GRAPHENE ON SILICON TECHNOLOGY FOR ADVANCED POWER SEMICONDUCTOR DEVICES

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Outlines

1. **Overview on Power Electronics**
2. **Graphene on Silicon for TMBS Rectifier Diode**
3. **Graphene on Silicon for Power MOSFETs**
4. **Graphene on Silicon process Development**
5. **Potential Applications**

Overview-Power Electronics

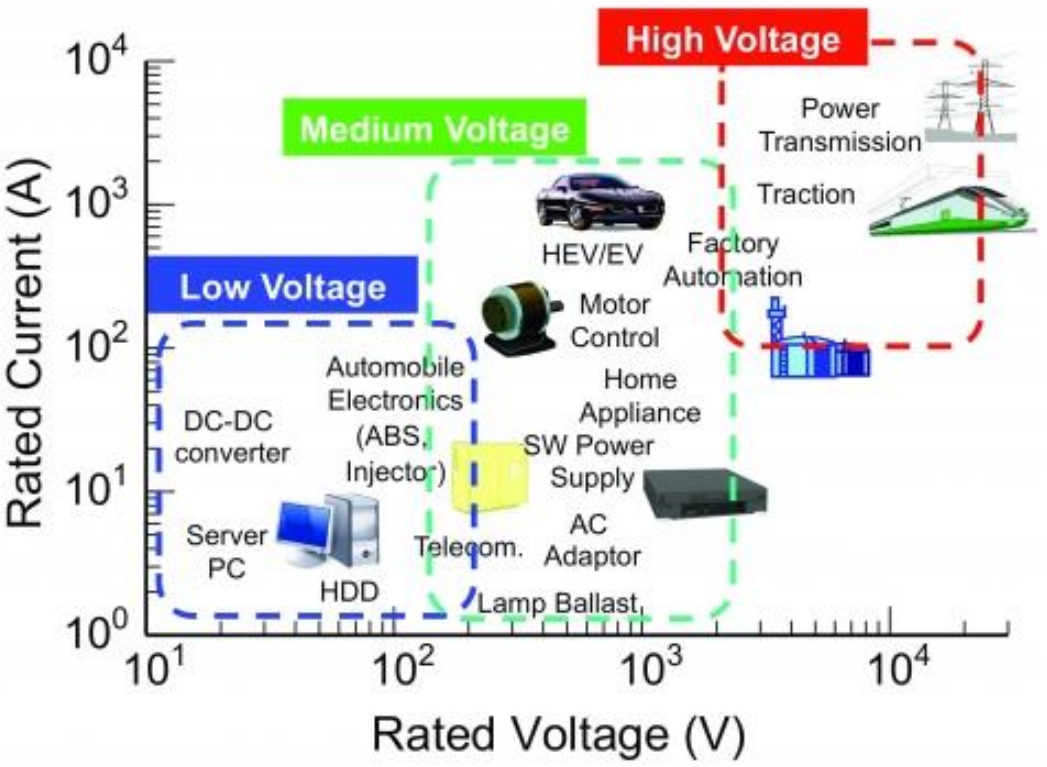


Fig 1: Applications for Power devices

Semiconductor components with a current rating of more than 1 Ampere are generally referred to as power semiconductors.

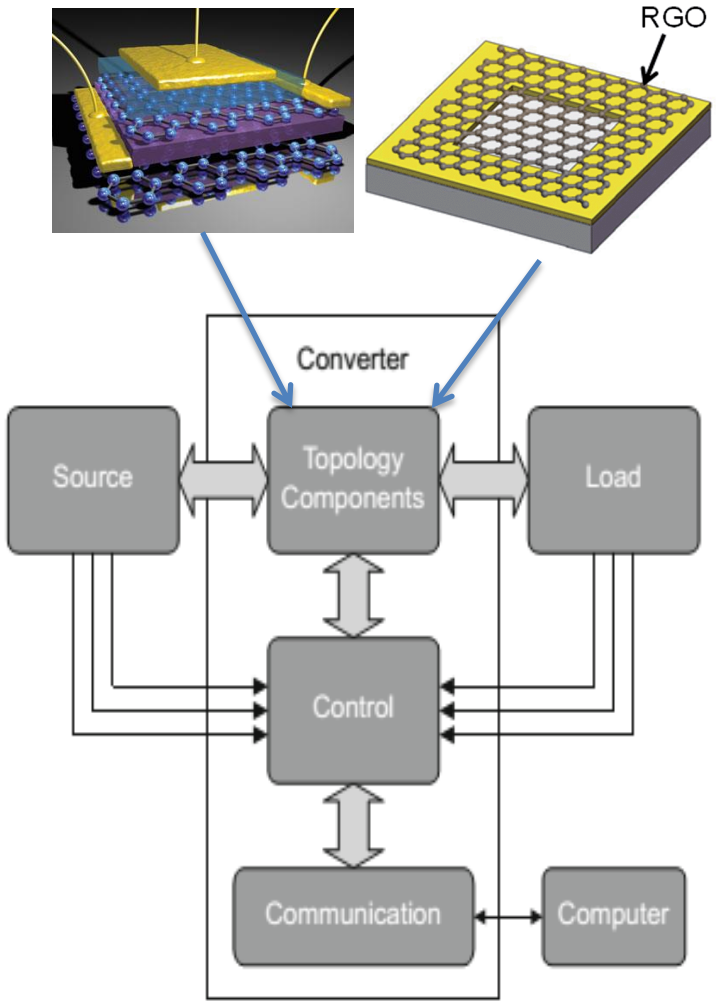
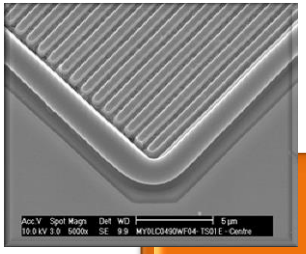


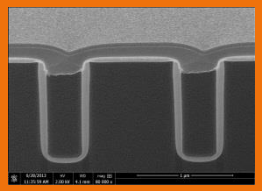
Fig 2: Power electronic systems convert and control electrical energy in an efficient manner between a source and a load.

MIMOS Power Semiconductor Devices

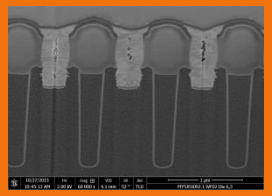


Power MOS Platform

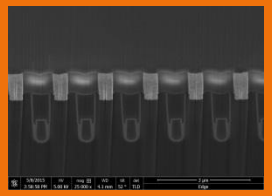
- **TMBS Rectifier Diode**



- **HVNMOS 0.4um**



- **HVNMOS 0.2um**



Technology Features

- Low threshold voltage (< 0.5V)
- VR: 50V-100V, IR: <150uA @25°C
- T_{jmax}: 150°C
- Thick metal (4um)

- BV: 60V – 70V
- VTH: 2.5V
- RDSON: 18mΩ @ 15V
- Thick metal (4.5um)

- BV: 20V
- VTH: 0.7V, 1V
- RDSON: 23mΩ @ 4.5V, 7mΩ @ 3.9V
- Thick metal (4.5um)

TMBS Rectifier Diode

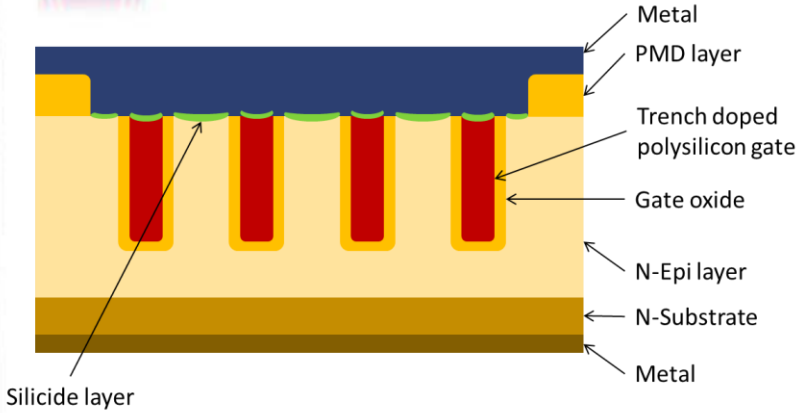


Fig.3: Diagram for Trench MOS Barrier Schottky Diode

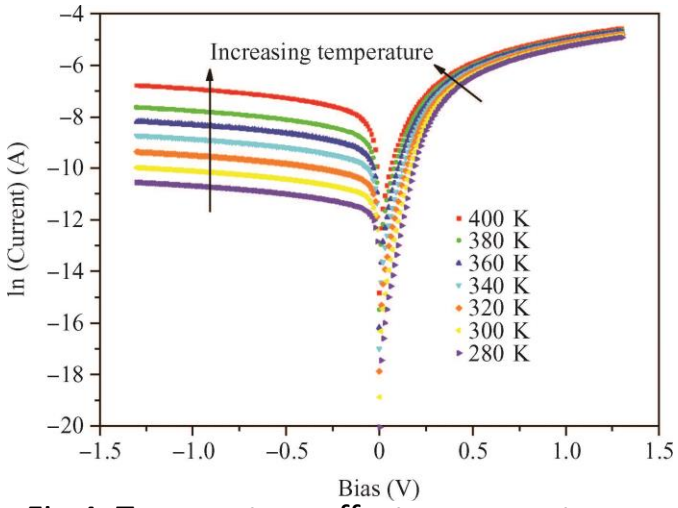
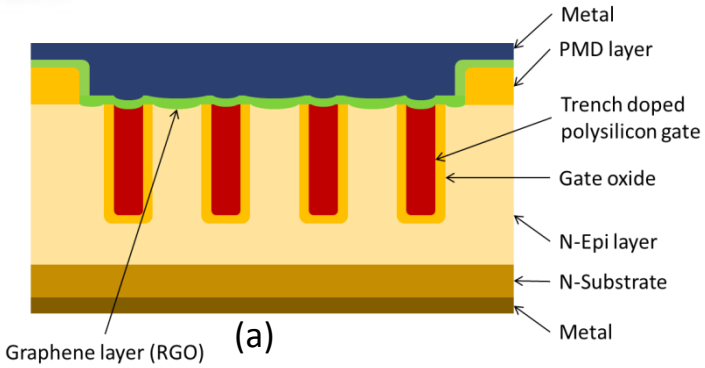


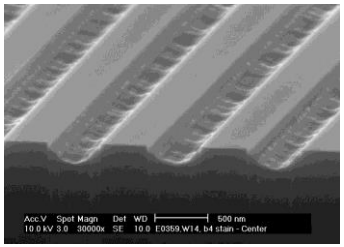
Fig.4: Temperature effect on current-voltage characteristics of Schottky Diode

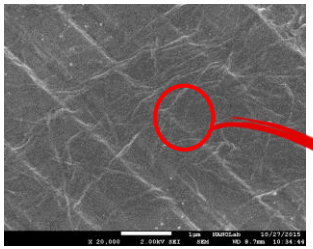
- TMBS rectifier is a semiconductor diode with low VF and fast switching speed.
- Contains a metal-semiconductor barrier to produce current rectification.
- Widely used as rectifiers in switched-mode power supplies, batteries, and power adapter.
- Extremely sensitive to elevated temperature.
- A very rapid increase in leakage current occurs with increasing temperature.
- When power dissipation due to the leakage current becomes dominant, it will increase the device junction temperature.
- Give a positive feedback mechanism that leads to unstable operation of the device (Thermal runaway).

Fig.5: Example of technology trend shows increasing demand for smaller and compact design of electronic products that leads to higher heat dissipation and cooling capability requirement.

Graphene on Silicon As a Heat Spreader




(b)


(c)

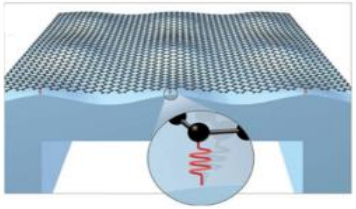

(d)

Fig.6: (a) Diagram of RGO deposited on Silicon TMBS diode, (b) SEM image of TMBS diode without RGO, (c) SEM image of TMBS diode with RGO, (d) Illustration of van der waals force of RGO to silicon substrate.

- Graphene has a high thermal conductivity of >3000 W/(mK)
- Graphene films can be used for the efficient cooling of TMBS Diode.
- Cool down TMBS diode by reducing the localized self heating effect at the metal-semiconductor interface.
- The heat spreader connect with heat sink through thermal interface material outside the active region.
- Heat produced by the diode can be removed and effectively transferred to the surrounding air as quickly as possible.

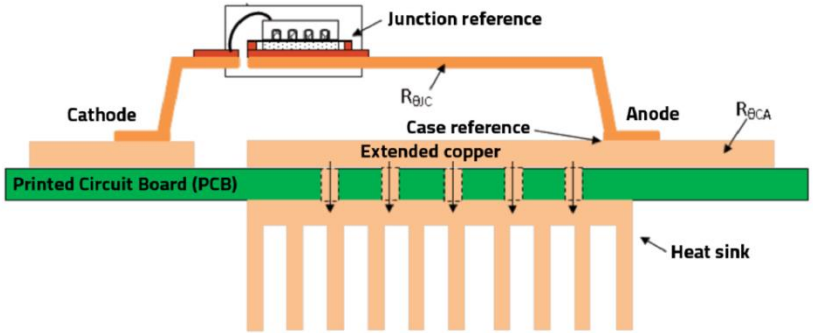
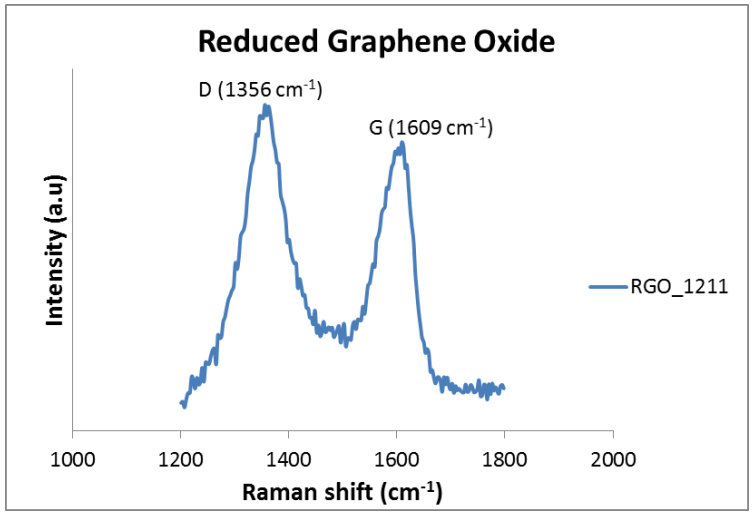


Fig.7: Graphene heat spreader connected to heat sink

Characterization

Material Analysis



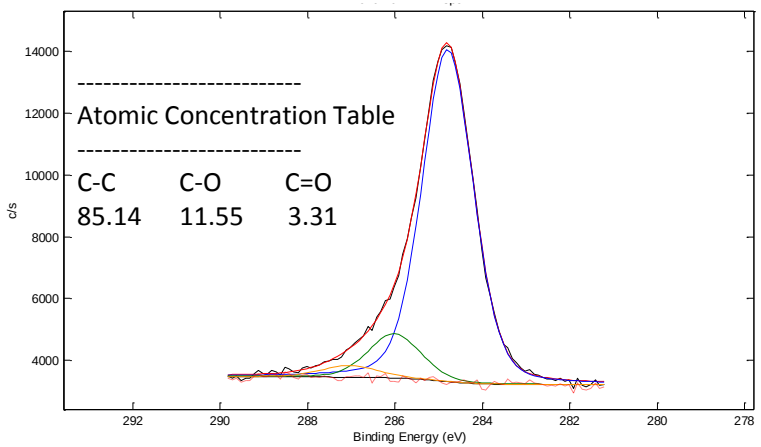
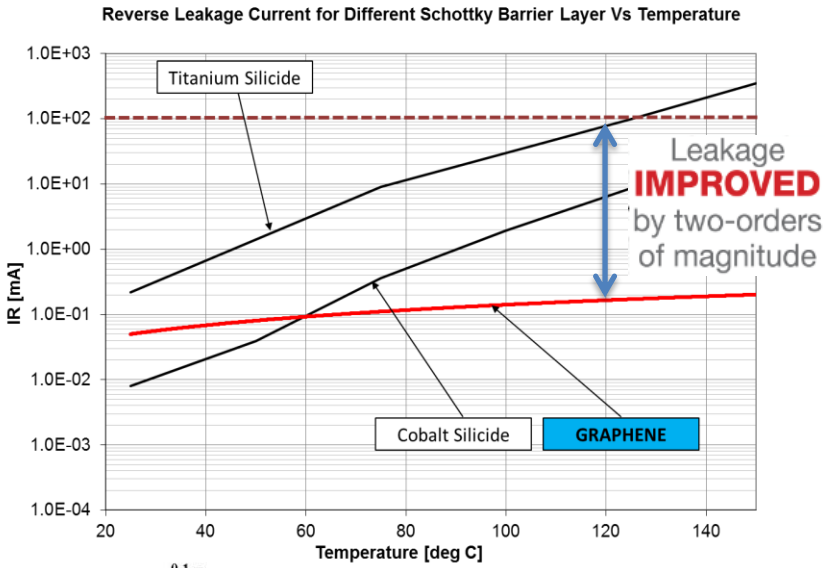


Fig.8: Material characterizations

Electrical Measurement



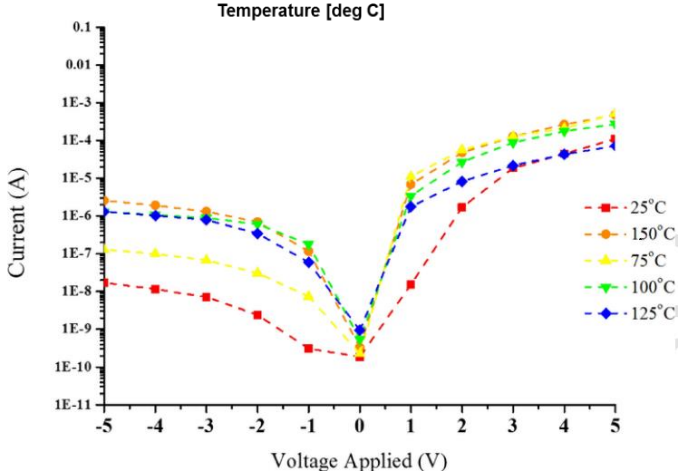
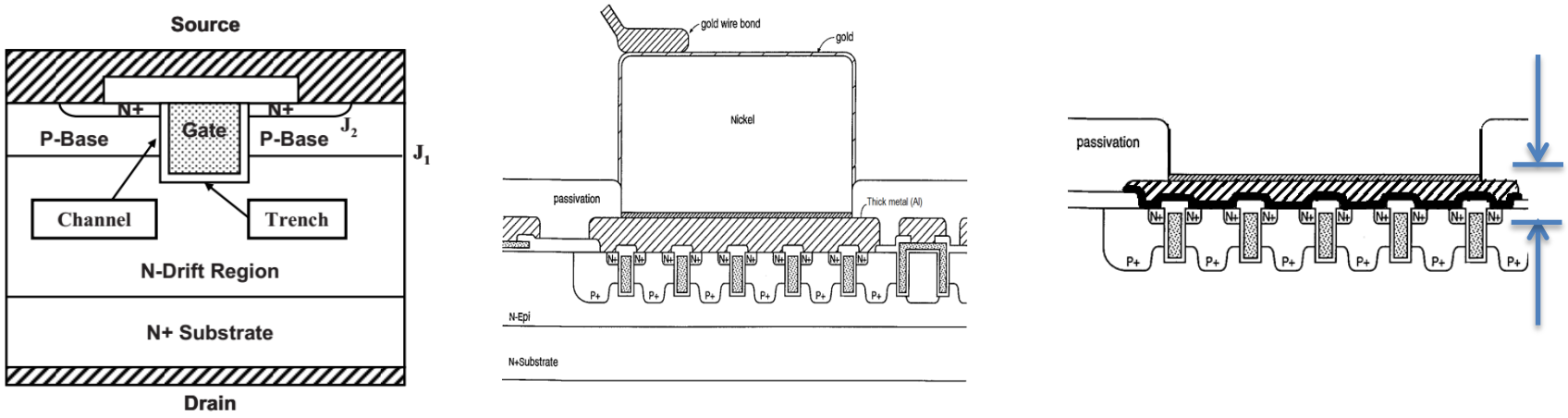


Fig.9: Graphene-based TMBS Diode electrical characteristics

Power MOSFETs



(a) (b) (c)

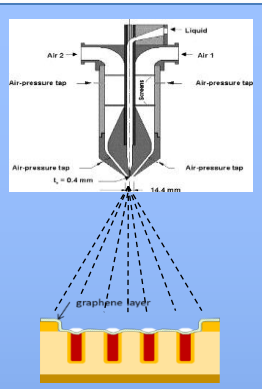
Fig.10: (a) Trench MOS Power MOSFET, (b) Thick metal layers in Power MOSFET, (c) Hybrid metal-graphene layers on Silicon Power MOSFET

- Power MOSFET requires thick metal layer to reduce distribution resistance and total RDSON. It is one of the factors that limits the manufacturing throughput.
- To improve this limitation, we are aiming to thinning down the metal pad by 50% by introducing a hybrid metal-graphene layers deposited on silicon substrate.
- The target is to increase the capacity at our PVD system by at least 40-50% and reduce the material cost.

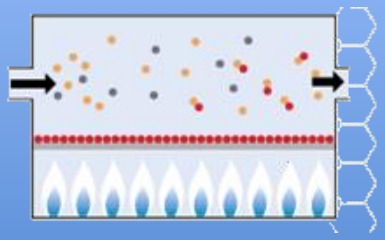
Graphene on Silicon Process Development

Process Method

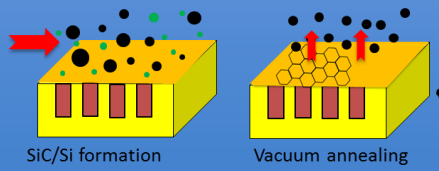
1. Deposition of graphene solution through spray/spin coating process



2. Low temperature CVD graphene growth on Cu/Si substrate



3. Epitaxial graphene growth on SiC/Si substrate



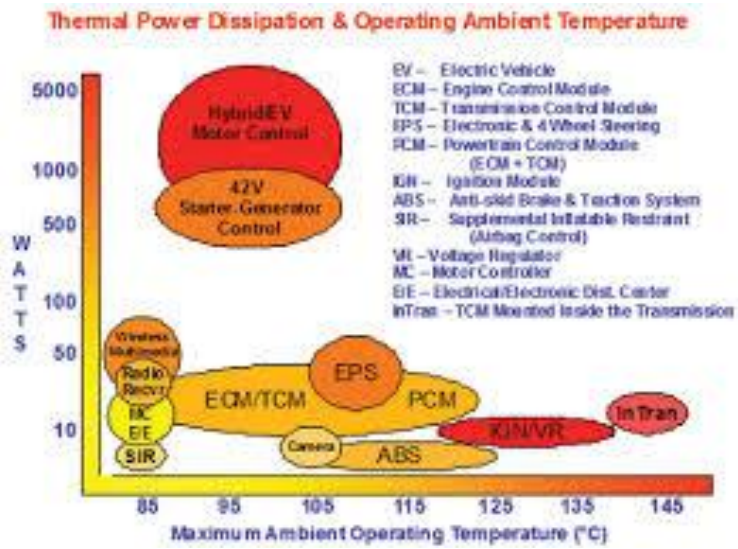
Collaborators

MIMOS
UniMAP
Universiti Pendidikan Sultan Idris
Sultan Idris Education University
MMU Multimedia University
Universiti Teknologi MARA

MIMOS
UTM Universiti Teknologi Malaysia

MIMOS
University of Malaya

Potential Applications



- **Key Advantages:**
  - High energy efficiency of power rectifier device for green technology applications.
  - On-chip electronic cooling capability
  - Excellent high temperature stability
  - Wider operating temperature range
  - Longer product lifetime
  - Thin metal process increases production output

Summary

- The main objective of graphene on silicon research activities in our lab is to enhance the performance of silicon power devices and to increase the production output.

- Graphene based Schottky diode has been developed in our FAB as our pilot project for power electronic applications. It shows better performance in high operating temperature. Having high potential to be developed as a commercial product and scale up.

- We are working with several local universities to develop graphene on silicon process for advance power semiconductor devices. They are UNIMAP, UPSI, MMU, UiTM, UTM, and UM. We are also looking for industry partner to collaborate in product development and process tools.

TERIMA KASIH

THANK YOU

Q&A

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