Graphene Frontiers

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Chief Science Officer

http://www.graphenefrontiers.com

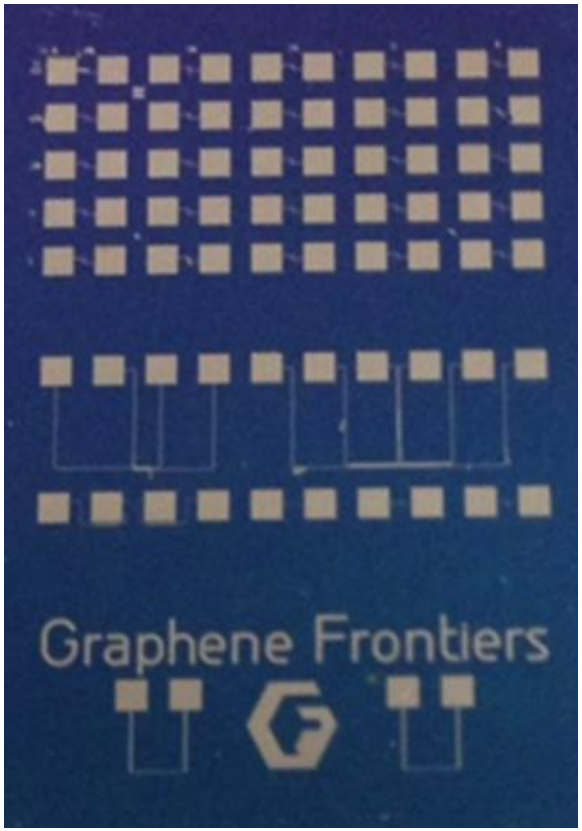
Characterizing Disruptive Innovation: Meet the 'Disruptors'

The Disruption Myth and Gaps in the Innovation Ecosystem

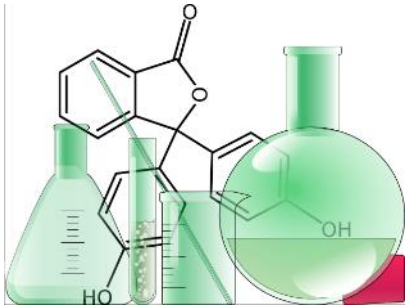
Government-University-Industry Research Roundtable Meeting
National Academies, Washington, DC
October 20-21, 2015

Government | University | Industry
RESEARCH ROUNDTABLE


six sensors
elevate your platform


Graphene Frontiers

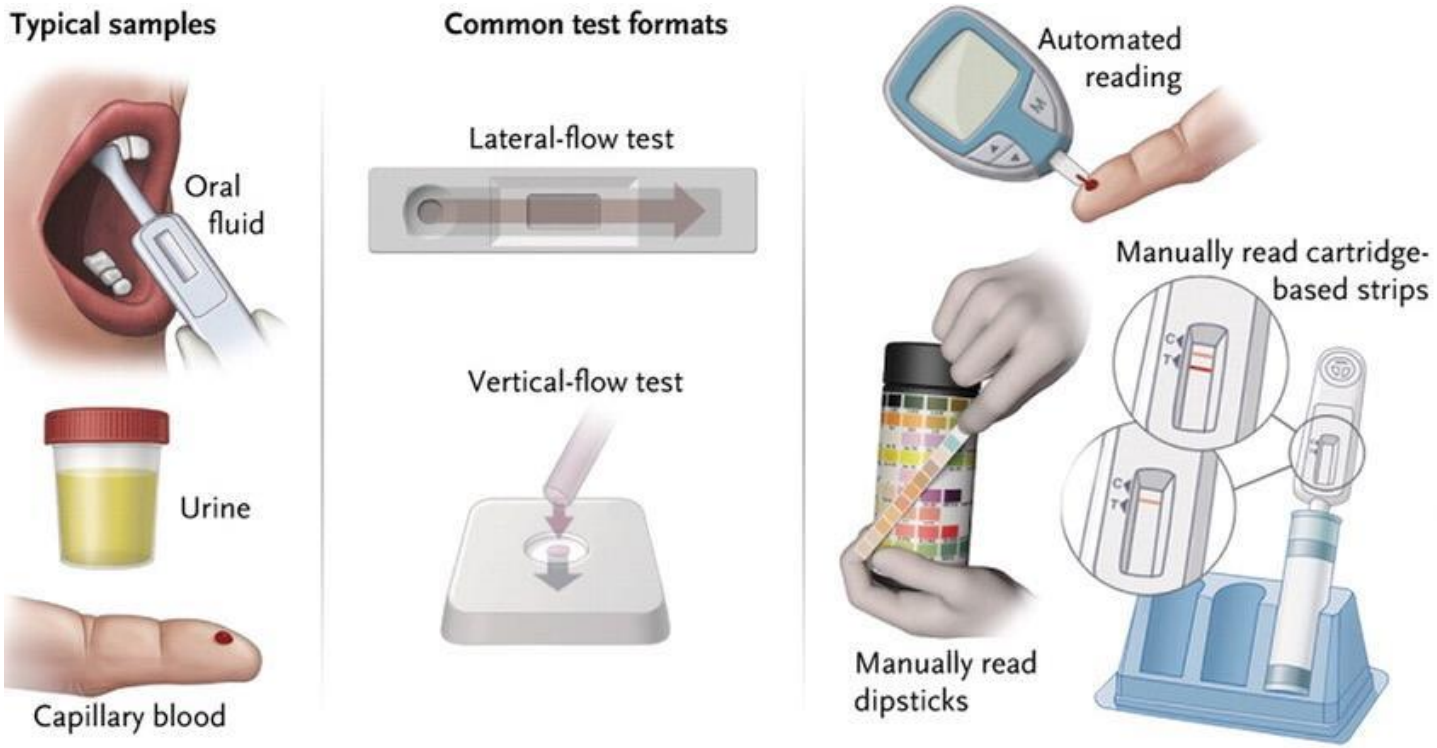
Today's Process – Clinical Laboratory Tests



Wait days for Results (or longer).

- Requires sending samples to a laboratory.
- The analysis is time-consuming, requiring several wet laboratory steps conducted by a skilled laboratory technician.
- Higher sensitivity, quantified results may take longer, if possible at all.

1st Gen POC Diagnostics: Not Good Enough



- **Limited sensitivity**
- **Inaccurate**
- **Slow**

Next Gen POC Diagnostics: Quantum Leap

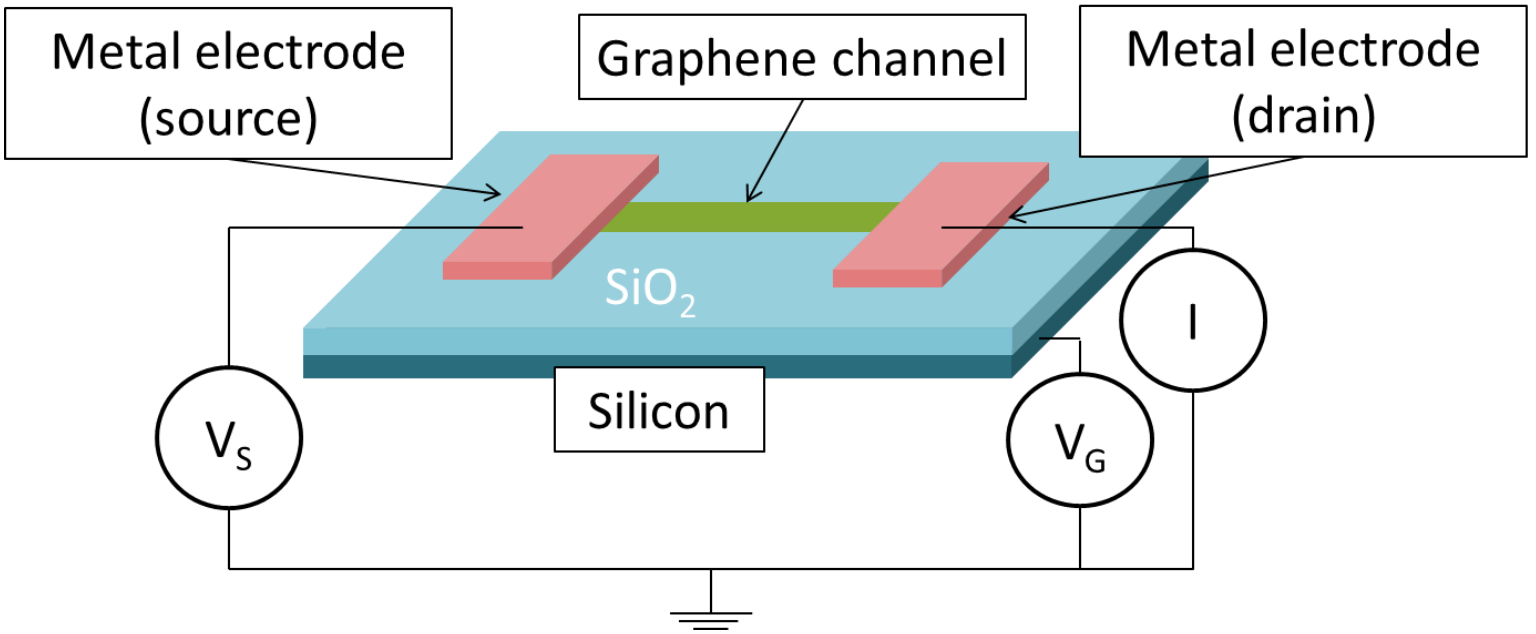
Samples
Capillary blood, oral fluid, urine, breath, and other samples

Multiple test formats
Handheld lab-on-a-chip devices
Disposable tests (no instruments)
Doctor's office desk-based devices

Devices will fully automate testing and analysis or display of results

Transmission of results
Devices are likely to have wireless connectivity to transmit result data

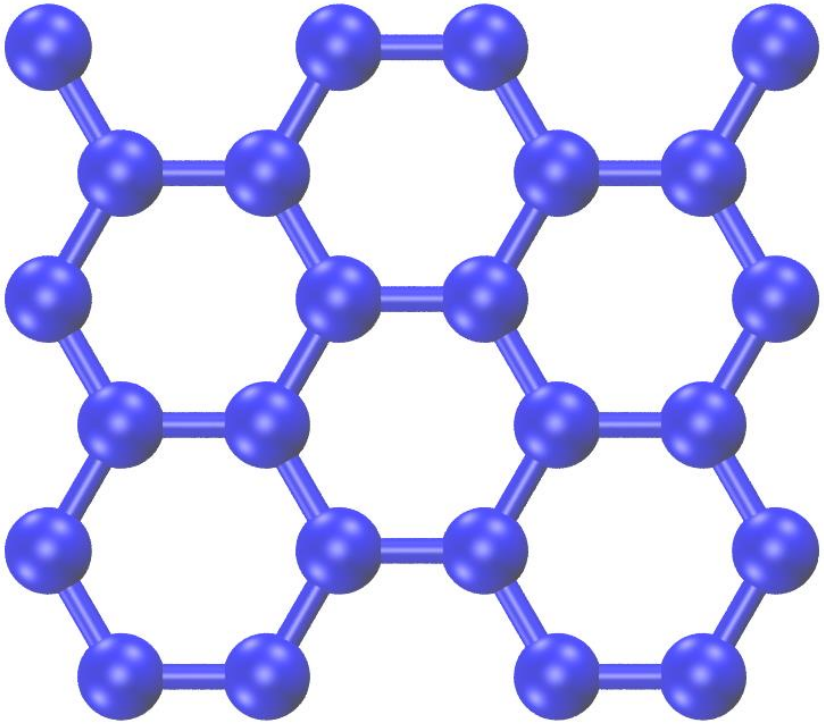
Graphene Biosensor



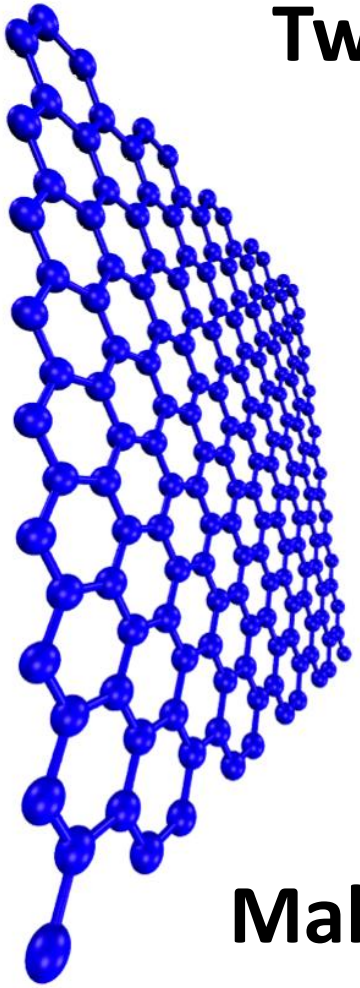
GFET = Graphene Field Effect Transistor

Graphene Structure

- Hexagonal structure
- Short, strong bonds 1.42A



Graphene Properties



Two Dimensional

Highly sensitive

Inert with Few Defects

Highly specific

Conductive

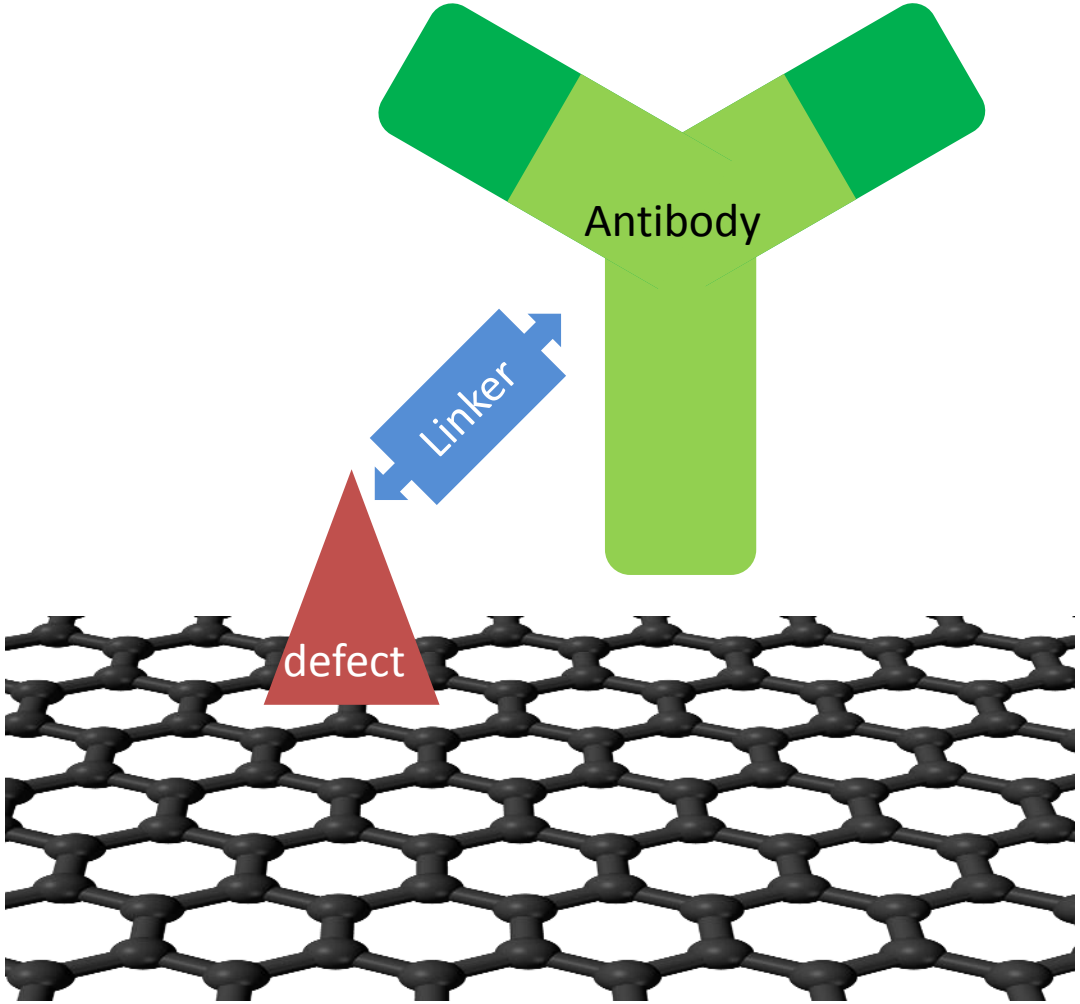
Strong signal

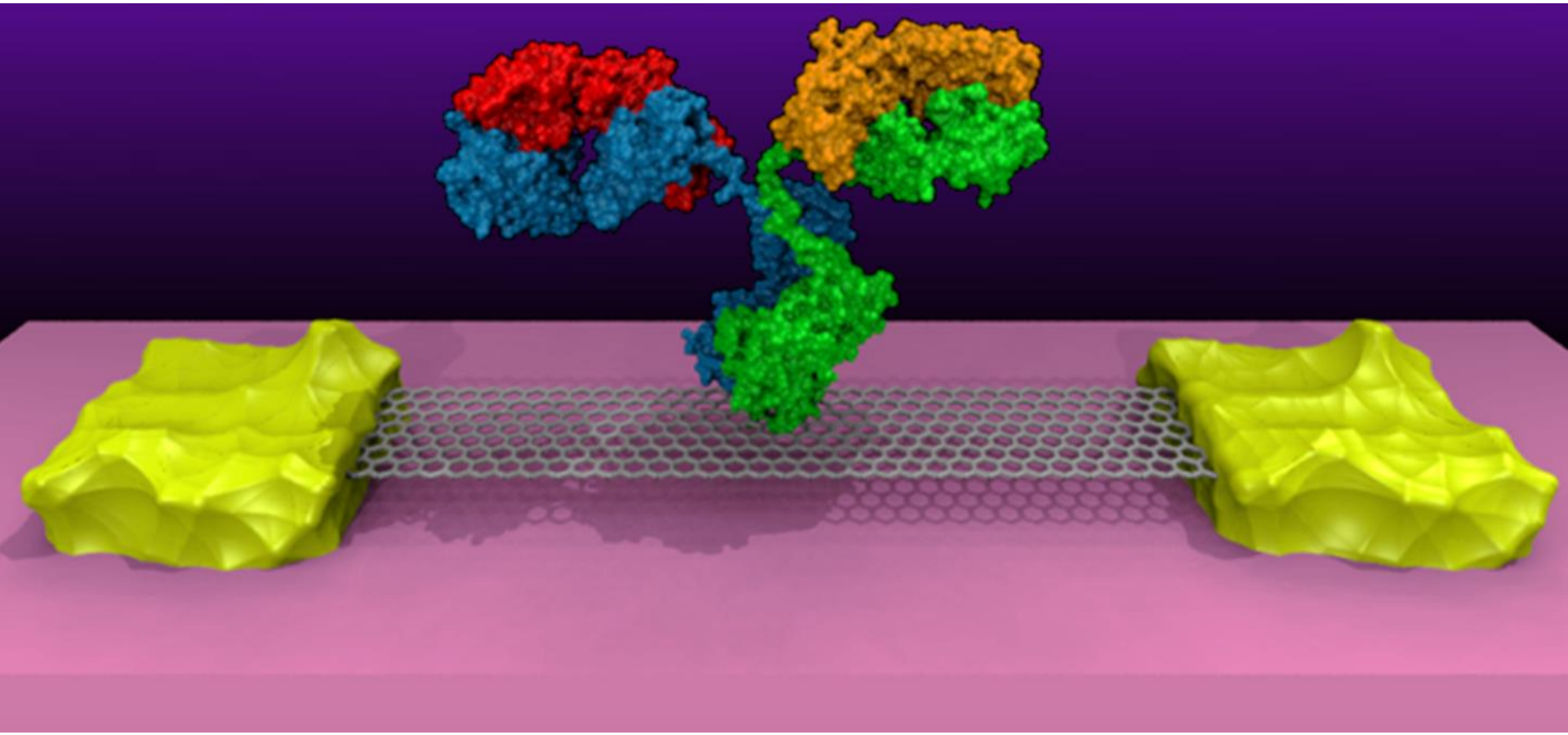
Strong

Robust devices

Make it ideal for biosensing applications…

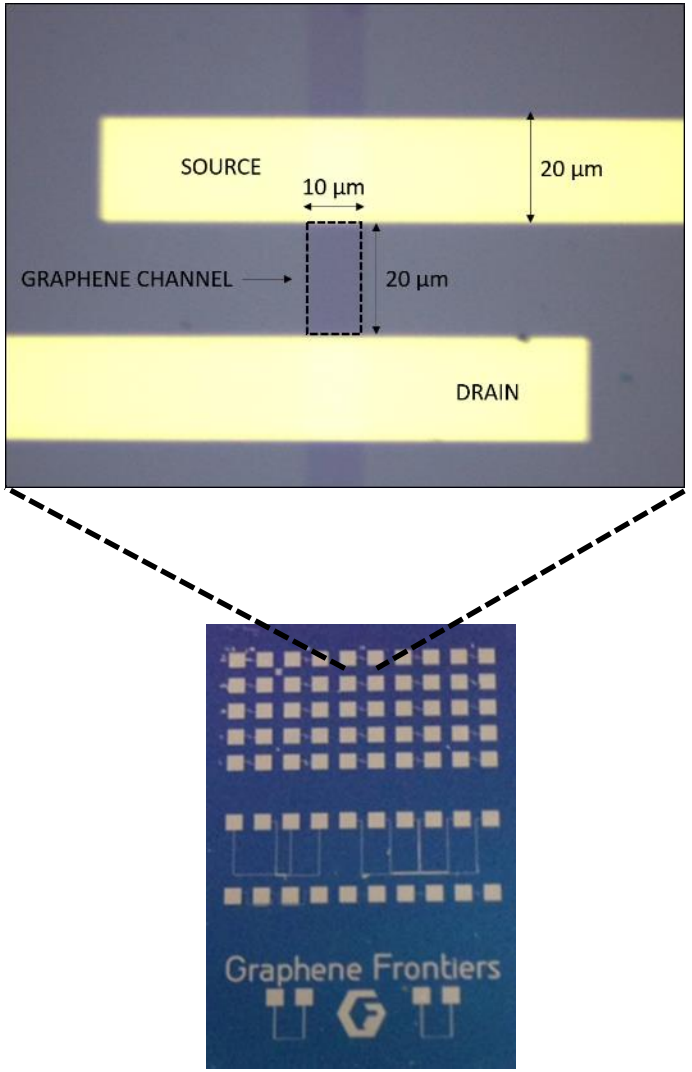
GFET Functionalization



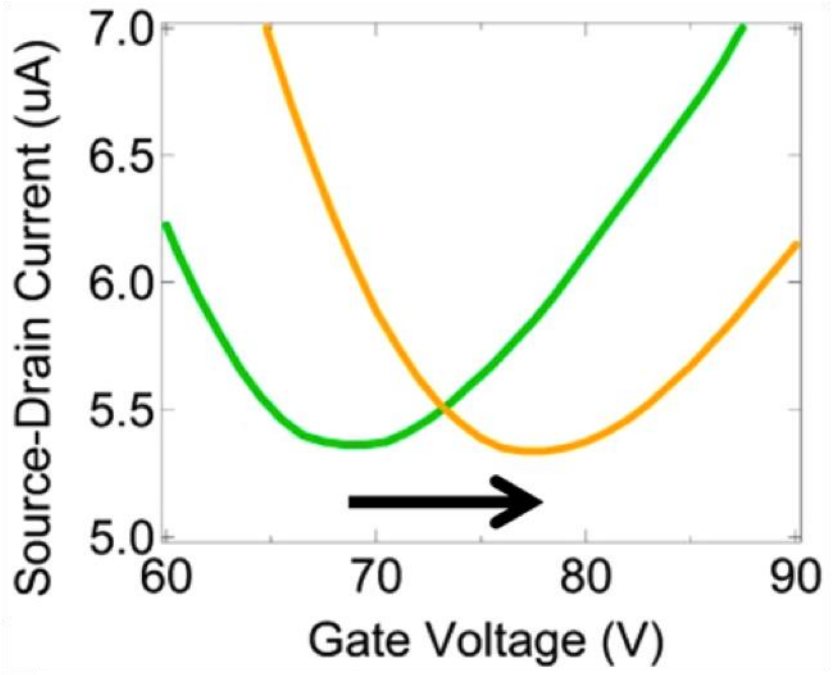


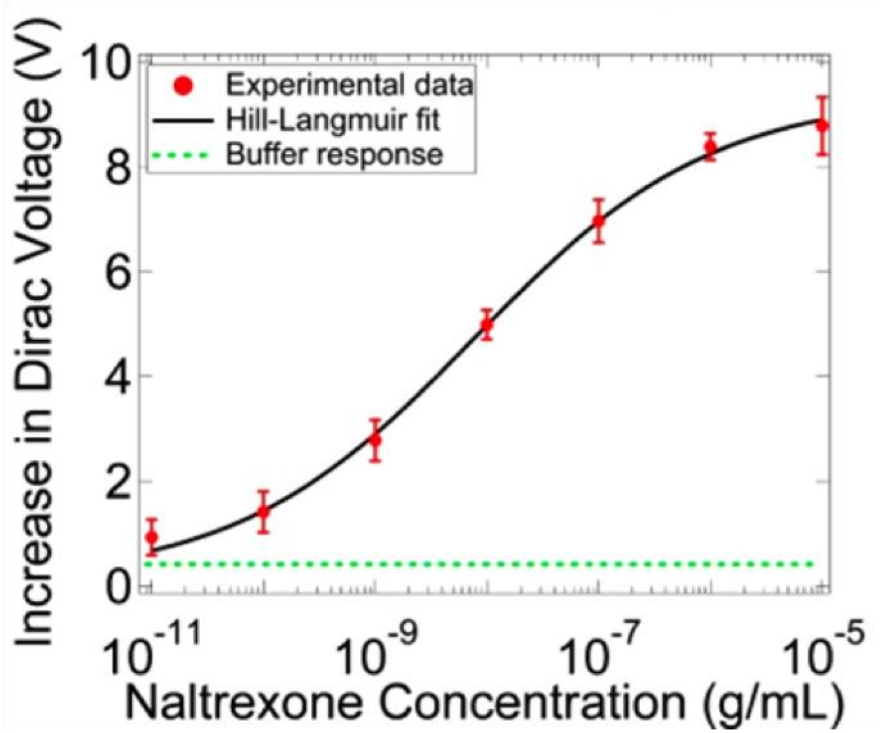
Biosensor Features

- Devices fabricated by IC lithography processes.
- Compact active area.
- High density arrays.
- Highly scalable production
- Device Array Integration for a Lab-on-a-chip



Example Results: Naltrexone Detection





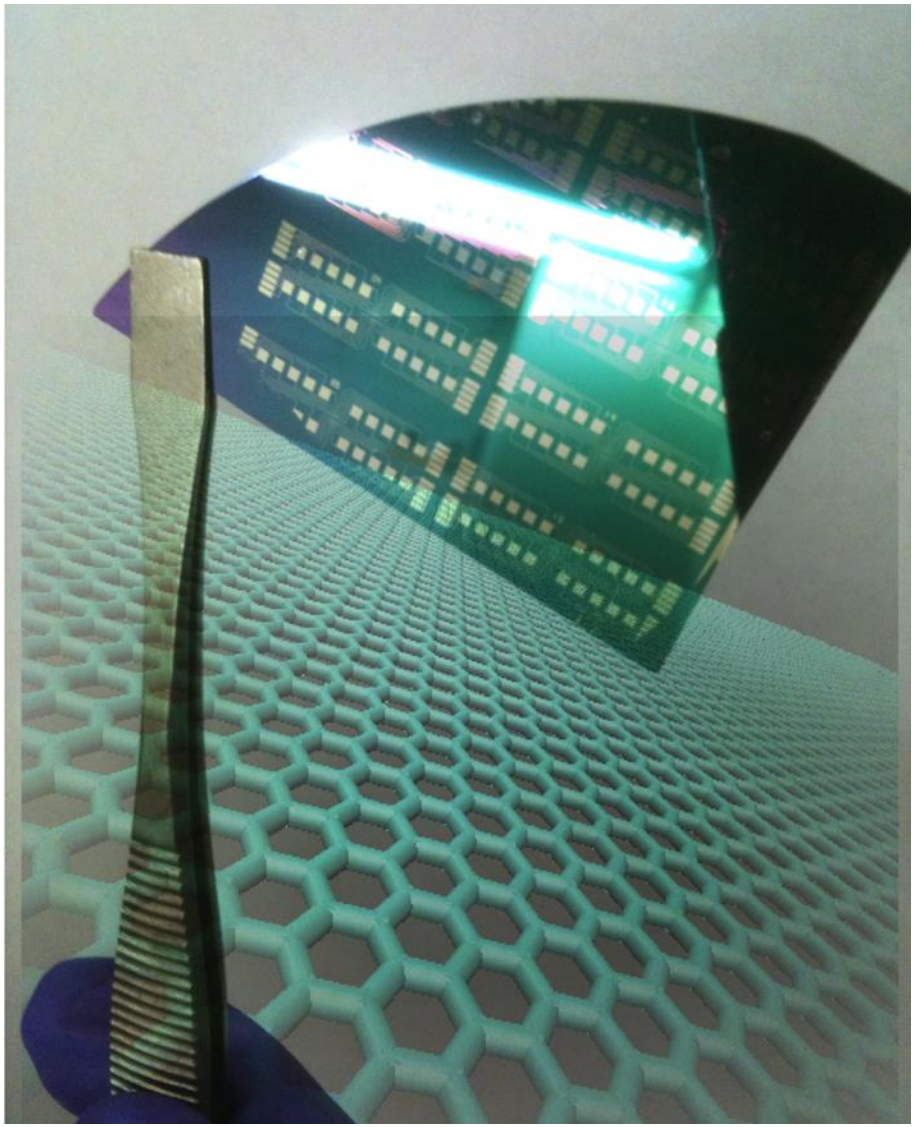
Clear signal to picograms per milliliter

Lerner, M. B., et al. (2014). Nano Letters, 14(5), 2709–2714.

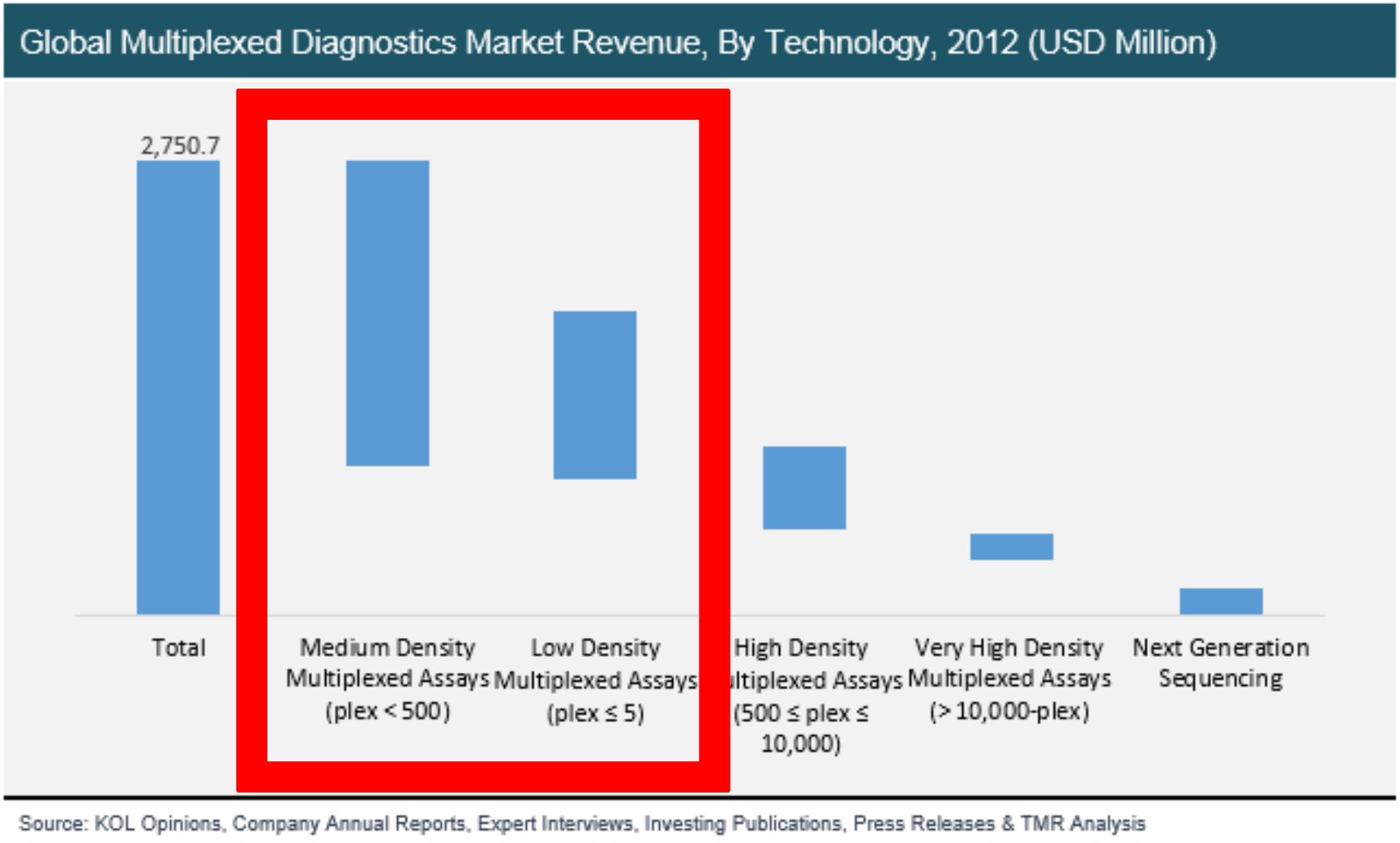
Demonstrated Results: Multiple Proteins

- IL-6
- Troponin I
- Borrelia burgdorferi
- Osteopontin (OPN)
- Salmonella

Signal @ 1pg/mL (30 fM)

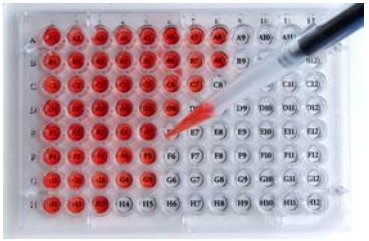


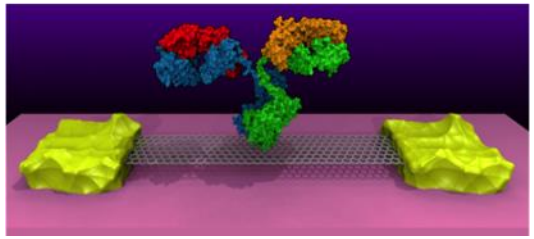
Biosensors: $20B



Low/Medium Density Multiplexed Assays: >$2B

Comparison with ELISA





	ELISA	GFET
Limit of Detection (LOD)	**1-20pg/ml**	100x-**1000x better** than ELISA
Ability to Multiplex	**No** (1 antibody per run)	**Yes**
Speed	**Hours** for incubation and processing	Sample to results in **minutes**
Cost	Expensive Optical Readers	All electronic, lower cost
Ease of Use	Trained **Lab Tech Needed**	After sample obtained, the rest is **automated**
Specificity of detection	Relies on secondary detection antibody **Higher false positives**	**Specific** and direct detection – all electronic

Go To Market: Path to Revenue

1. **Research Use Only**
   - Currently available through Sigma-Aldrich
2. **Real-time Biomonitor**
3. **Point of Care Diagnostics**
   - Developed and distributed via partners*

Commercialization Challenges

Point of Care Diagnostics is the large application.

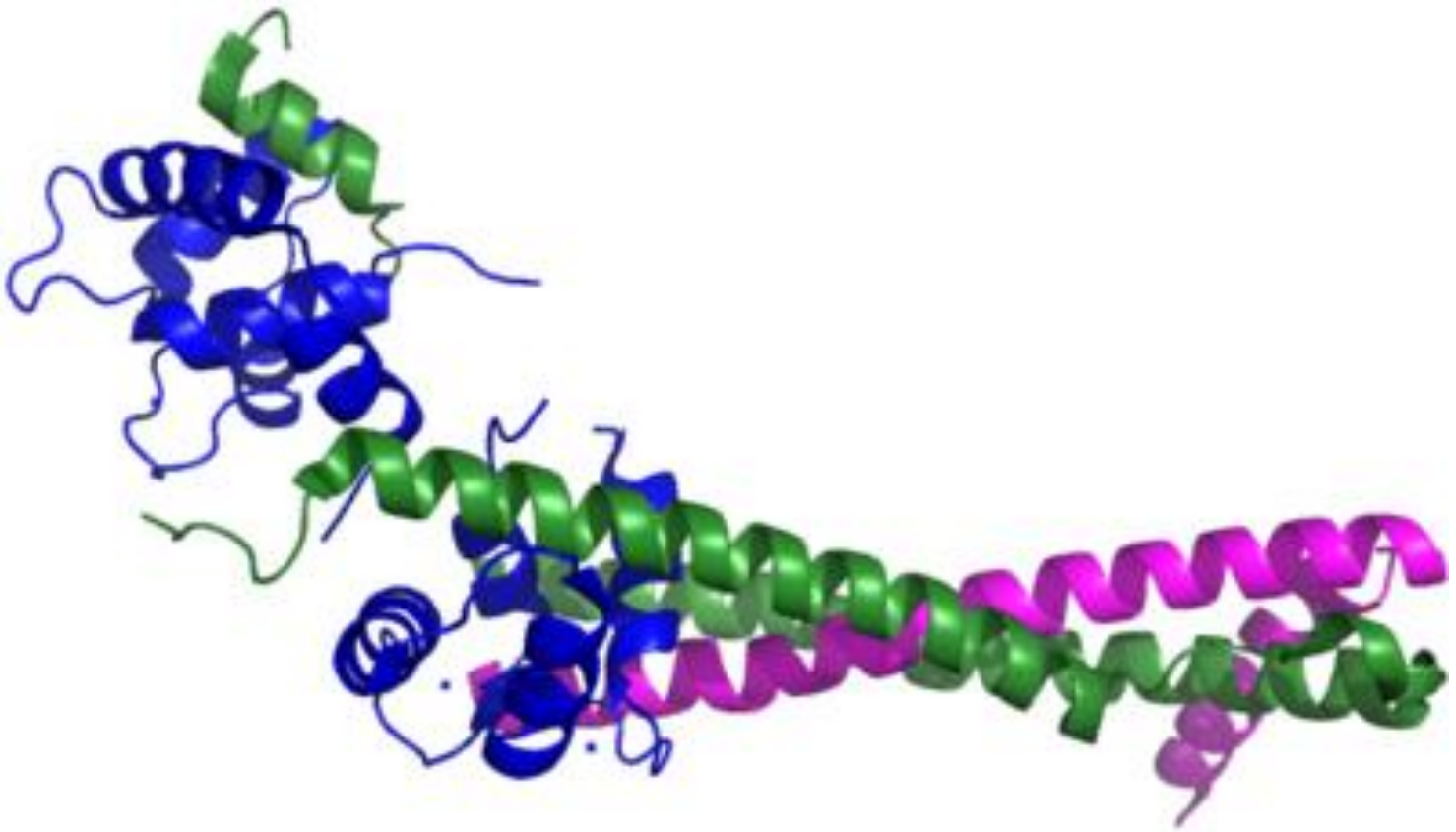
Challenges:

- A large, established industry.
- Healthcare industry does not like change.
- Many different tests for many different conditions.
- Approval path is slow and expensive and needs to be repeated for each test.
- Revenue Path is critical (i.e. HCPCS Codes)

Our Solution:

- Begin targeting diagnostic tests with impact.
- Partner with existing diagnostic companies.
- Focus our work on our expertise and team with others for our shortcomings.

Proof of Concept Program: Troponin I



POC Diagnostics: Potential Partners

Company Origin

- Spin-out from the University of Pennsylvania.
  - Formed in 2011
- Formed around IP for low-cost, production of graphene films (developed in the Physics Department lab of A.T. Charlie Johnson).
- Additional graphene production technology developed at Graphene Frontiers.

Problem: Commercial Production

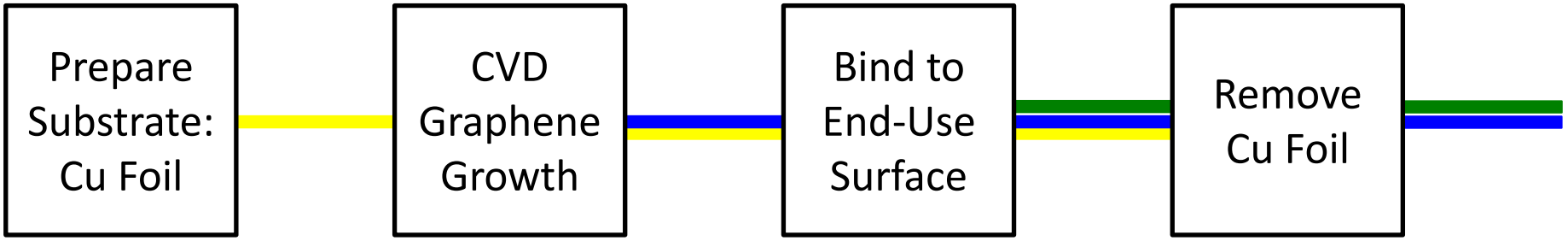
1) Low Volume

2) Expensive

3) Not Uniform

4) Harsh Chemicals

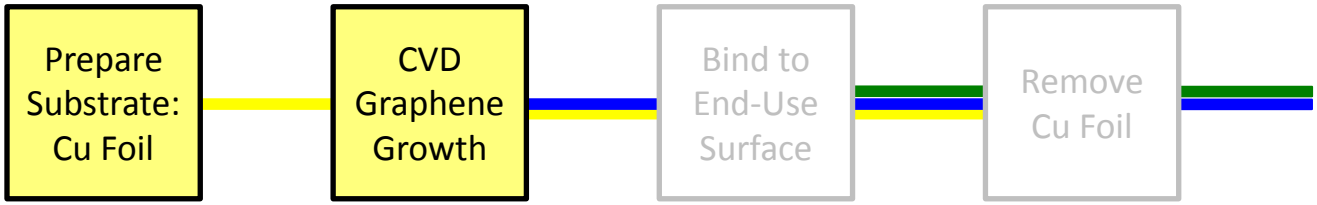
Breakthrough: Problem Solved!



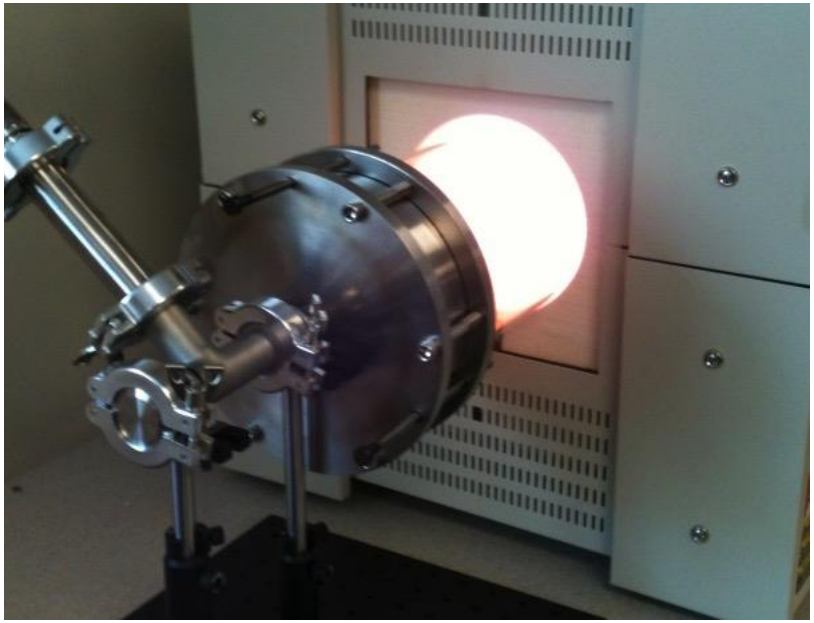
- Developed Processes For:
- Scalable single atomic layer graphene deposition
- Graphene handling
  - Transfer of the graphene to different substrates.

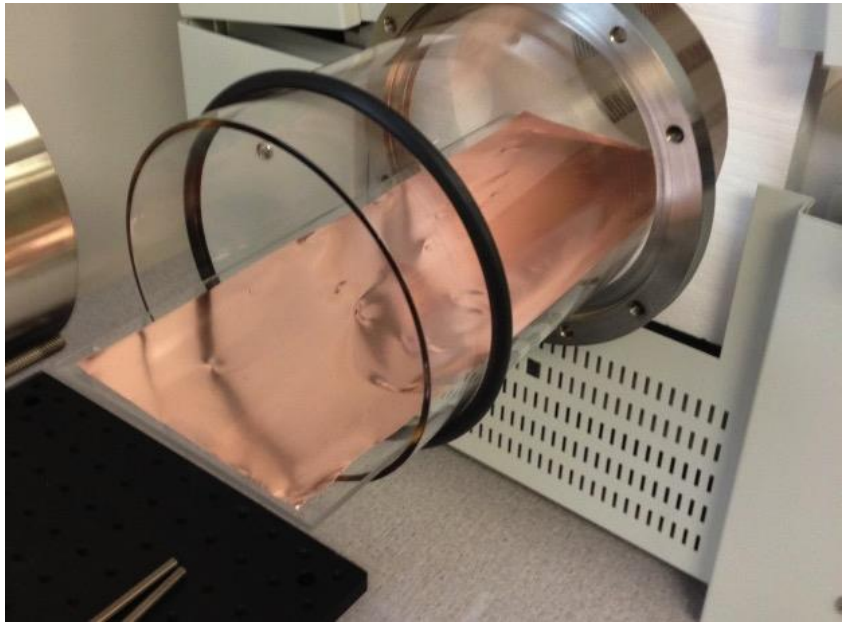
National Science Foundation
WHERE DISCOVERIES BEGIN

Graphene Chemical Vapor Deposition

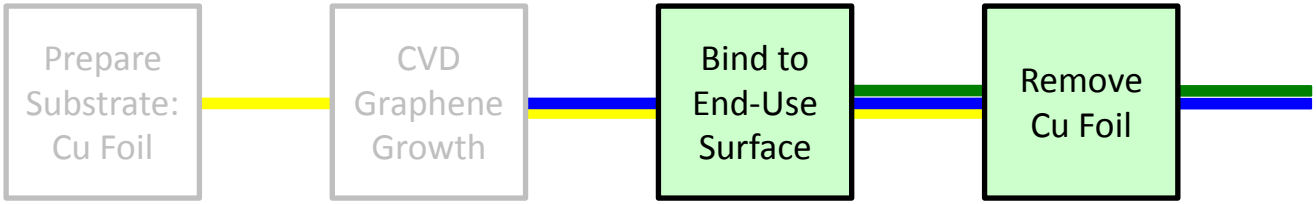


Atmospheric Pressure Chemical Vapor Deposition

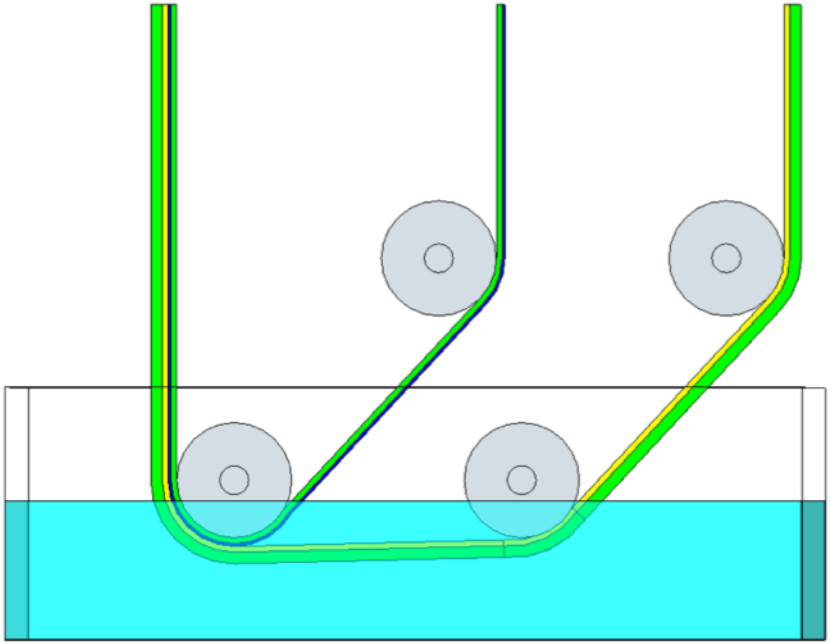


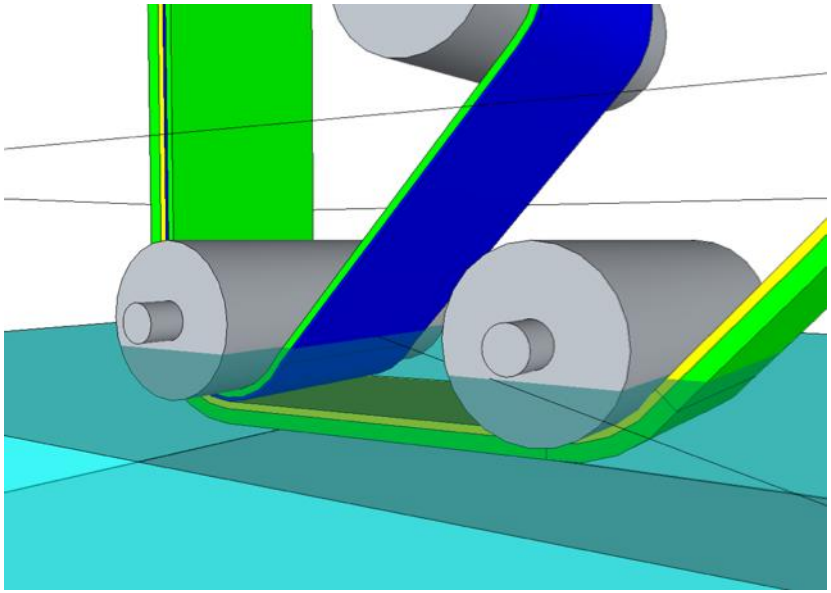


Continuous Graphene Transfer



- Hydrolysis-Assisted Mechanical Separation





Scaled Graphene Production

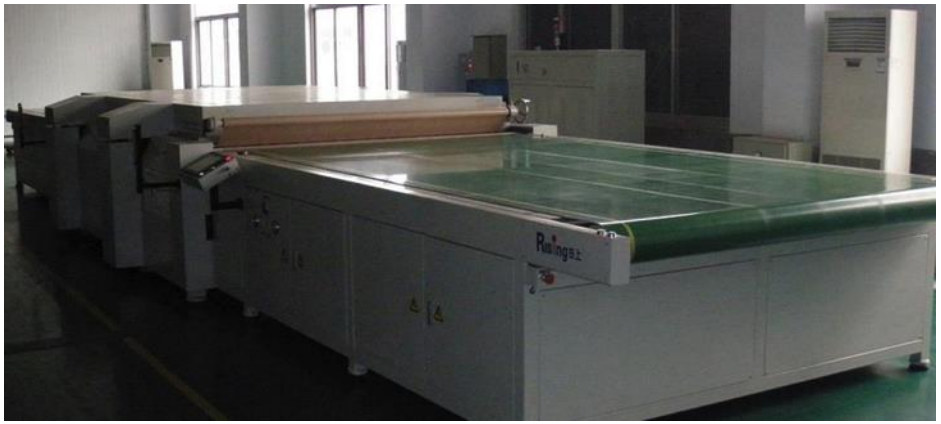
2010

1 cm² > $10,000

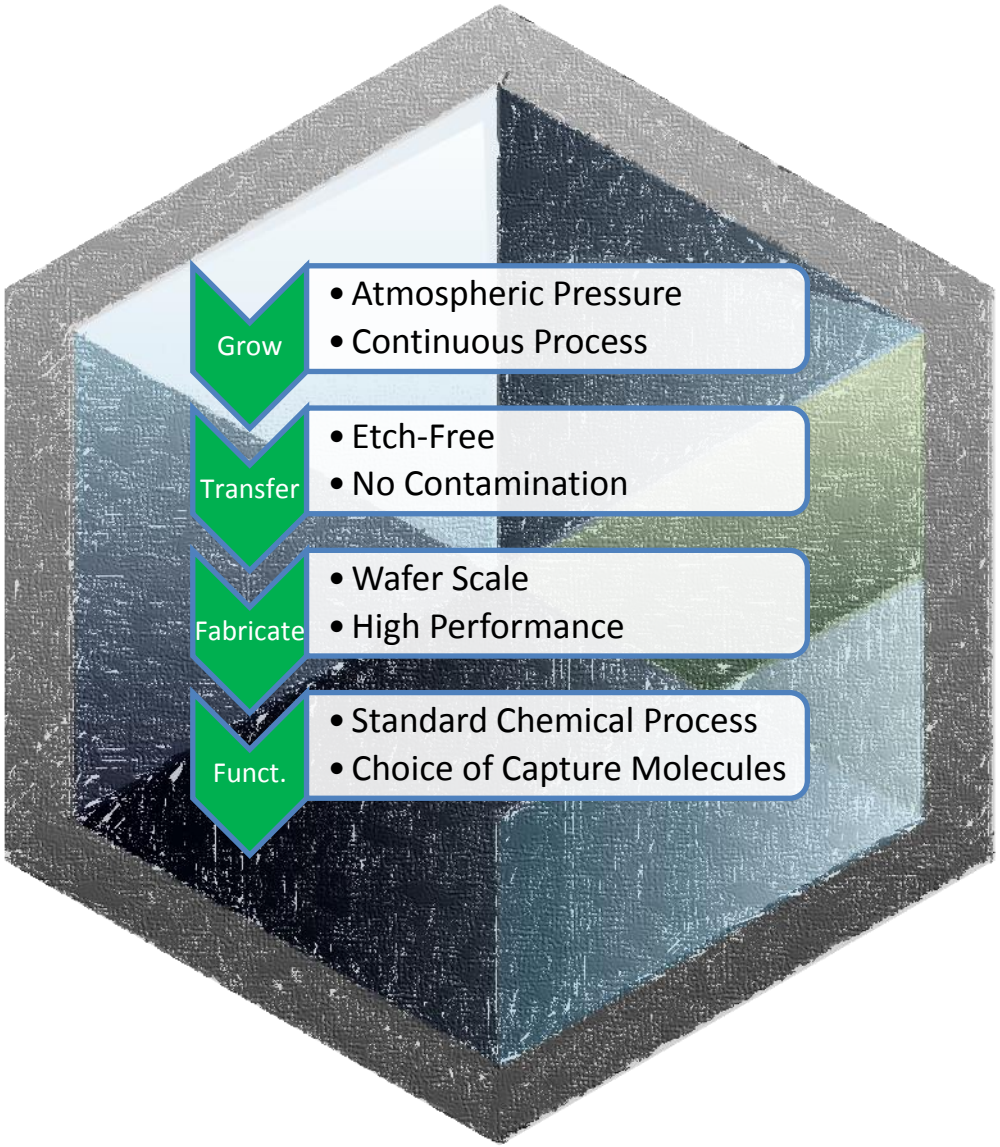
2012

1 cm² < $10

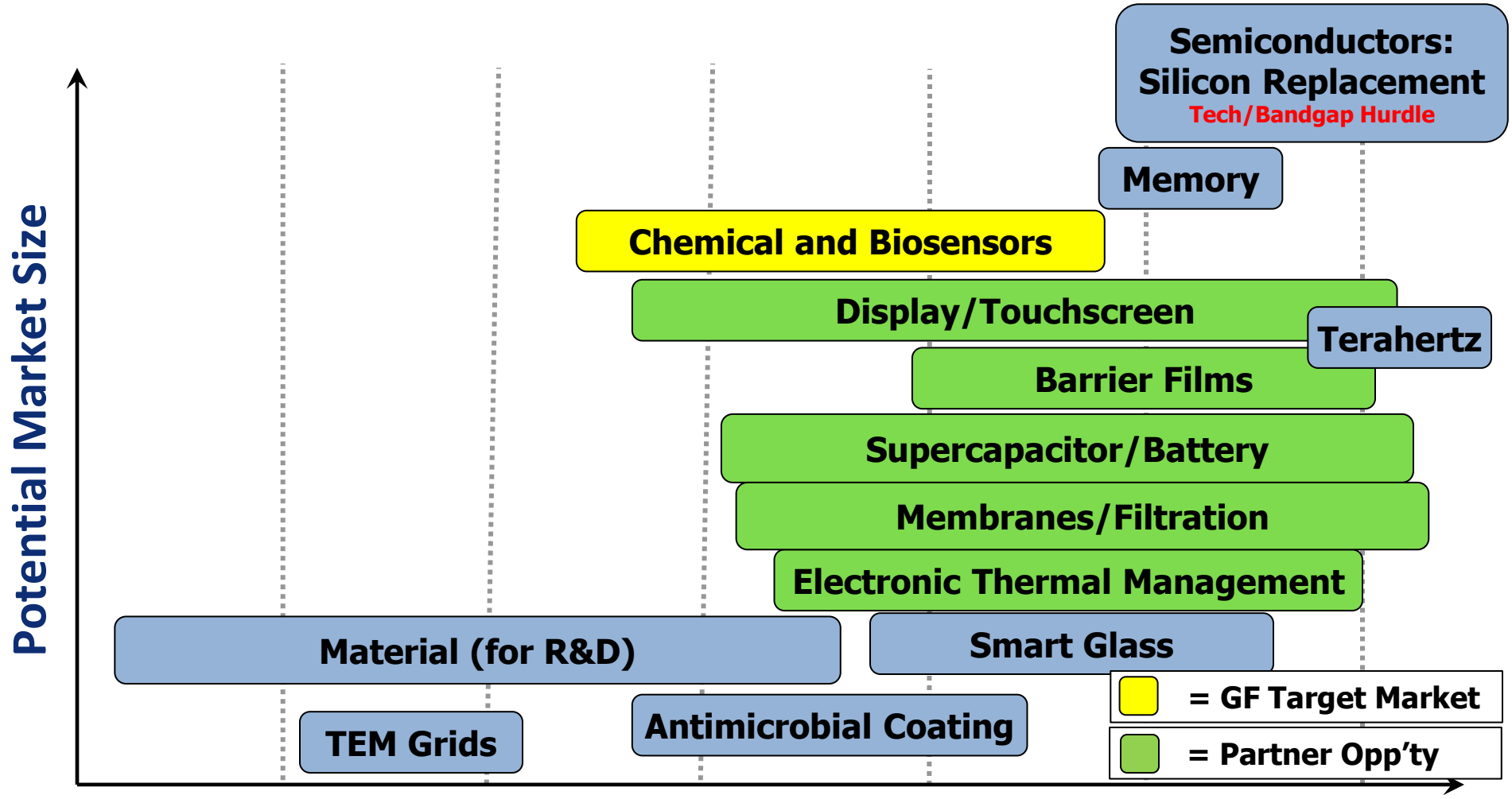
2016



1 cm² < $0.01


Grow
• Atmospheric Pressure
• Continuous Process
Transfer
• Etch-Free
• No Contamination
Fabricate
• Wafer Scale
• High Performance
Funct.
• Standard Chemical Process
• Choice of Capture Molecules

Markets: Size and Timing



Thank You

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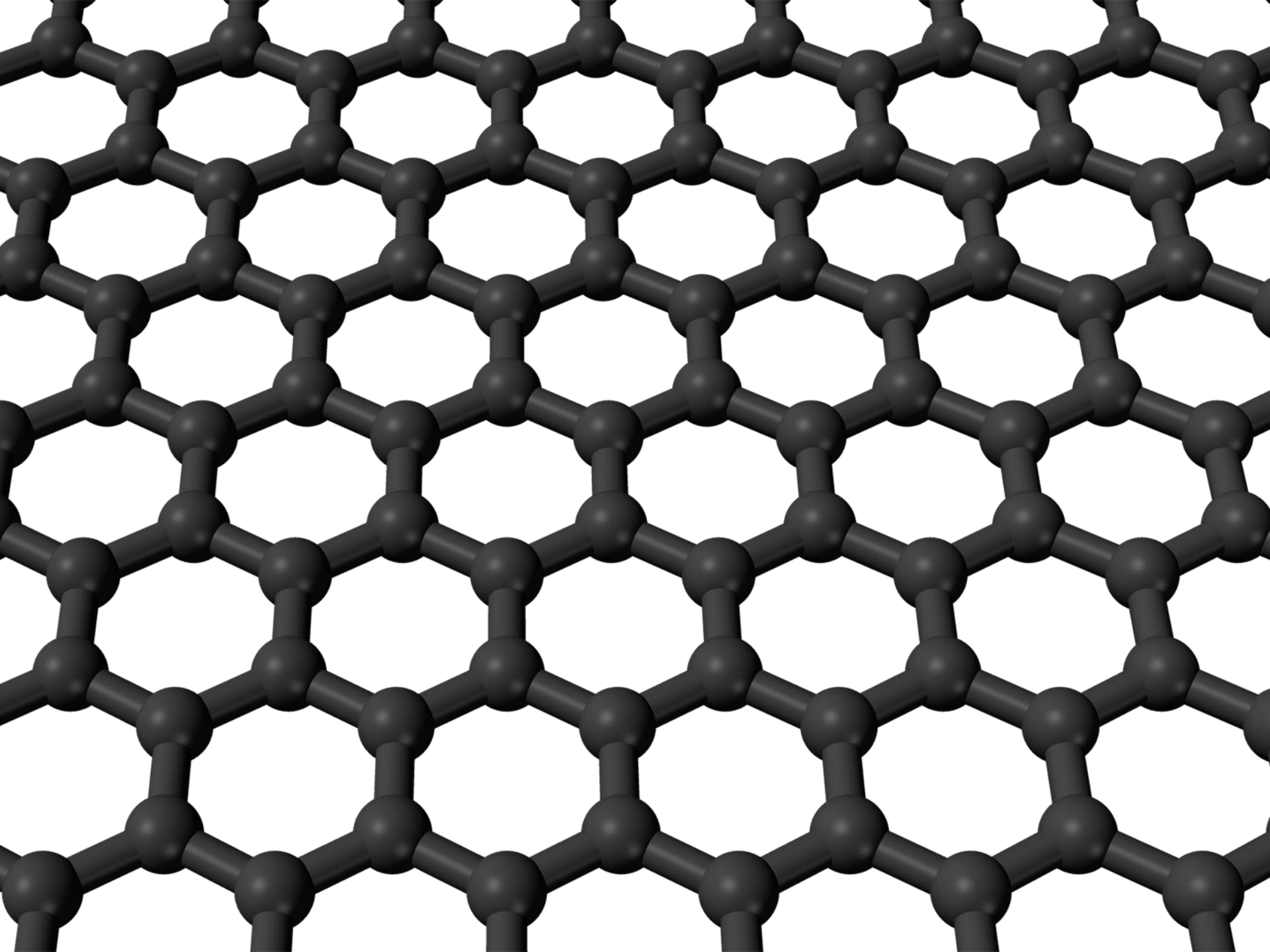
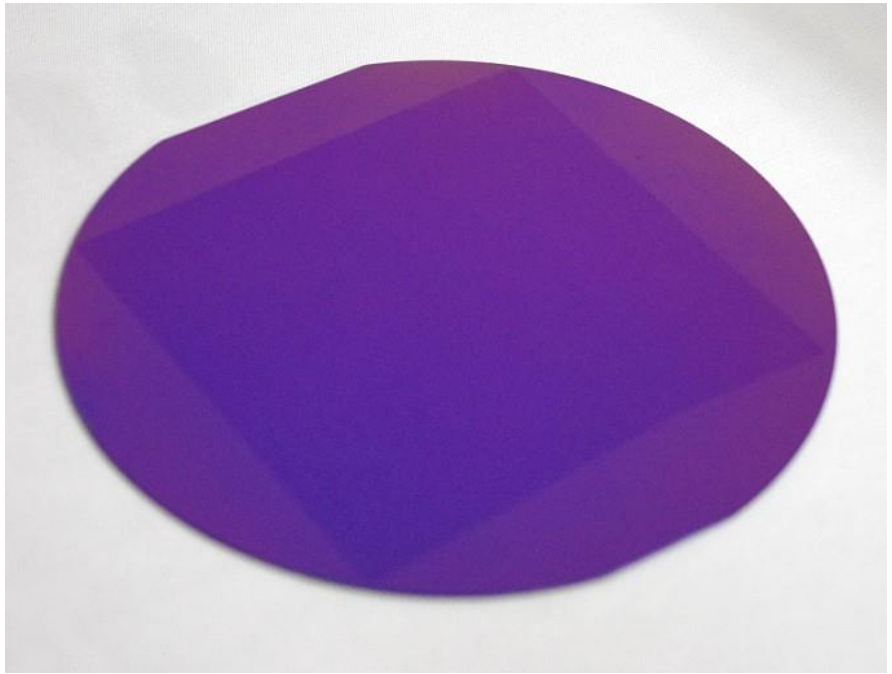


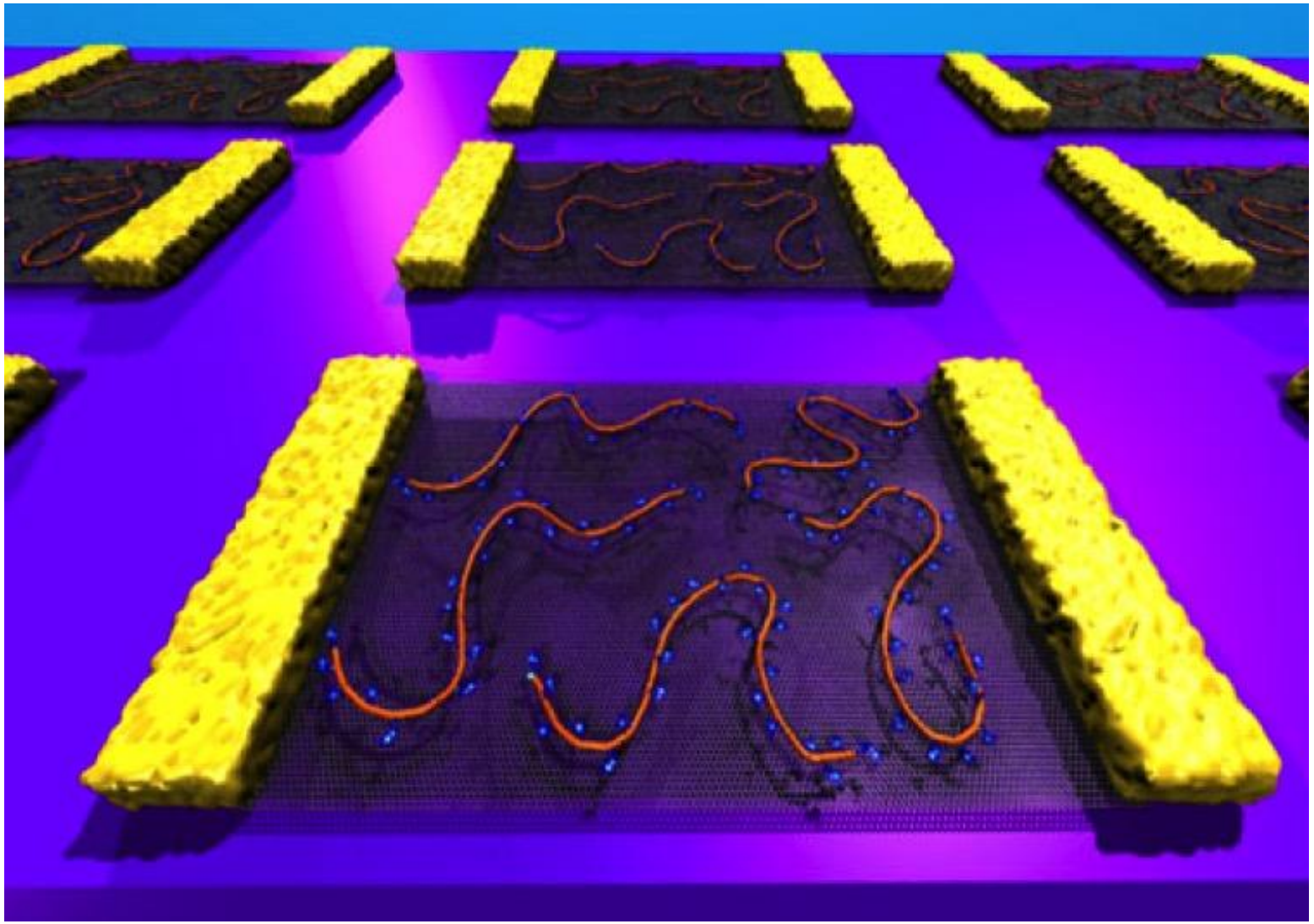
Rigid Substrate Transfer

- Transfer to rigid surfaces using an intermediate transfer substrate.



- Patterned Transfer
  - Pattern the graphene through selective adhesion of the graphene.

Vapor Phase Detection



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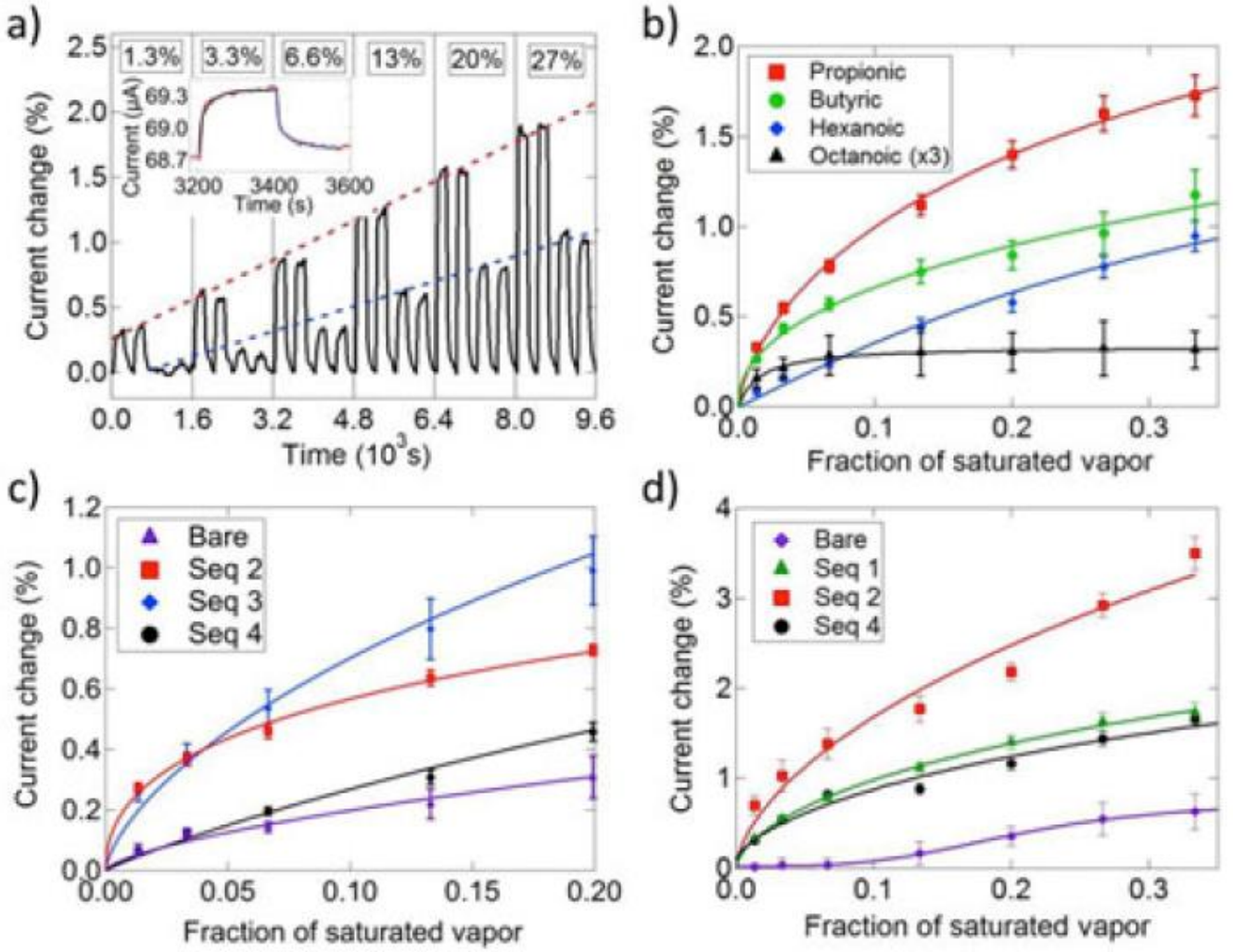

Kybert, N., et al (2014). Nano Research, 7(1), 95–103.