Applications of MoS_2 as a Two-Dimensional Materials Beyond Graphene

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Overview

Search for new Materials

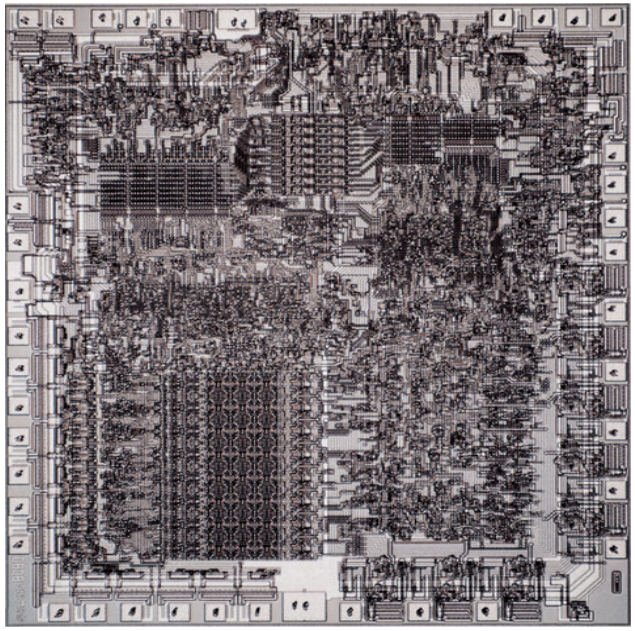

Figure: The Intel 8080 introduced in 1974 consisted of approximately 5,000 transistors

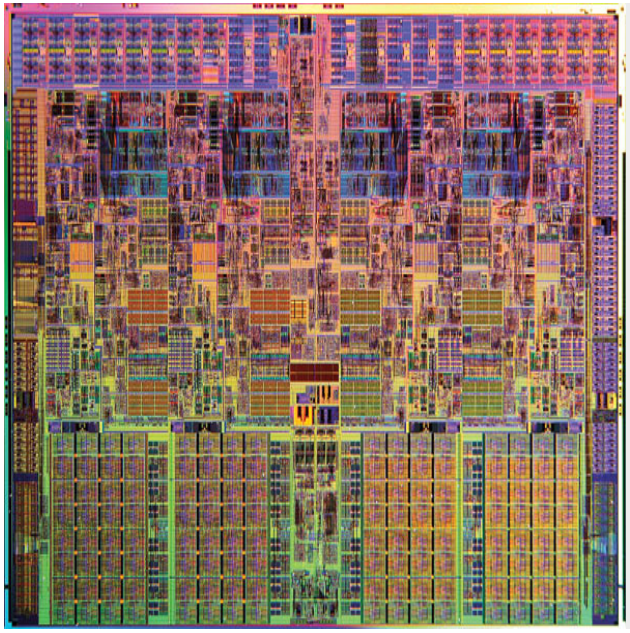

Figure: The Intel Core i7 in 2008 consisted of approximately 731 million transistors

[Grifantini, 2008]

Discovery of Graphene

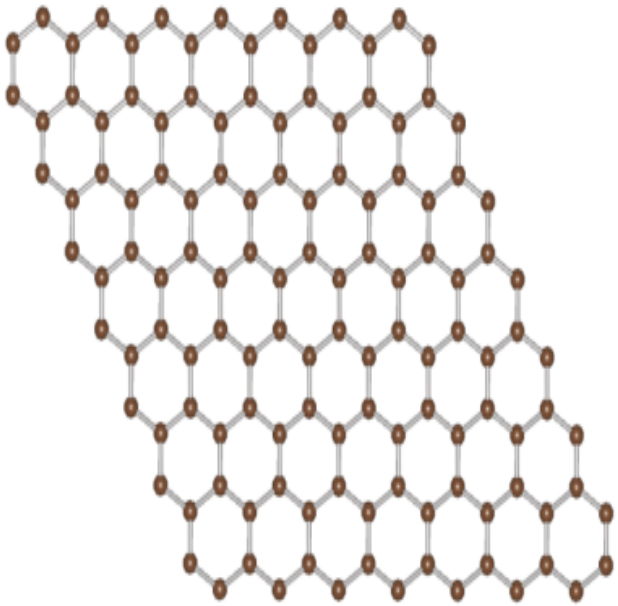

Figure: [Riken, 2012]

- 1985 suggestion of 1-D structure of carbon
- Several theoretical studies on formation of single layer of graphite
- 2004 Geim et al. isolate single layer of carbon atoms

Properties of Graphene

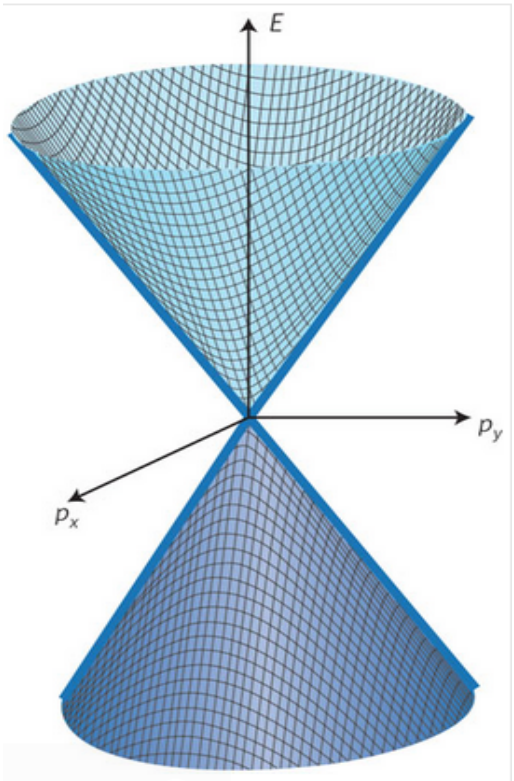

Figure: Electronic band structure of graphene [Fuhrer, 2010].

- Band Gap
- Mobility
- Young's Modulus
- Drawbacks
- "Relativistic" properties

MoS_2

Transistion Metal Dichalcogenides (TMDs)

- Renewed research in the last decade
- Instrinsic semiconductor

- Metal atom M
  - Mo, W, Nb, Re, Ni, or V
- 2 chalcogenide atoms X_2
  - S, Se, Te

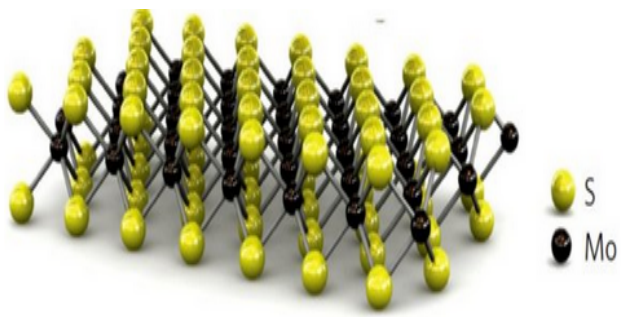

Figure: Bulk MoS_2 crystal [Wang, 2012].

Properties of MoS_2

- Monolayer MoS_2
  - Direct Band Gap $1.8\,\mathrm{eV}$
  - Young's Modulus $270\,\mathrm{GPa}$
- Bulk MoS_2
  - Indirect Band Gap $1.3\,\mathrm{eV}$
  - Young's Modulus $240\,\mathrm{eV}$

Micromechanical Exfoliation of MoS_2

Figure: Bulk MoS_2 crystal [Wang, 2012].

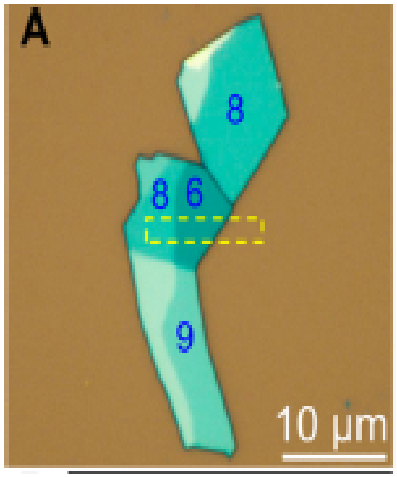

Figure: Image of MoS_2 [Li, 2014].

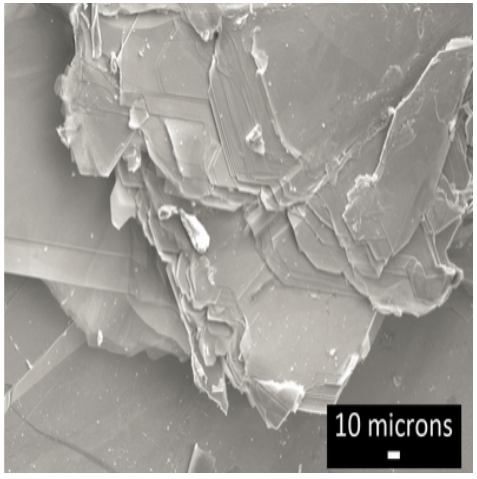

Figure: Example of layering in MoS_2 flakes [Radisavljevic, 2011].

MoS_2 in FETs

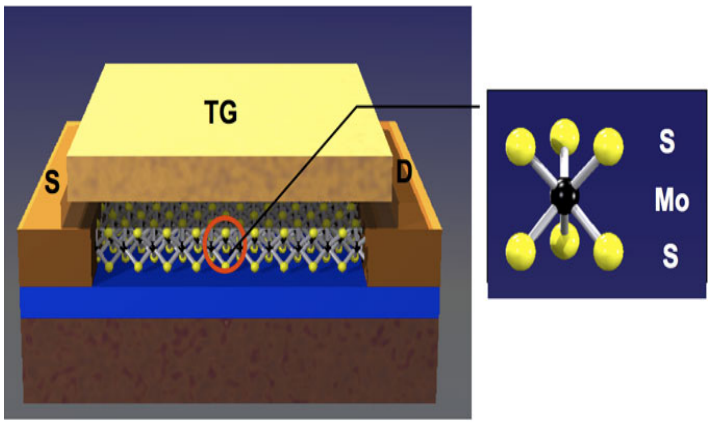

Figure: Schematic of FET with monolayer MoS_2.

- High on/off ratio
- Mobility of monolayer MoS_2 at room temperature $\sim 0.1 - 10.0\,\mathrm{cm^2V^{-1}s^{-1}}$
- Mobility of bulk MoS_2 $\sim 100\,\mathrm{cm^2V^{-1}s^{-1}}$.

MoS_2 in FETs Continued

- Increased mobility with use of HfO_2 dielectric
- Mobility increased to $\sim 200\,\mathrm{cm}^2\mathrm{V}^{-1}\mathrm{s}^{-1}$
- Drawbacks & problems still remain

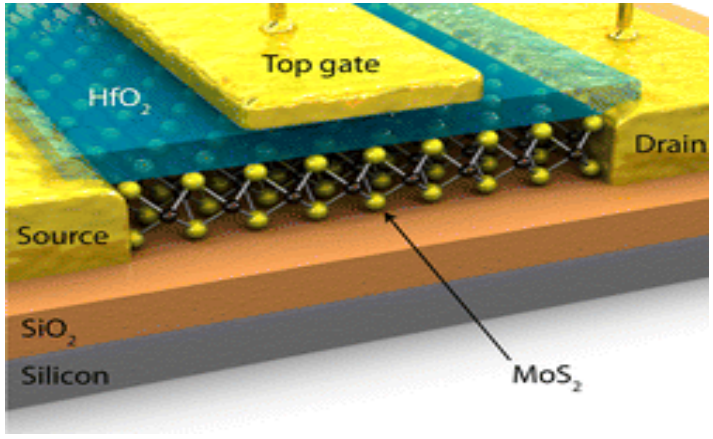

Figure: Detailed schematic of MoS_2 FET

Outlook and Conclusion

- Improving mobility in MoS_2 FETs
- Other materials

References

Fuhrer, M.S. (2010)

Graphene: Ribbions piece-by-piece

Nature Materials (9), 611–612.

Grifantini, K. (2008)

Moore's Law

MIT Technology Review
http://www.technologyreview.com/photoessay/411485/moores-law/.

Riken (2012)

Successful Development of a Precision Graphene Production Control Method (Press Release)

Wang, Q.H. and Zadeh, K.K. and Kis, A. and Coleman, J.N. and Strano, M.S. (2012)

Electronics and optoelectronics of two-dimensional transition metal dichalcogenides

Nature Nanotechnology (7), 699–712.

References

Li, H. and Wu, J. and Yin, Z. and Zhang, H. (2014)

Preperation and applications of mechanically exfoliated single-layer and multilayer MoS_2 and WSe_2 nanosheets

Accounts of Chemical Research 47(4), 1067–1075.

Radisavljevic et al. (2011)

Single-Layer MoS_2 transistors

Nature Nanotechnology (6), 447–500