Novel Diamond Semiconductors Operate at Highest Power Ever

Prof. Makoto Kasu, Saga University

Niloy Chandra Saha, Toshiyuki Oishi (SU)
Seong-Woo Kim (Adamant Namiki Precision Jewel)

1) Diamond semiconductor possessing ultimate power capability
2) Wide and high-pure diamond wafer growth technology
3) Realization of diamond semiconductor devices with a novel principle
4) Output power density of 179 MW/cm^2, which is the highest ever reported
5) Resulting output power density boosts the output power of Beyond-5G base stations and power control in electric car vehicles
6) Long-range reliability enables the of diamond semiconductor devices in space

Fig. 1. Demand for high-frequency high-power semiconductors for Beyond 5G communications

Output Power (W)

10 K

1 K

100

10

1

0.1

Broadcasting stations

Communication satellites

Diamond replaces vacuum tubes (TWTs) and boosts output power

Diamond

SiC

Wireless base stations

GaN

Beyond 5G

Cell phones

GaAs InP

Si

0.1 1 10 100 1000

Operation Frequency (GHz)

M. Kasu, NTT Technical Review, Vol.8, No. 8, online (August 2010).

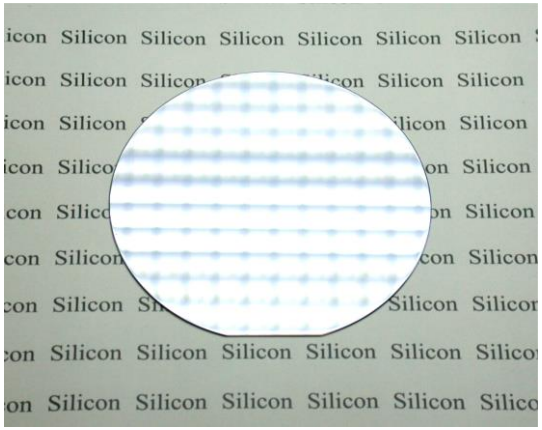
SAGA University 佐賀大学

ADAMANT Namiki

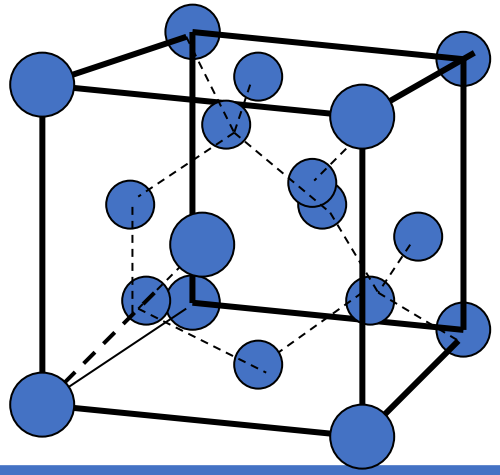
Fig. 2. Diamond's superior physical properties and expected device capabilities

Diamond

Silicon



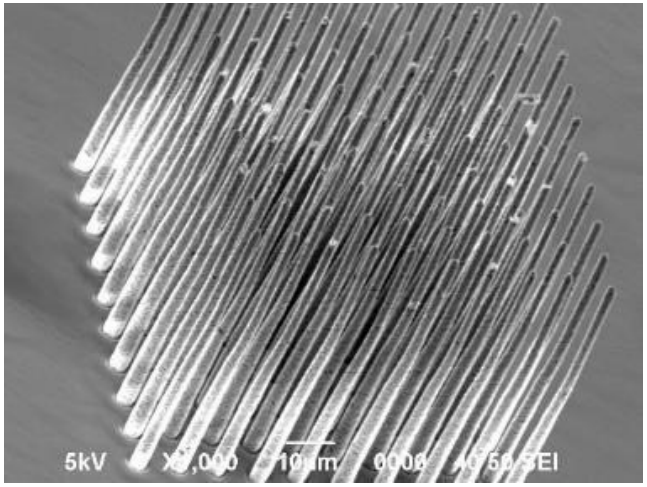
Crystal structure



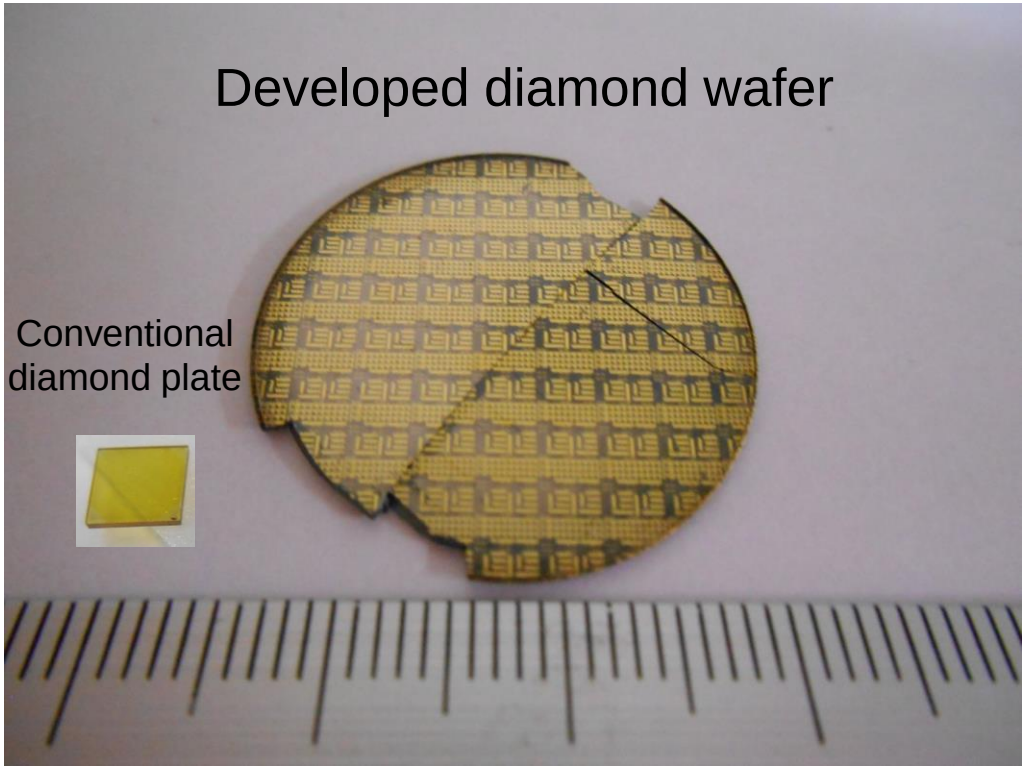
	Silicon	SiC	GaN	Diamond	Diamond's properties
Bandgap energy	1	2.9	3.0	4.9	5 times high temperature
Breakdown field	1	9.3	16.6	33	33 times high voltage
Thermal conductivity	1	3.8	1.2	17	17 times heat dissipation, less temperature rise
Baliga's FOM	1	580	3800	49 000	50 000 times high power and high efficient device characteristics
Johnson's FOM	1	420	1100	1225	1200 times high-speed power device characteristics for Beyond 5G

Fig. 3. Technology (1) Wide and high-pure diamond wafer growth technology

Microneedle method and sapphire substrate enable the growth of wide-scaled high-pure diamond wafer



Microneedle method



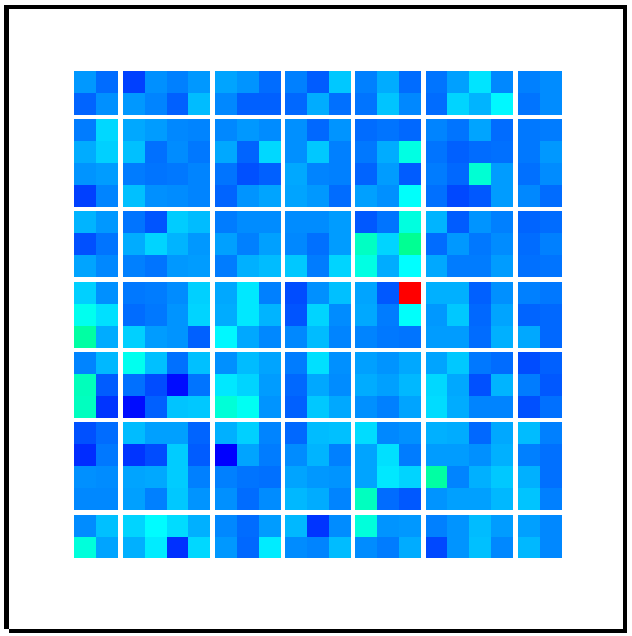
- Mass-production technology of world's widest 1 inch
- Sapphire substrate makes high pure and max. 6 inch possible

SAGA University 佐賀大学

ADAMANT Namiki

Highest quality diamond confirmed by Synchrotron

Saga Synchrotron Light Center



High crystal quality on entire surface

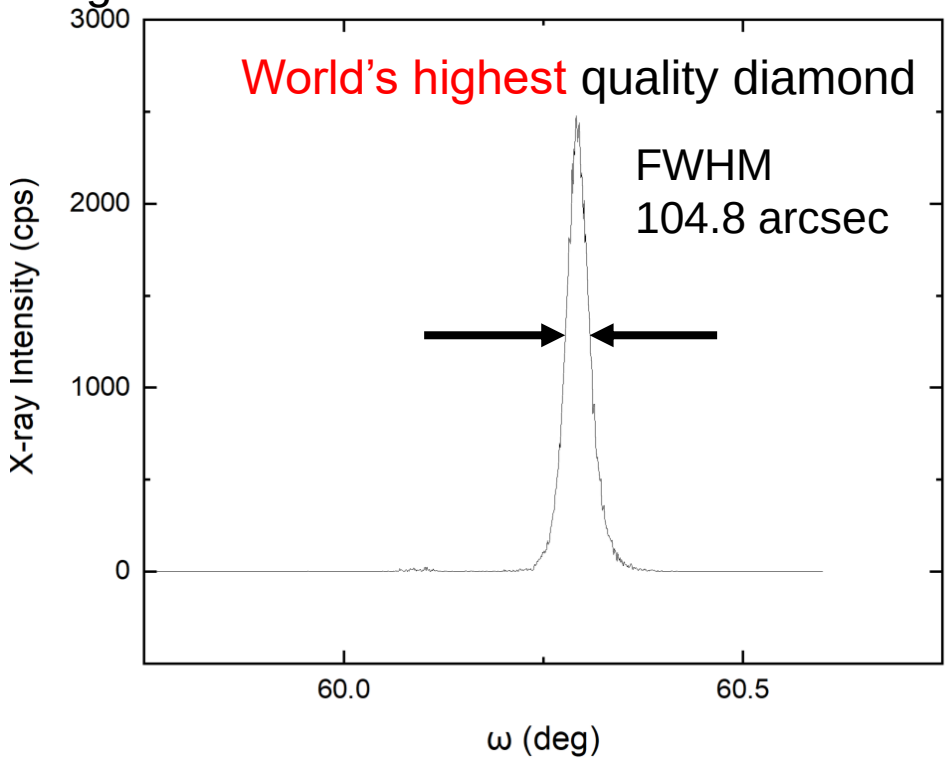
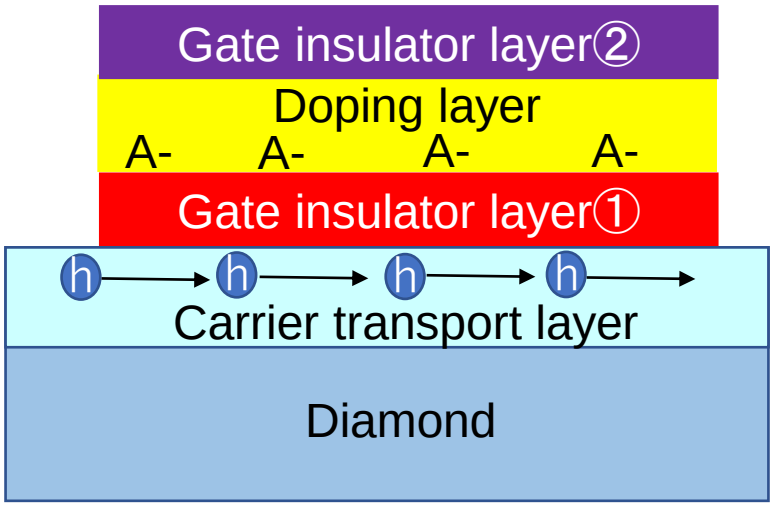


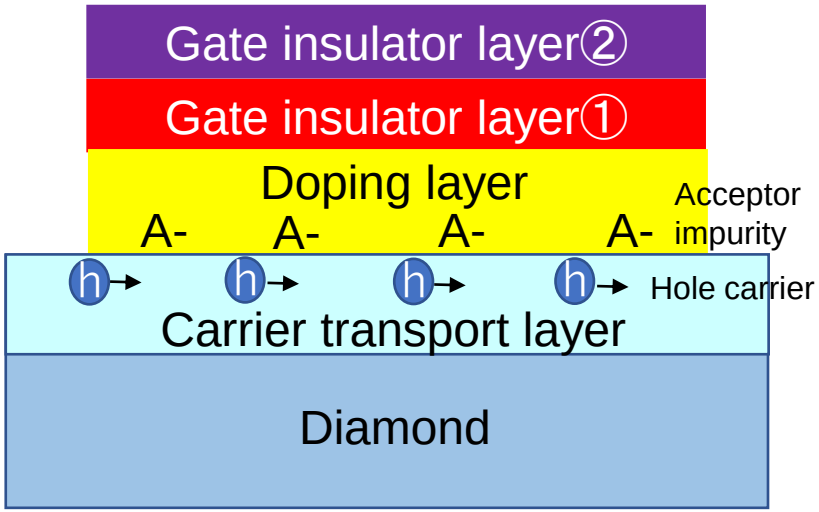
Fig. 4. Technology (2) Diamond semiconductor devices with novel principle

Novel structure



- Doping layer and carrier transport layer are spastically separated
- Carriers (h) are not influenced by acceptor impurities (A^-), and mobility increases
- Spastically separated doping layer and carrier transport layer leads to no degradation

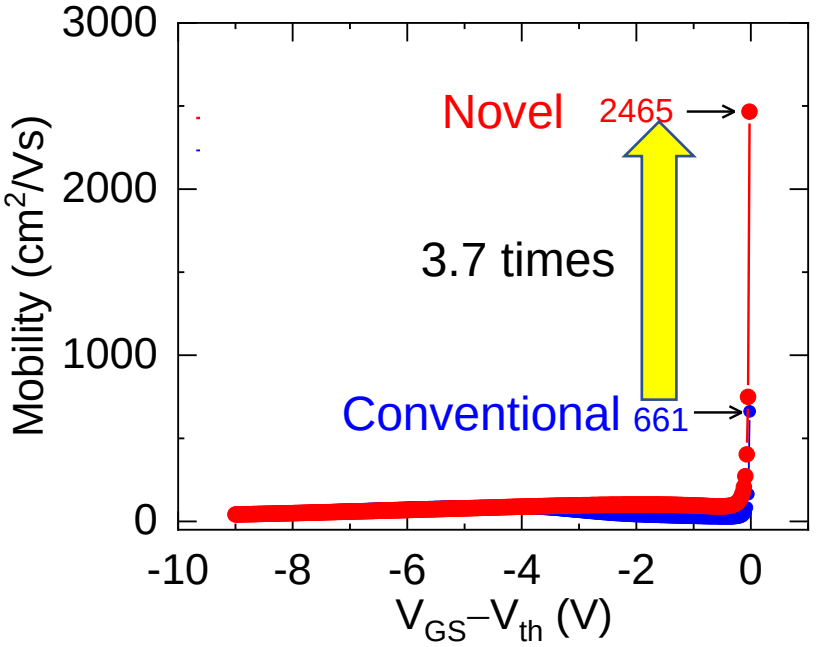
Conventional structure

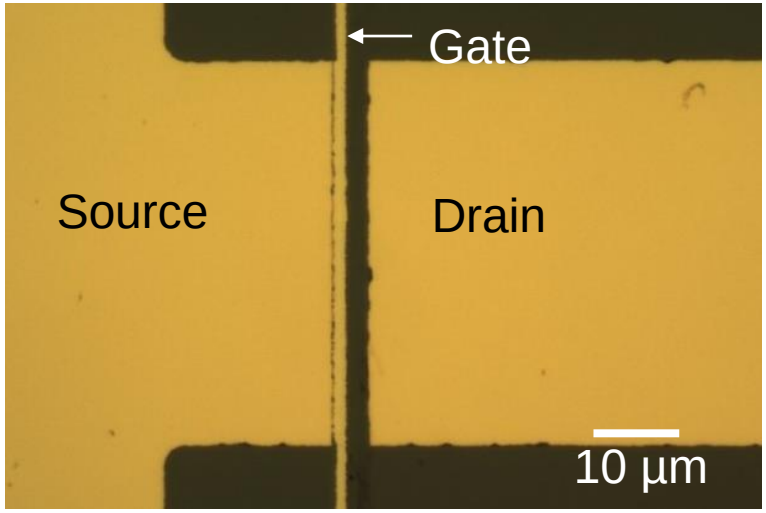


- Doping layer and carrier transport layer are in close proximity
- Carriers (h) are influenced by acceptor impurities (A^-), and mobility decreases drastically
- Oxygen in doping layer and hydrogen in carrier transport layer react chemically and the device degrades rapidly

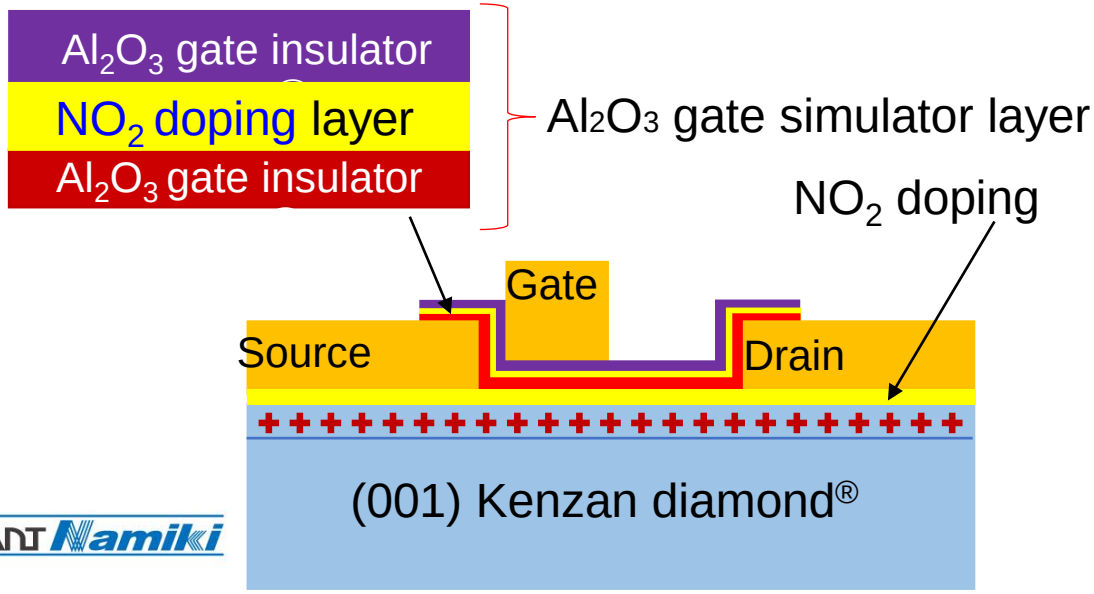
Fig. 5. Extremely high carrier mobility in device characteristics

High carrier mobility (2465 cm^2/Vs) close to the realistic value was achieved





Diamond semiconductor device



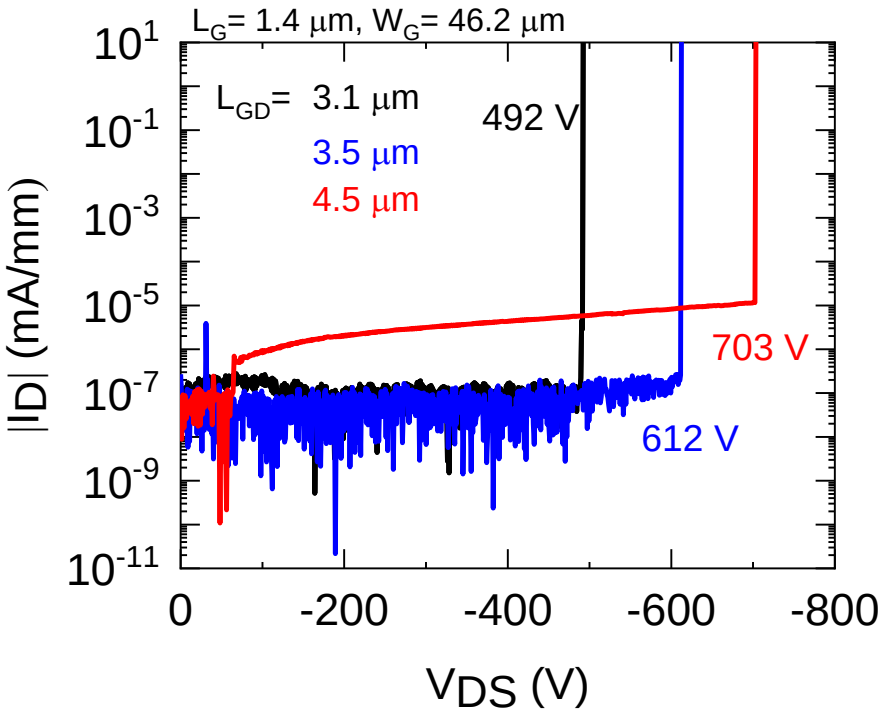
SAGA University 佐賀大学

ADAMANT Namiki

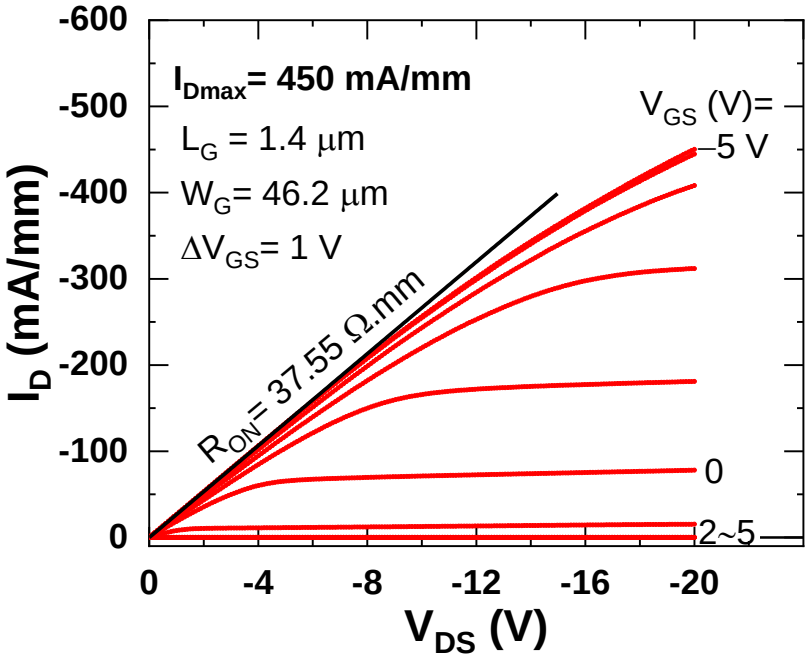
Fig. 6. Technology (3) Highest output power in diamond semiconductor devices

Diamond's highest ever output power of 179 MW/cm^2

High voltage



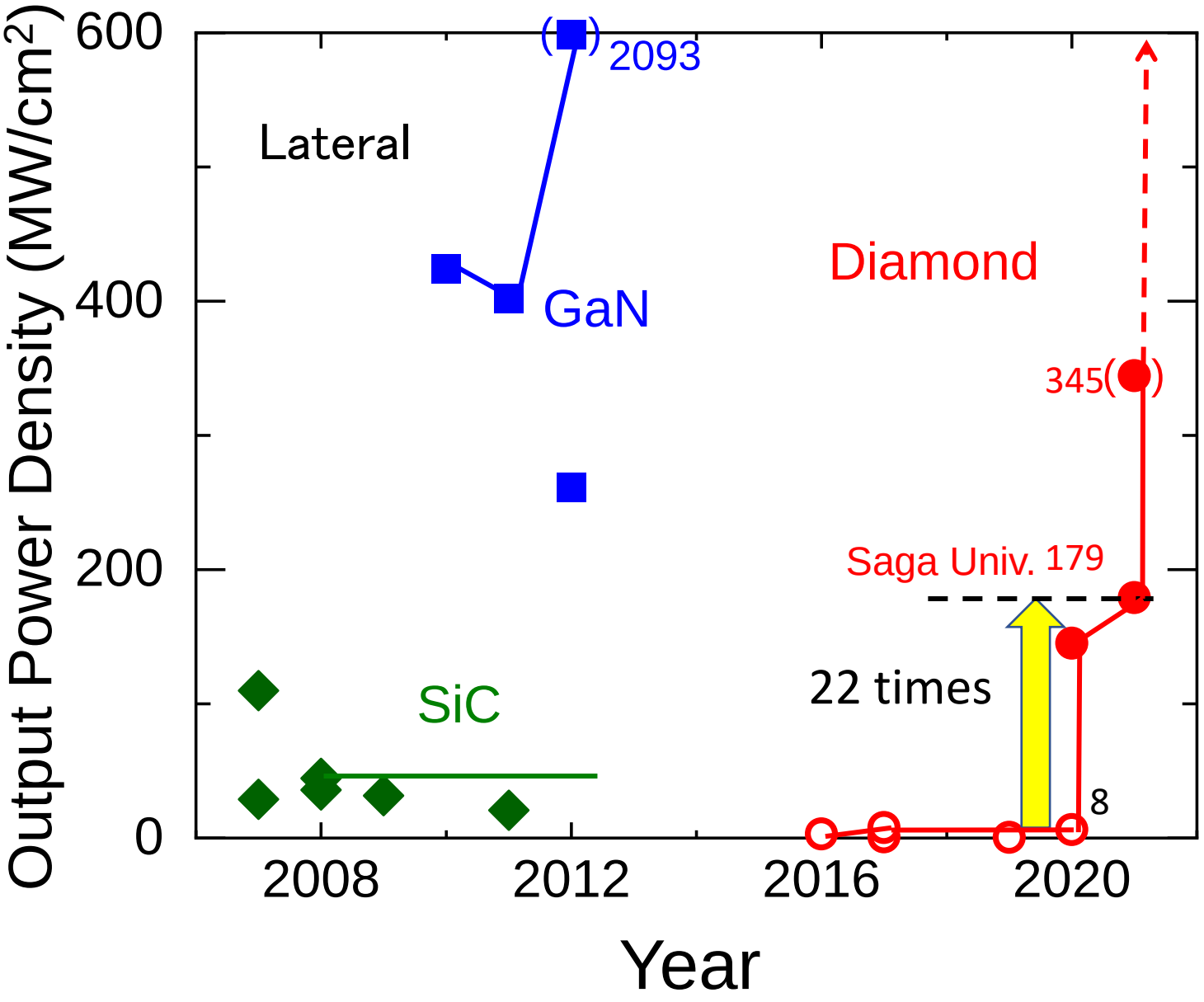
High current



SAGA University
佐賀大学

ADAMANT Namiki

Fig. 7. Roadmap to Beyond-5G communications



SAGA University
佐賀大学

ADAMANT Namiki

Summary

1) Diamond semiconductor possessing ultimate power capability.

2) Wide and high-pure diamond wafer growth technology.

3) Realization of diamond semiconductor devices with a novel principle.

4) Output power density of 179 MW/cm^2, which is the highest ever reported.

5) Resulting output power density boosts the output power of Beyond-5G base stations and power control in electric car vehicles.

6) Long-range reliability enables the of diamond semiconductor devices in space.

Appendix. Other possible applications of diamond

【 Power control for electric vehicles 】

- Control smoothly
- High heat dissipation, No cooling system

(Source : Kenichi Kawabe, Mechanism of Fuel cell vehicles)

【 Power control for transmission】

- High energy efficiency
- High voltage, high current

(Source: Koichi Iwamoto, Offshore wind power generation)

【6G】

- High speed communications, high frequency, high power
- High energy efficiency

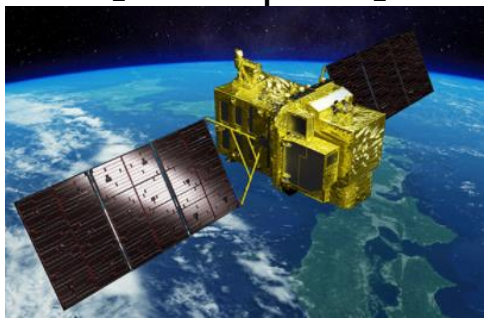
(Source : Tec＆Science)

【 Quantum computing 】

- High speed calculation
- High energy efficiency

(Source： Google quantum computer, D-Wave)

【Aerospace】



- High frequency, high energy efficiency
- High reliability (Source : JAXA Daichi 3, HP)