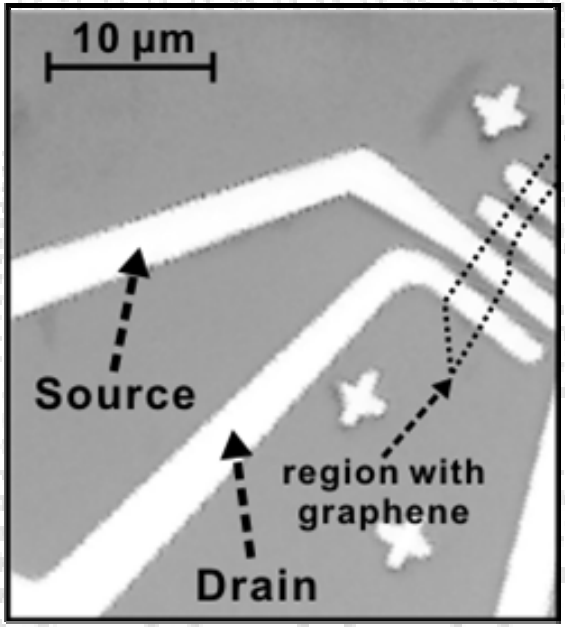
Fabrication of Graphene Frequency Multipliers

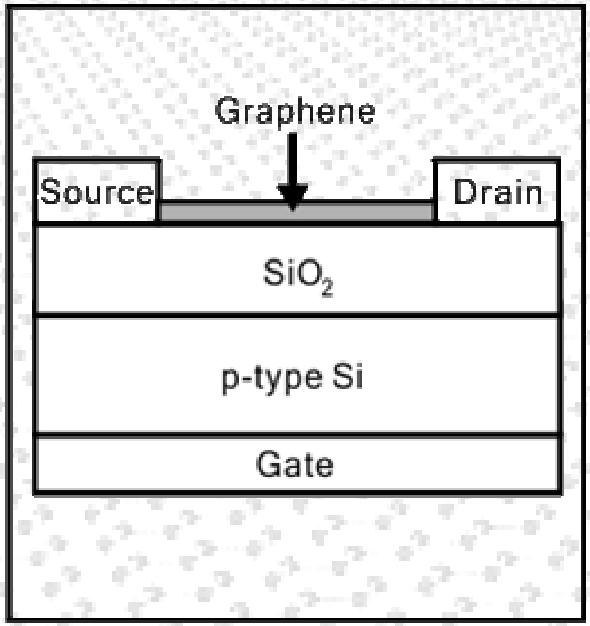
Optical Interference Image of graphene flakes



Final Device



Schematic Structure



H. Wang, D. Nezich, J. Kong, and T. Palacios "Graphene Frequency Multipliers" *IEEE Electron Device Letters*, May 2009..

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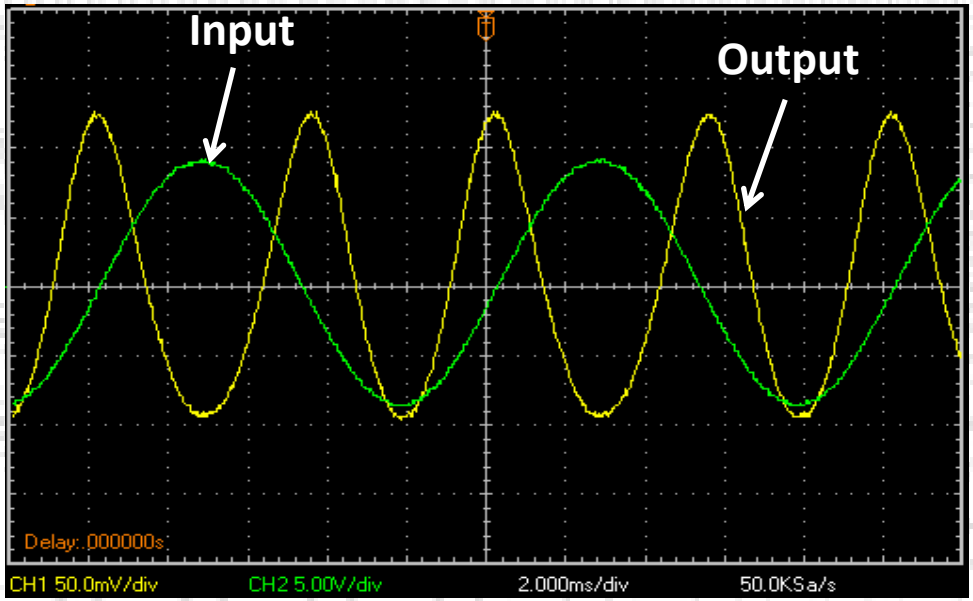
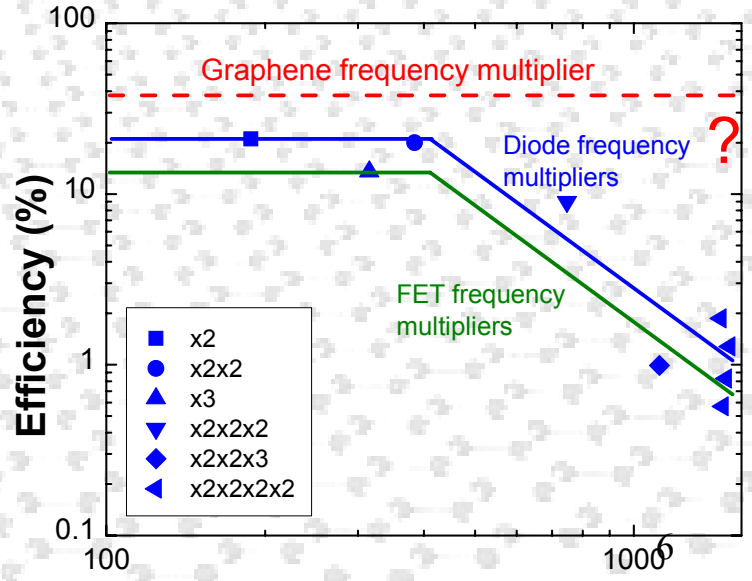
Experimental results…
Graphene frequency doubler

- 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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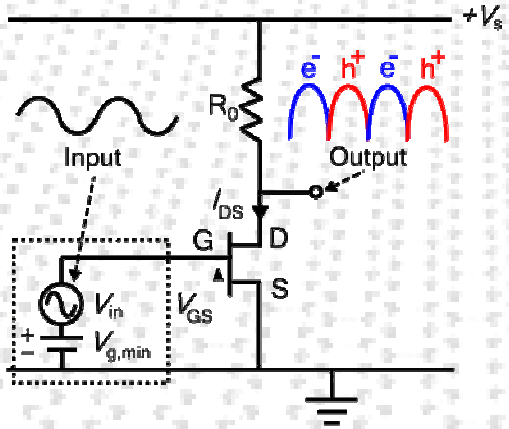
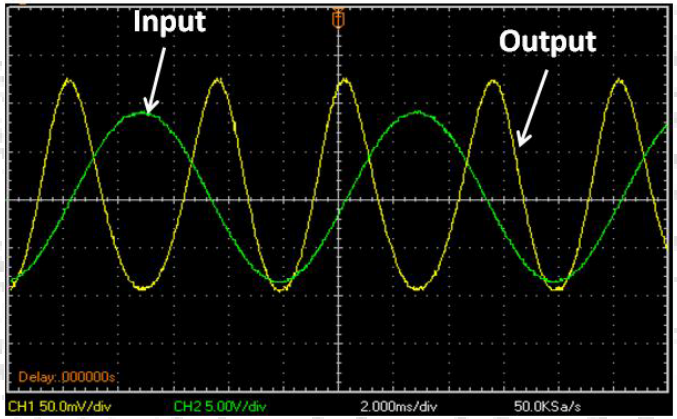
Conclusion and Future Work

- 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
-…

H. Wang, D. Nezich, J. Kong, and T. Palacios, *IEEE Electron Device Letters*, May 2009.

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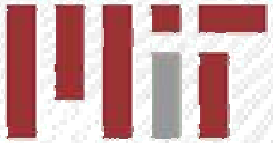

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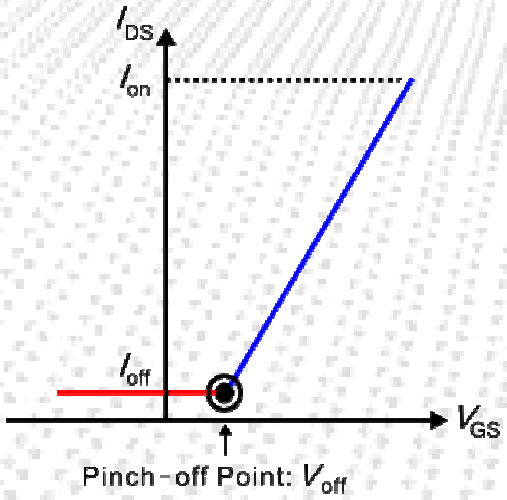
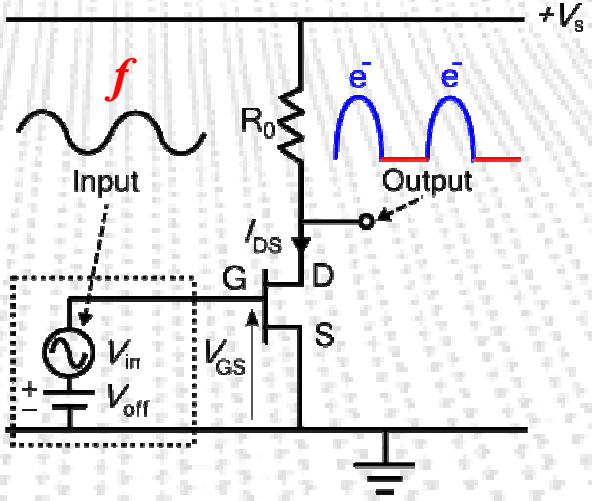
Ambipolar Frequency Multipliers

Conventional FET Frequency Multipliers

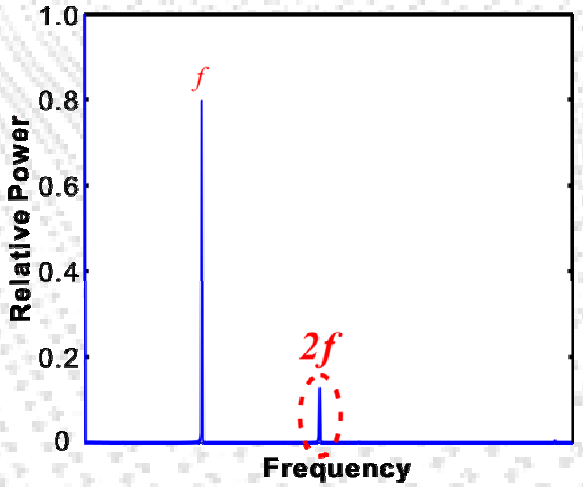
I-V Characteristics



Circuit and Output Waveform

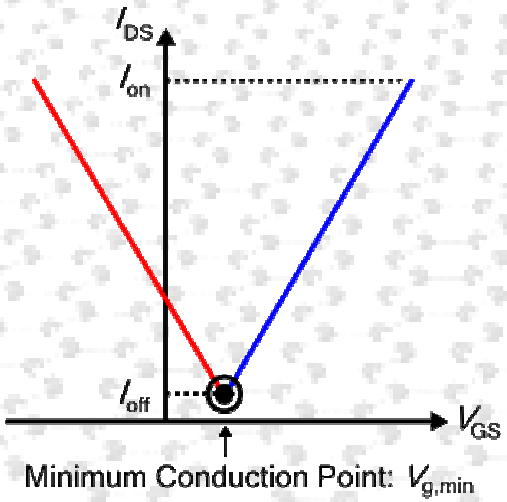


Output Power Spectrum

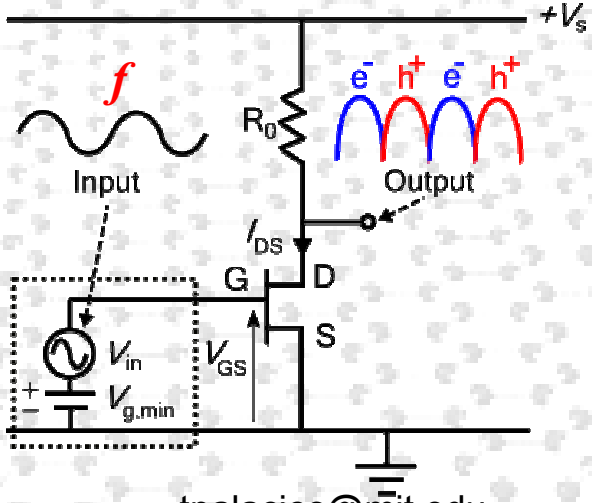


Ambipolar Frequency Multipliers

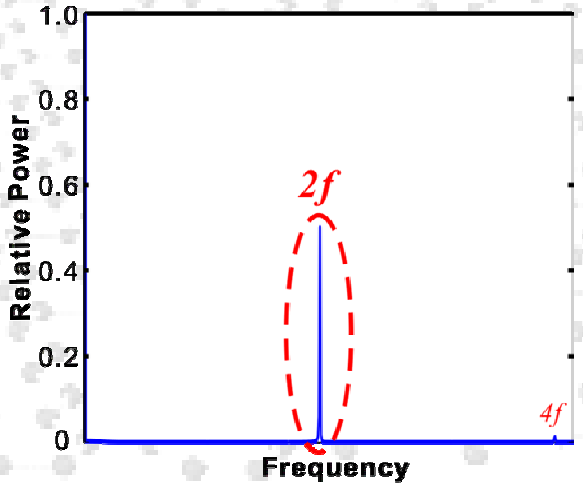
I-V Characteristics



Circuit and Output Waveform



Output Power Spectrum



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Why is spectral purity so high at the output?

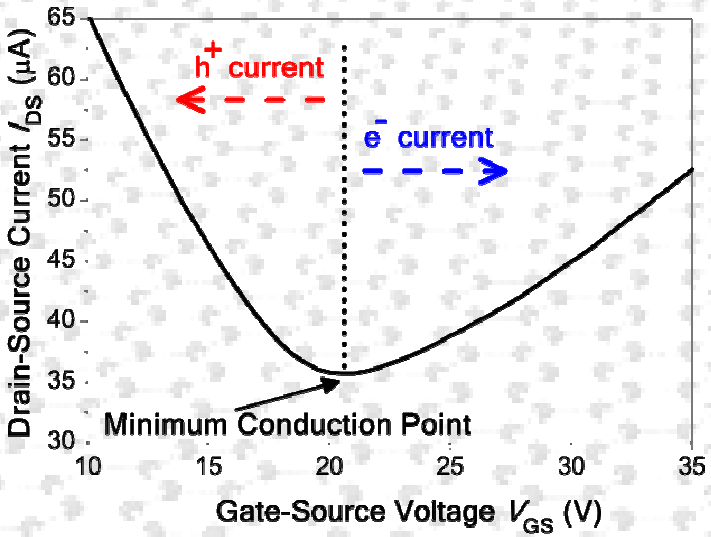
Sub-linear I_{ds}-V_{gs} characteristics in fabricated GFETs

↓

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

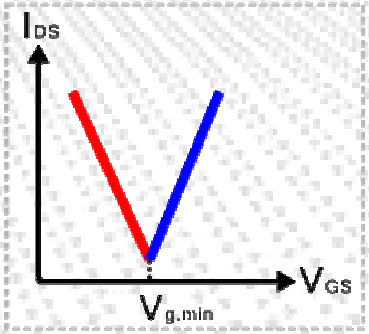
↓

Less higher order harmonics, hence higher spectrum purity

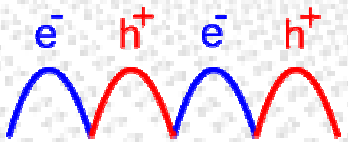


GFET with Ideal Graphene 78% maximum

Input

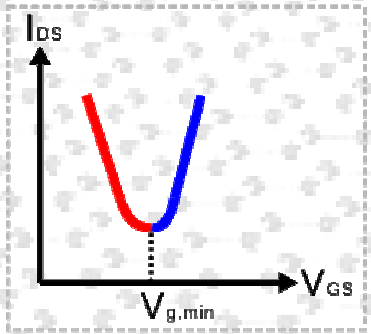


Output

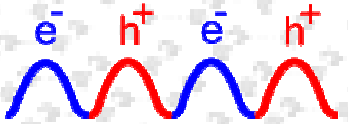


GFET with Graphene containing Impurities 94%

Input



Output



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