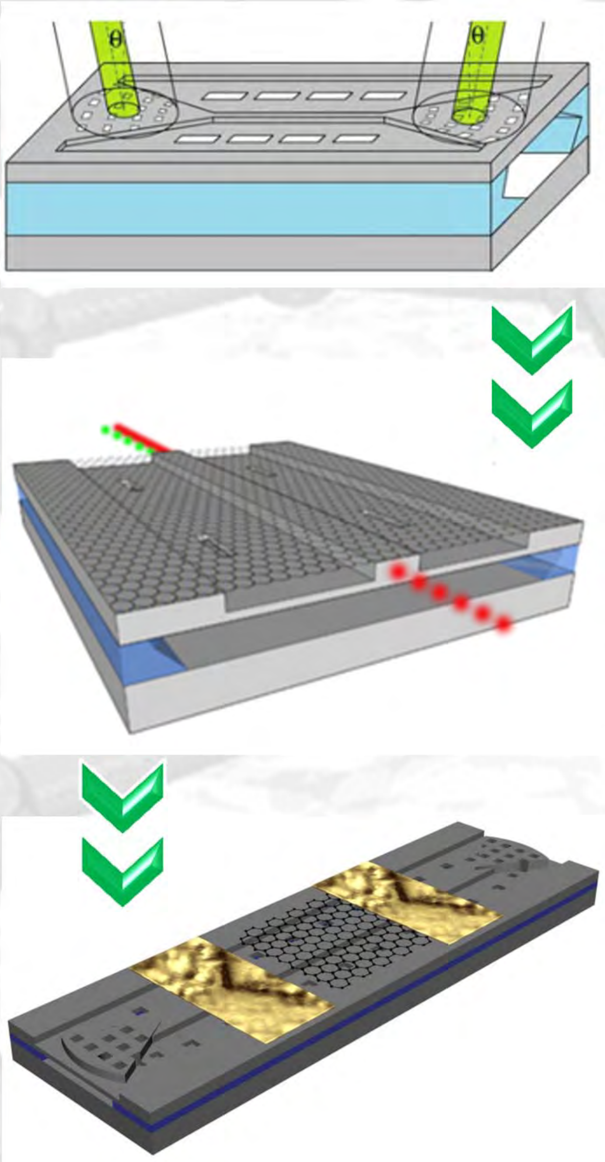
THE CHINESE UNIVERSITY OF HONG KONG

Electronic Engineering, Faculty of Engineering



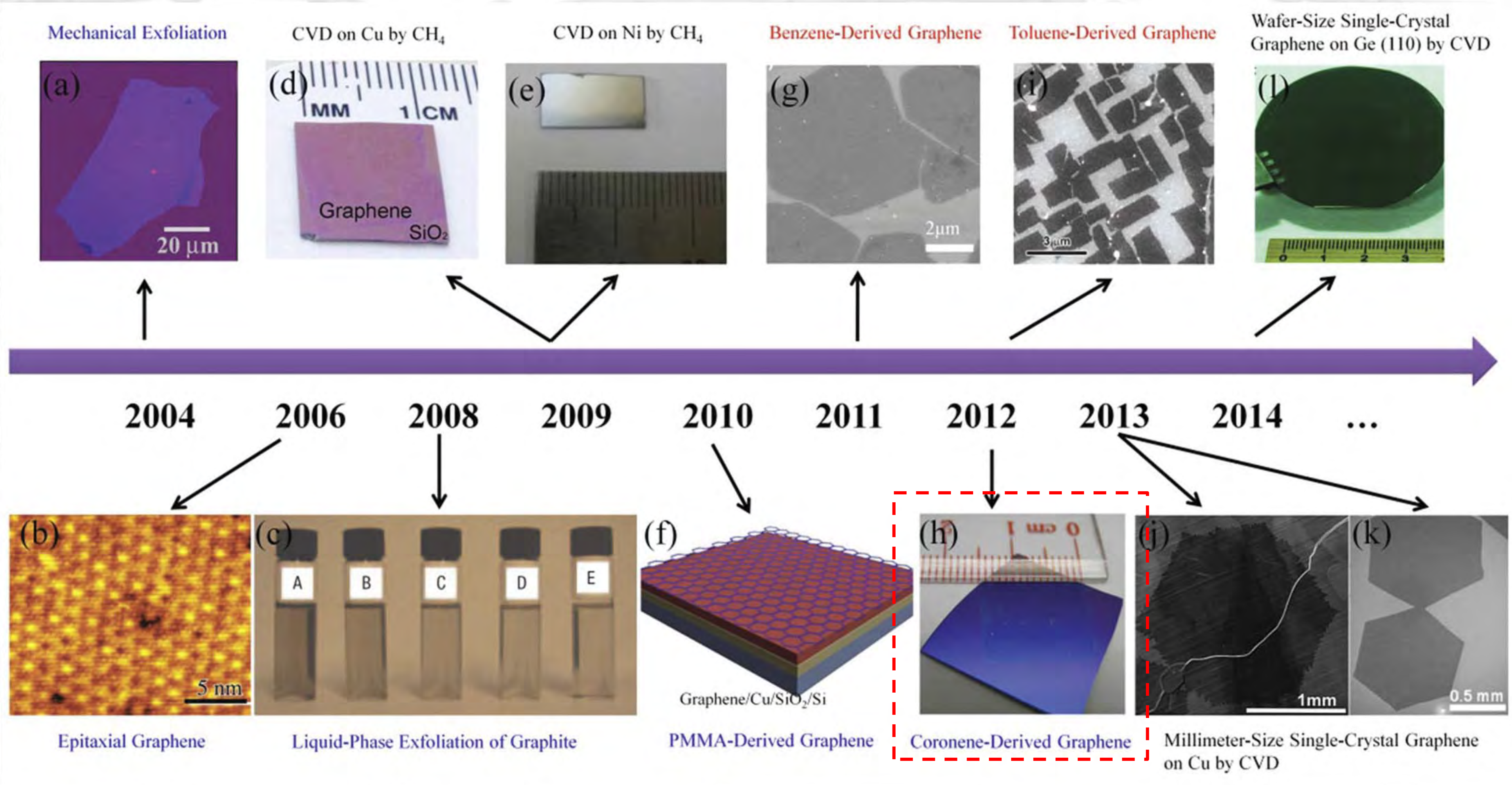
Interface Engineering for Graphene Transistors and Photodetectors

Prof. Jianbin XU, Prof. Hon-Ki TSANG; Drs. Xiaomu WANG, Xi WAN, Kun CHEN, Zhenzhou CHENG, Xiao-qing TIAN, and Prof. Weiguang XIE

MOE Natural Science Awards Presentation

7th May, 2015

Graphene Synthesis

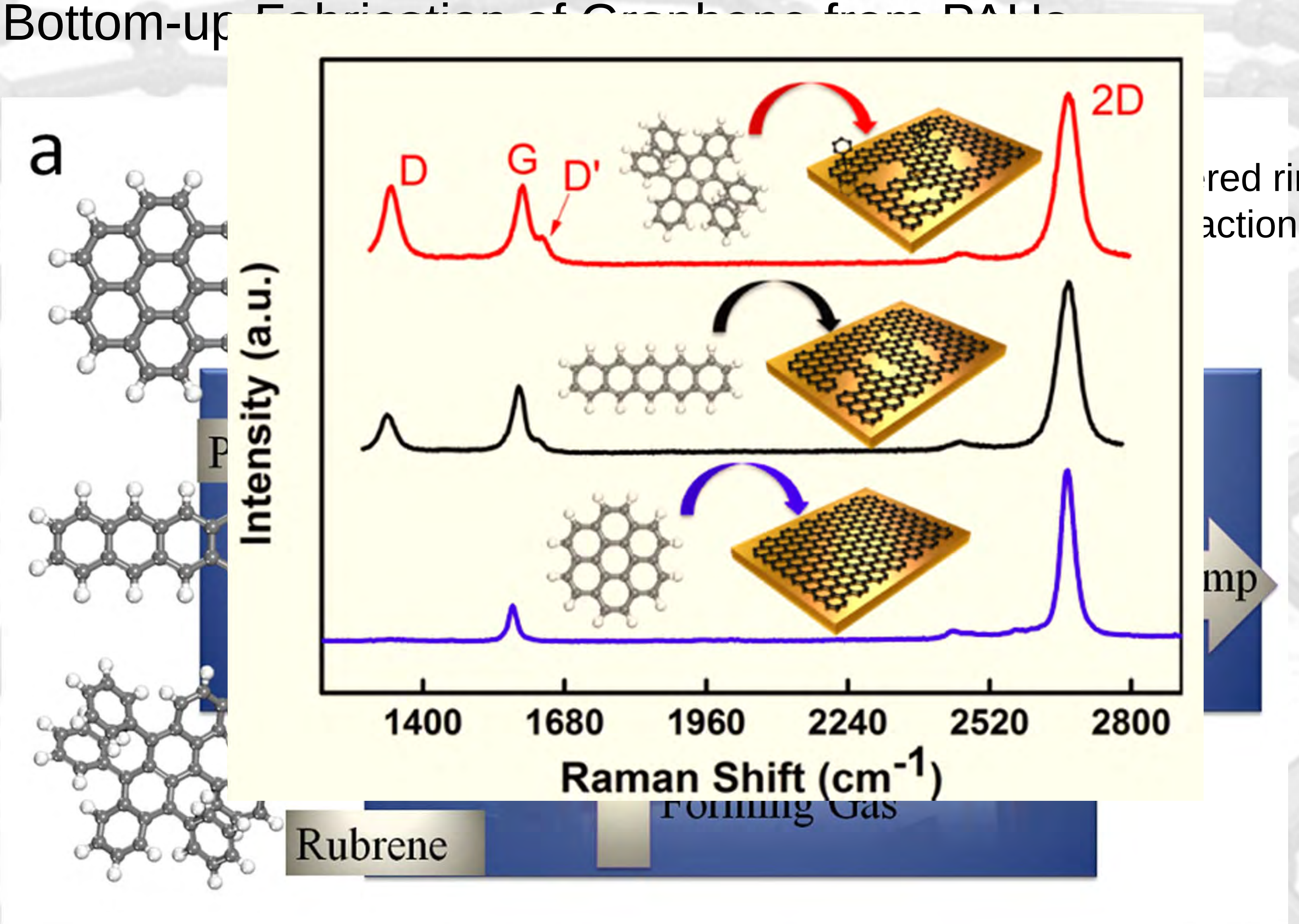


Gaseous (black text), liquid (red), and solid(blue) precursors

X. Wan, K. Chen, J. B. Xu, ***Small,*** 10(22), 4443-54, (2014).

Graphene Synthesis

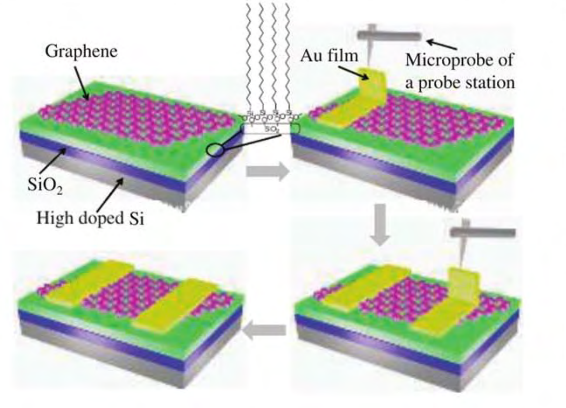
Bottom-up Fabrication of Graphene from PAHs

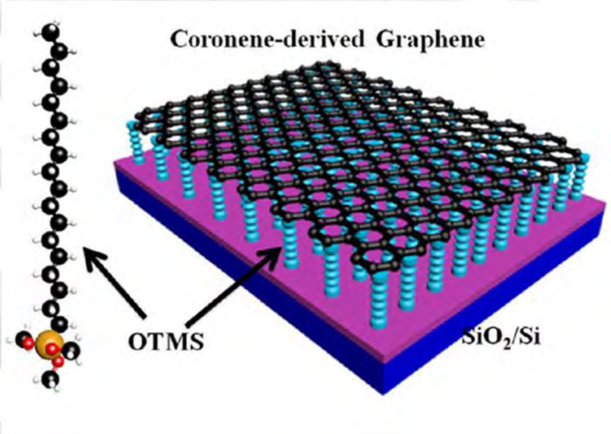


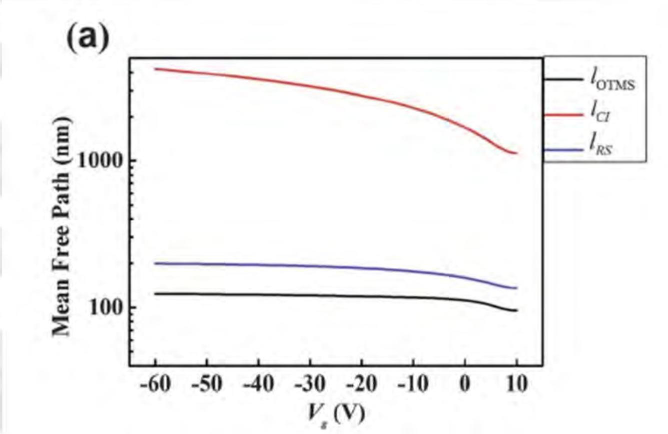
…red rings
…action with Cu

X. Wan, K. Chen, J. B. Xu, et al., ***Chem. Mater.***, 24, 3906-3915 (2012)

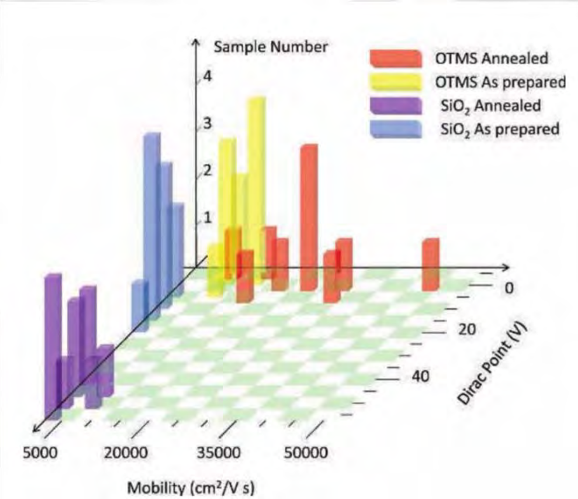
Enhanced Performance of Graphene Transistors by Interface Engineering

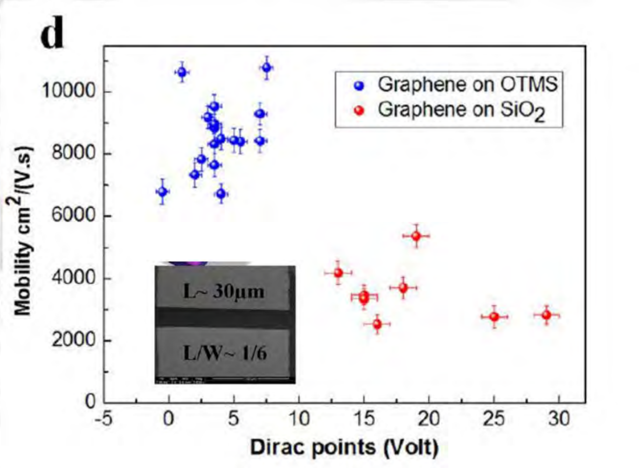


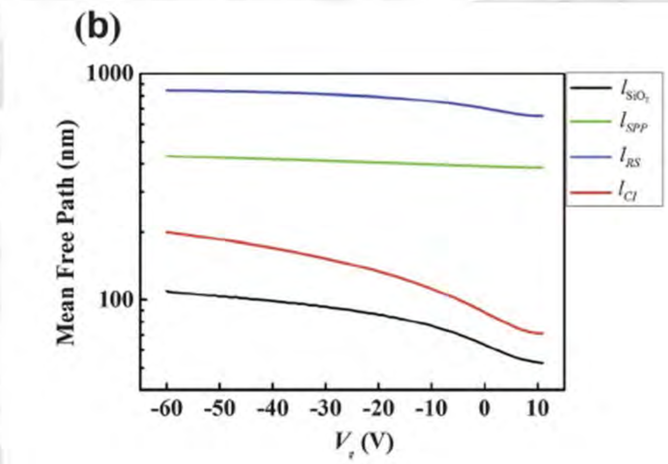




resonant scattering dominated







mechanical exfoliated

PAH-derived

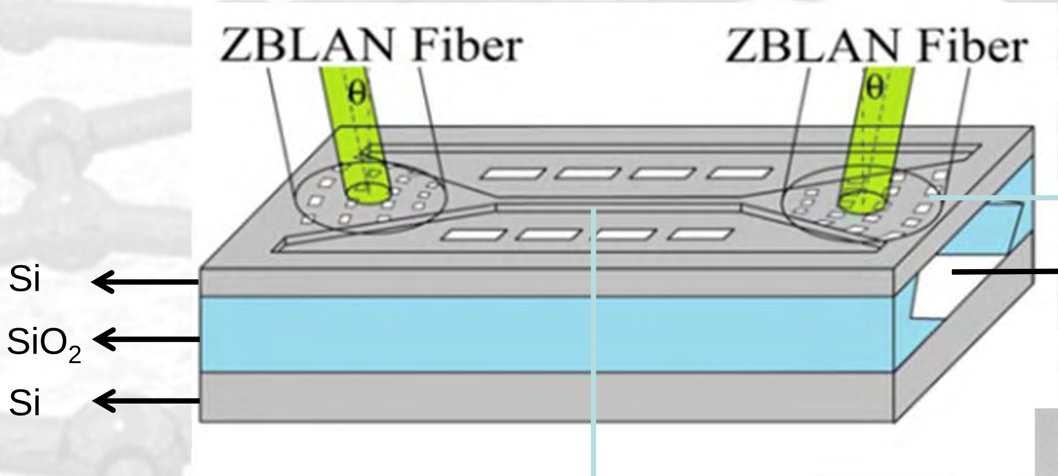
charged impurity dominated

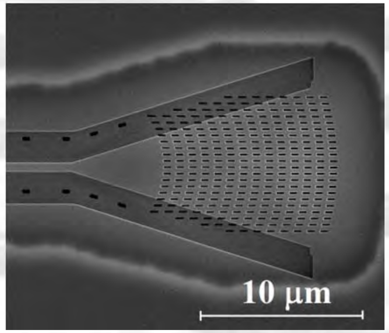
X. M. Wang, J. B. Xu, et al., ***Adv. Mater.*** *23* , 2464，(2011)
X. Wan, X. Wan, J. B. Xu, et al., ***J. Phys. Chem. C*** 117, 4800-4807, (2013)
K. Chen, X. Wan, J. B. Xu, ***Nanoscale*** **5**, 5784-5793, (2013).

Suspended Membrane Platform

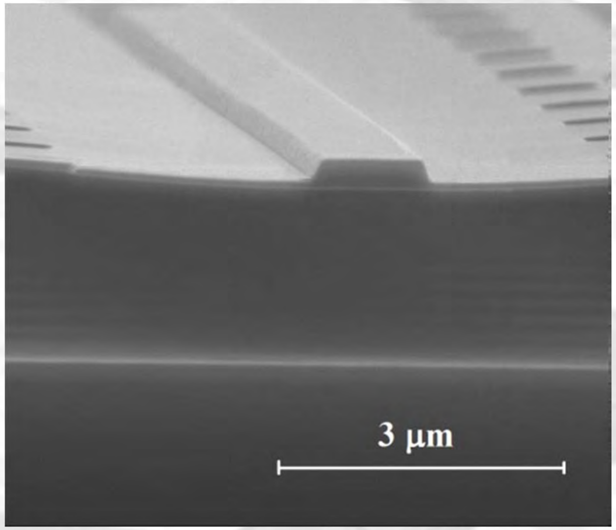
- Suspended Membrane Waveguides (SMWs)

[1]





BOX under device is locally removed by HF etch



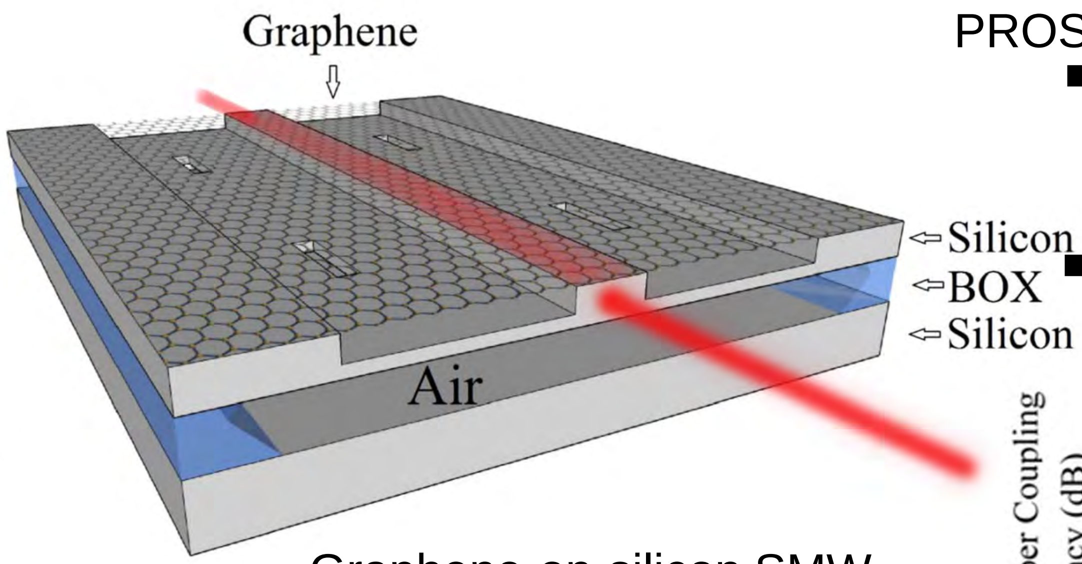
- Advantages of SMW

1. High quality SOI start wafer
2. Using the high-yield silicon fabrication process
3. Accurate & repeatable dimension control
4. Less limitation on device size and wavelength

[1] *Z. Cheng, et al.,* ***Opt. Lett.****37, p. 1217 (April 2012).*

Graphene on Silicon Suspended Membrane Devices

- Integrated graphene on silicon suspended membrane devices

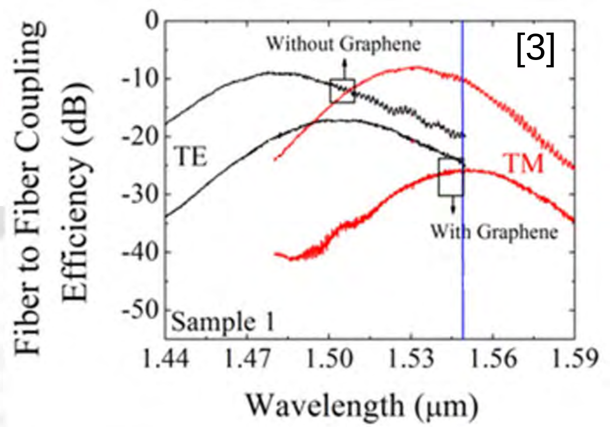


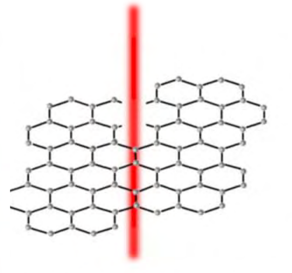
Graphene-on-silicon SMW

PROS.

→ Ultra-wide bandwidth devices (from 1.1 µm to 8.0 µm) [1]

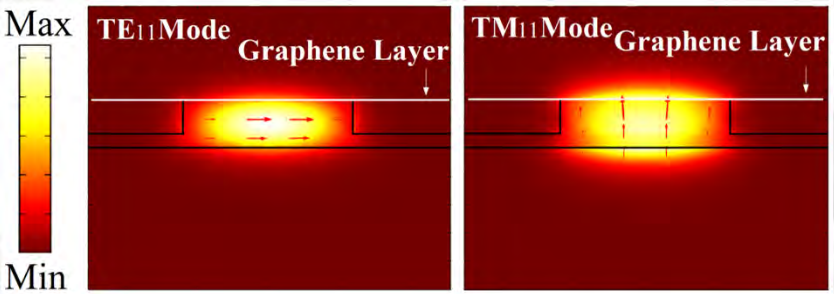
→ In-plane absorption increase the interaction. [2]





2.3% absorption

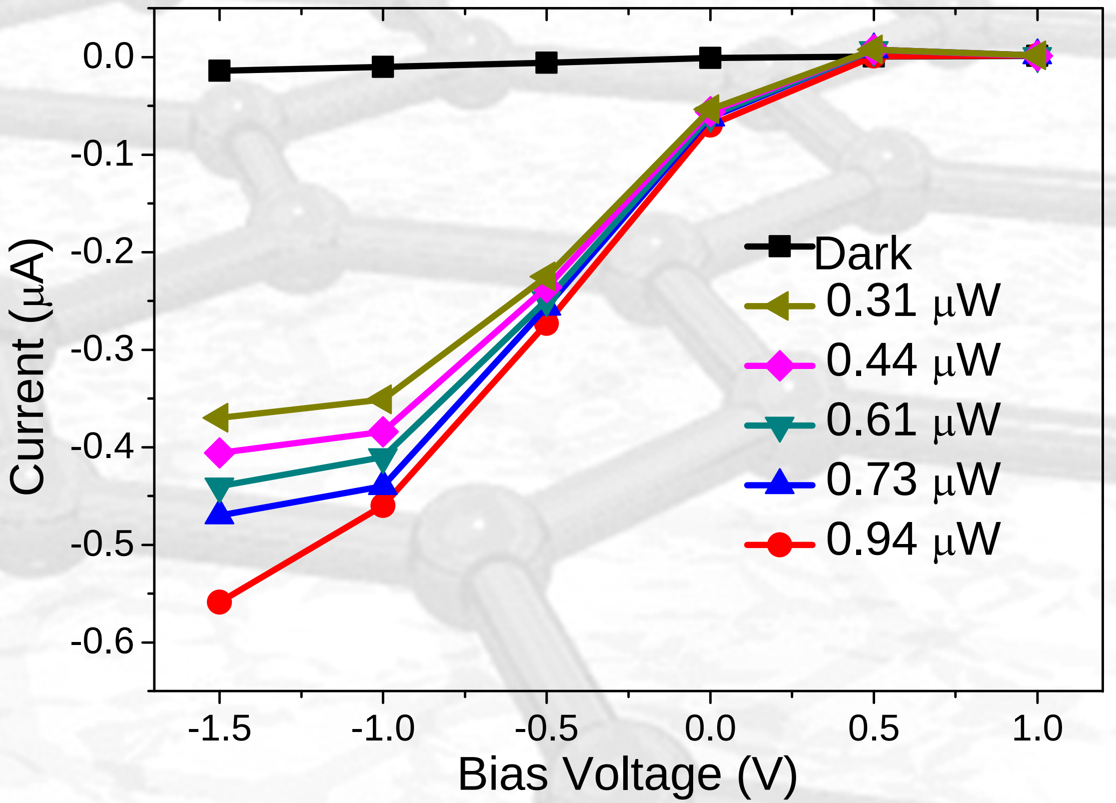
→ Polarization dependence



[1] *R. Soref, et al., J. Opt. A: Pure Appl. Opt. 8, p. 840 (2006).*
[2] *H. Li, et al., APL 101, p. 111110 (2012).*
[3] *Z. Cheng et al., IEEE IPC, Bellevue Washington, USA, (Sep. 2013).*

Photodetector Experimental Results

- Photodetector characterization at 2.75 µm wavelength



- ✓ The responsivity is measured as *0.130 mA/mW* under room temperature.
- ✓ The *in-plane absorption* plays an important role in high responsivity.

*Xiaomu Wang, Zhenzhou Cheng, Ke Xu, Hon Ki Tsang, & Jian-Bin Xu, **Nature Photonics** 7, 888–891 (2013)*

Photodetector Comparison

F. H. L. Koppens, T. Mueller, P. Avouris, A. C. Ferrari, M. S. Vitiello, M. Polini, Nature Nanotechnology 9, 780 (2014); Review: Photodetectors based on graphene, other two-dimensional materials and hybrid systems

Table 1 | Performance parameters.

Reference	Description	Responsivity	Detector type	Bandwidth	Wavelength	IQE (%)	EQE (%)
18,19	Graphene-metal junction	6.1 mA W^{-1}	Photocurrent (PV/PTE)	>40 GHz	Visible, NIR	10	0.5
30,37,52	Graphene p–n junction	10 mA W^{-1}	Photocurrent (PTE)		Visible	35	2.5
20–22	Graphene coupled to waveguide	0.13 A W^{-1}	Photocurrent (PV/PTE)	>20 GHz	1.3–2.75 μm	10	10
90	Graphene–silicon heterojunction	0.435 A W^{-1}	Schottky photodiode	1 kHz	0.2–1 μm		65
31	Biased graphene at room temperature	0.2 mA W^{-1}	Bolometric		Visible, infrared		
94	Dual-gated bilayer-graphene at low temperature	10^5 V W^{-1}	Bolometric	>1 GHz	10 μm		
105	Hybrid graphene–QD	10^8 A W^{-1}	Phototransistor	100 Hz	0.3–2 μm	50	25
63	Graphene with THz antenna	1.2 V W^{-1}	Overdamped plasma waves		1,000 μm		
120	Graphene interdigitated THz antenna	5 nA W^{-1}	Photovoltaic and photoinduced bolometric	20 GHz	2.5 THz		
147,148	Graphene–TMD–graphene heterostructure	0.1 A W^{-1}	Vertical photodiode		<650 nm		30
130	Biased MoS_2	880 A W^{-1}	Photoconductor	0.1 Hz	<700 nm		
143	Graphene double-layer heterostructure	>1 A W^{-1}	Phototransistor	1 Hz	0.5–3.2 μm		
7,8,134	WSe_2 p–n junction	16 mA W^{-1}	p–n photodiode		<750 nm	60	3
136	GaS nanosheet	19.1 A W^{-1}	Photoconductor	>10 Hz	0.25–0.5 μm		

Graphene-on-Silicon Heterostructure Waveguide Photodetectors

nature photonics | LETTERS

High-responsivity graphene/silicon-heterostructure waveguide photodetectors

Xiaomu Wang*, Zhenzhou Cheng*, Ke Xu, Hon Ki Tsang* and Jian-Bin Xu*

➢The work has been highlighted by *Nature* and *Nature Photonics*

nature International weekly journal of science

Home | News & Comment | Research | Careers & Jobs | Current Issue | Archive | Audio & Video | For A

News & Comment > News > 2013 > November > Article

NATURE | NEWS

Graphene makes light work of optical signals

nature photonics

Access provided to The Chinese U

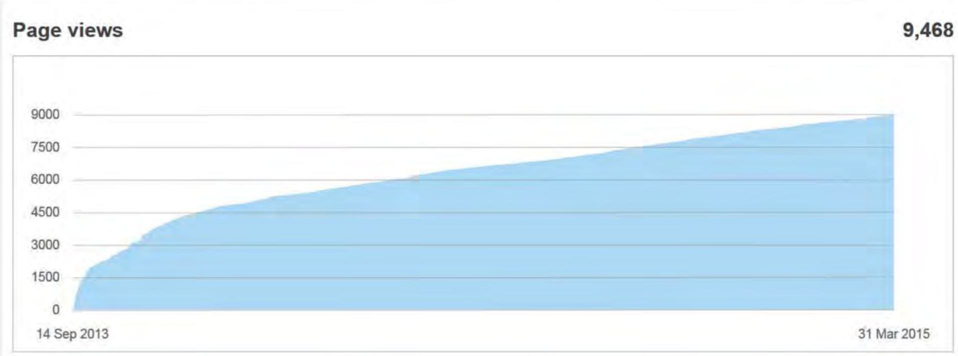
nature.com ▸ journal home ▸ current issue ▸ news and views ▸ full text

NATURE PHOTONICS | NEWS AND VIEWS

Silicon photonics: Graphene benefits

Ming Liu & Xiang Zhang

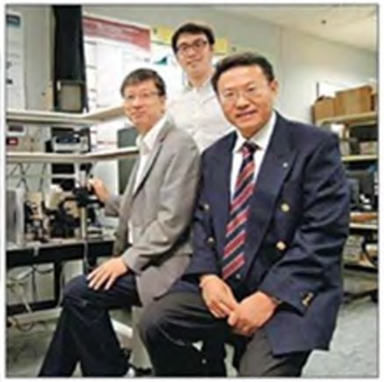
➢The work has been read online ~*9,500* times



➢Over *30* website news outlets.

➢The work has been reported by medium.

中大發明光電器 高效低成本



■曾漢奇教授(前排左)、許建斌教授(前排右)及博士後研究員程振洲(後排)共同研發。

【新報訊】香港中文大學電子工程學系曾漢奇教授和許建斌教授及其科研團隊，最近成功發明了一項全新的光電檢測器，有效推進高效率、低成本紅外光譜技術，可應用於環境和生物醫學工程，如監測空氣污染和分析人類呼吸疾病標記。

電子工程系獨立完成

在曾教授和許教授的帶領下，科研團隊利用透明膠帶，從石墨中機械剝離出單一碳原子層的石墨烯，並將石墨烯置於矽懸浮薄膜光波導路的頂部，製作出異質結結構的光探測器。該器件在室溫下具有很寬的光譜探測範圍。

這項突破性的實驗進展，有望實現高效率、低成本、高集成度中紅外新一代光探測器。科研團隊證明，利用單層石墨和矽光波導製作的異質結中紅外探測器具有很高靈敏度。整個研究從材料製備、器件設計、製造以至測量，均由中大電子工程學系科研人員獨立完成。

許建斌教授表示，科研團隊提出並開發了一種新穎的，用聚焦光柵耦合的中紅外懸浮薄膜波導

Conclusions

- High-quality large-area graphene sheets can be synthesized on Cu foils from PAHs
- The quality of the synthesized graphene sheets strongly depend on the molecular structures of PAHs
- The underlying growth mechanism mainly involves a surface-mediated process of dehydrogenated PAHs
- Coronene-derived graphene sheets have a carrier mobility up to ~ 5300 $cm^2/V \cdot s$ on SiO_2 and ~11000 $cm^2/V \cdot s$ on OTMS modified SiO_2, while triphenylene-derived graphene sheets show similar quality, while for mechanically exfoliated graphene, a carrier mobility can be as high as 70,000 $cm^2/V \cdot s$, one of the highest on large substrtae surface so far.
- Dramatically increasing the mobility of GFETs OTMS SAMs modification provide a new avenue to achieve high quality graphene devices, with intrinsic graphene nature
- A new platform to dramatically enhance light interaction with graphene has been developed, with which an ultra-high sensitive Mid-IR photodetector was developed. It is generic for all 2D materials.