室温电子封装 技术的发展及展望

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科技引领绿色发展
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2021年11 月 24 日

简介

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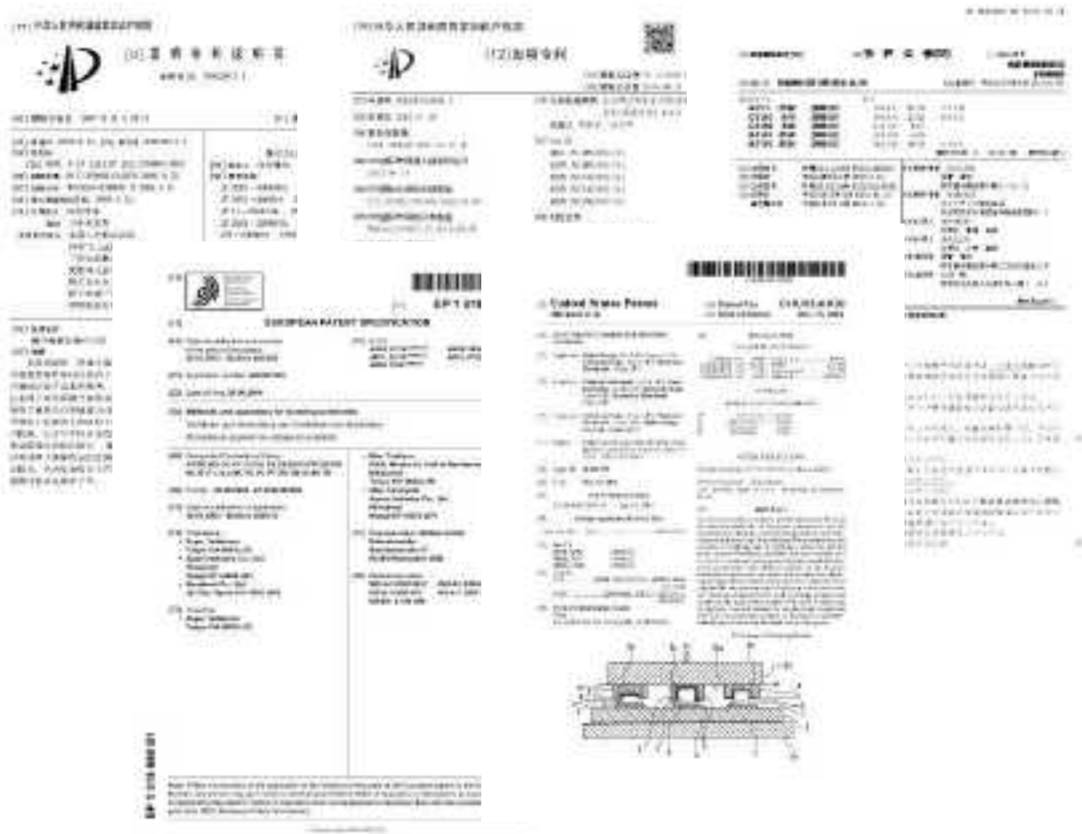
东京大学教授(1994-2019) 荣誉教授(2019-)
明星大学客座教授(2019-)
中国科学院微电子研究所荣誉教授（2012-2021）

须贺教授曾在日本历任：

① 日本学术会议会员
② 日本电子封装学会会长
③ 日本砥粒加工学会理事
④ 日本精密工学会理事
⑤ IEEE CPMT Society Japan Chapter 主席
⑥ 日环保设计学会秘书长
⑦ NPO环保设计推进机构常务理事等

须贺唯知先生有着30年微电子系统键合的经验，是目前世界先进封装键合领域中的几位大师之一。他提案并研究的固体材料的常温键合（表面活性化连接）技术已广泛应用于微电子集成的各领域中，有着丰富的产学合作经验。

代表著作与专利



科学论文650， 出版著作5

中、美、日 90专利授权

須賀唯知 Tadatomo Suga

Born in Kanazawa, Japan, 1953.

Bachelor 1977,
Master (Engineering) 1979:
University of Tokyo
Prof. H. Funakubo

Max-Plank Institute für Metallforschung, 1979-1984
Dr. rer nat. , Uni. Stuttgart, 1983
Prof. Fischmeister,
Prof. Gerold, Prof. Pteztow,
Dr. Elssner, Dr. Rühle

1984-: Faculty member,
The University of Tokyo
Dept. Precision Engineering

1994.2～2004.1
Research Center for Advanced Science and Technology (RCAST)

2003-2007 Director of Eco-materials Research Center,
National Institute for Materials Science (NIMS)

2006-2008 Council Member of the Science Council of Japan (SCJ)

2004.2～2019.3
Dept. Precision Engineering.

明星大学
2019.4～

Institute for Advanced Microsystem Integration (IMSI) 1998～.

JSPS Research Committee 191
2015～2021

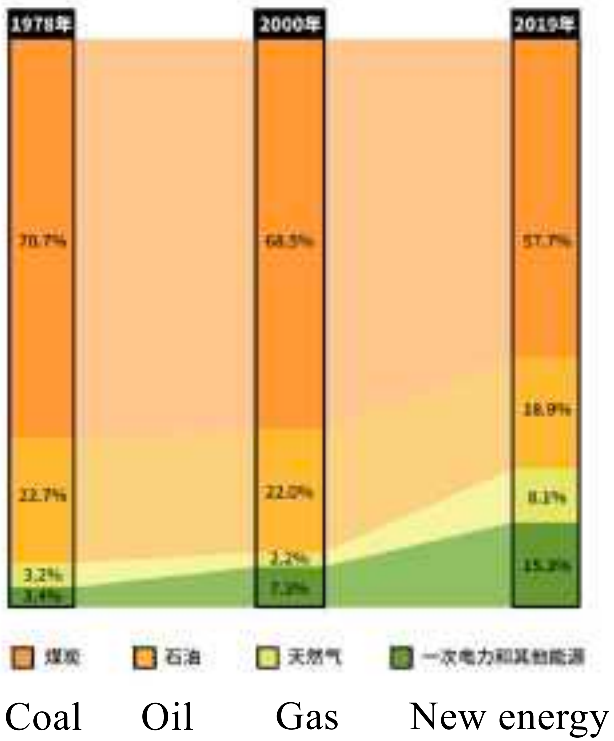
Ecodesign Promotion Network (EcoDeNett)1999～.

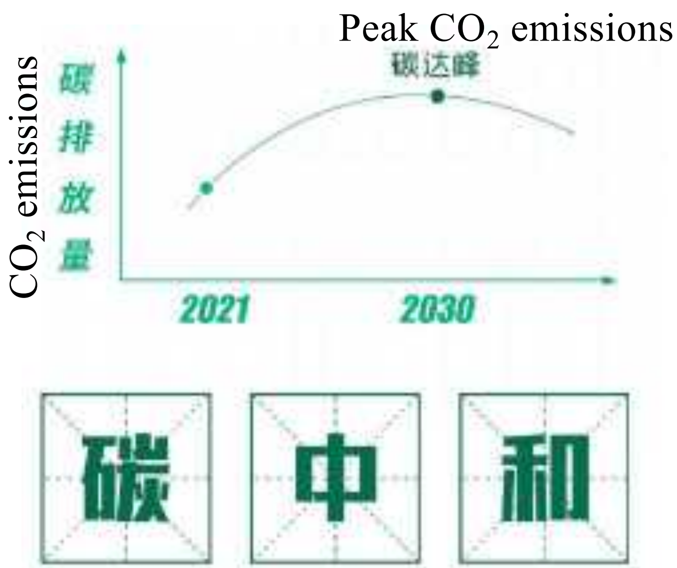
EcoPack China
2005～2019

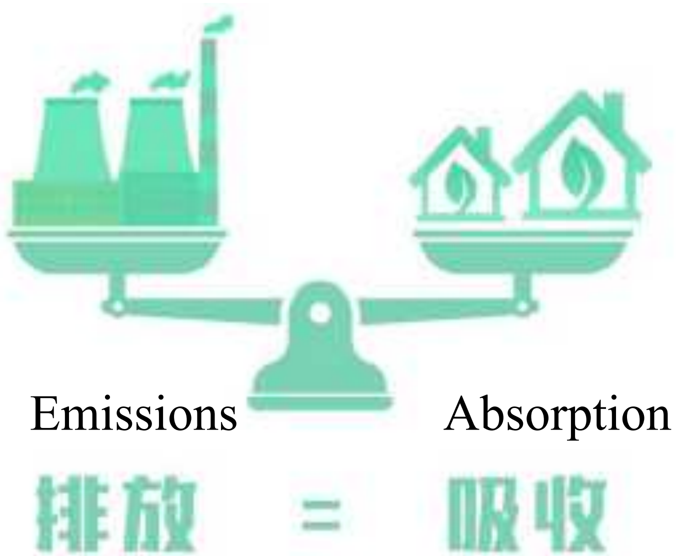
Background

Carbon Neutrality (碳中和)

2020年9月22日，中国政府在第七十五届**联**合国大会上提出：“中国将提高国家自主**贡**献力度，采取更加有力的政策和措施，二氧化碳排放力争于2030年前达到峰**值**，努力争取2060年前**实现**碳中和。

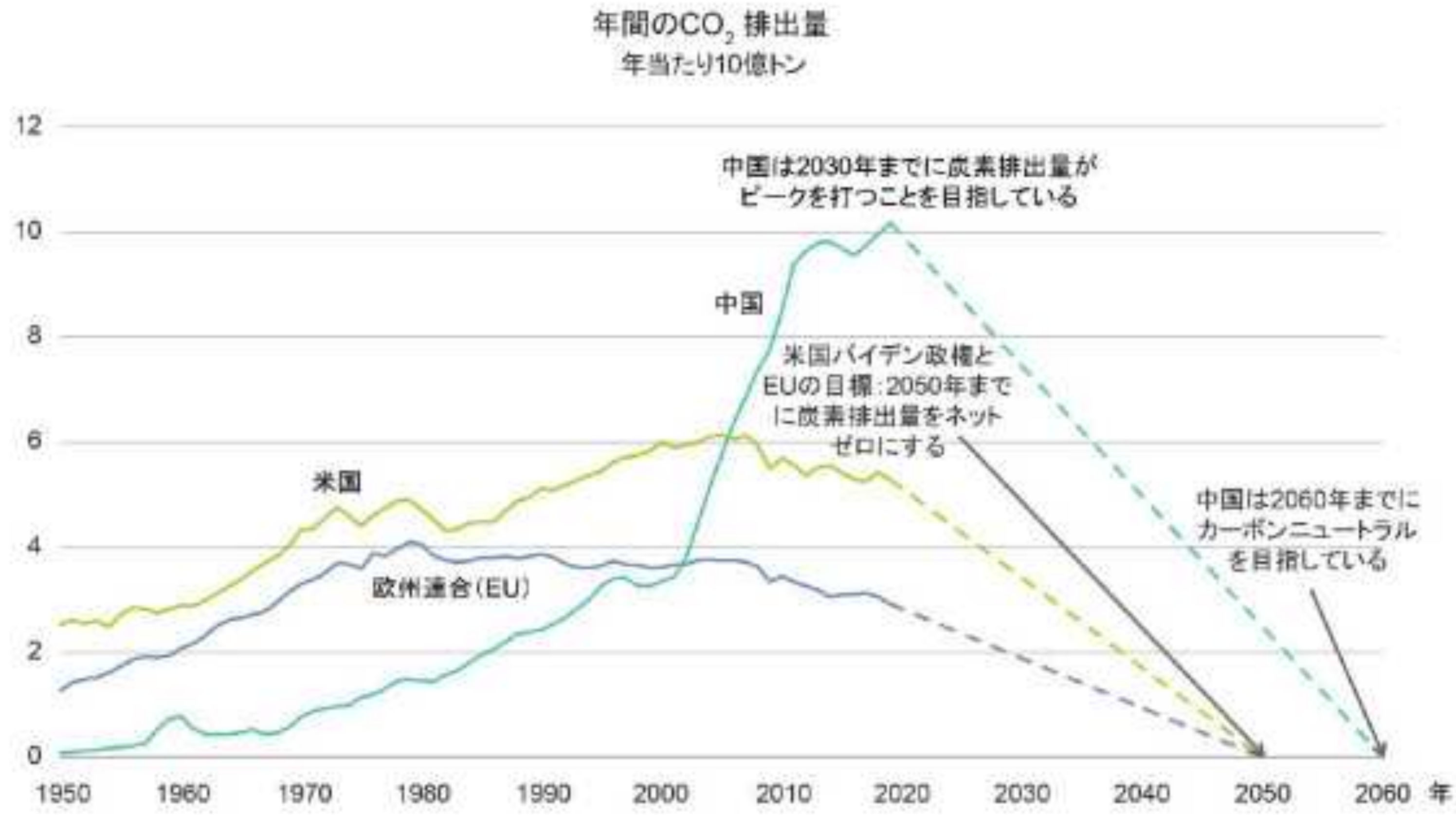






日本のカーボンニュートラル宣言

- 2020年10月、菅総理は、**日本は2050年までに、温室効果ガスの排出を全体としてゼロにする、すなわち2050年カーボンニュートラル、脱炭素社会の実現を目指すことを宣言**。
- 2021年4月、米国主催の気候サミットにおいて、菅総理は、**2030年度において、温室効果ガスの2013年度からの46%削減を目指す**ことを宣言するとともに、さらに、**50%の高みに向け、挑戦を続けていく**決意を表明。



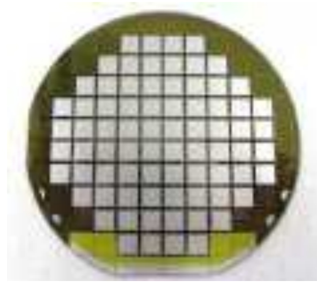
Solutions: グリーン成長戦略(重点14分野)

令和3年6月18日
「2050年カーボンニュートラルに伴う
グリーン成長戦略」（概要資料）抜粋

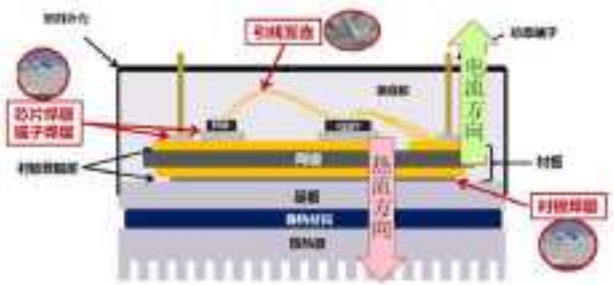
New Energies	New Green Technologies		
エネルギー関連産業	輸送・製造関連産業		家庭・オフィス関連産業
①洋上風力・太陽光・地熱産業（次世代再生可能エネルギー）	⑤自動車・蓄電池産業	⑥半導体・情報通信産業	⑫住宅・建築物産業・次世代電力マネジメント産業
②水素・燃料アンモニア産業	⑦船舶産業	⑧物流・人流・土木インフラ産業	⑬資源循環関連産業
③次世代熱エネルギー産業	⑨食料・農林水産業	⑩航空機産業	⑭ライフスタイル関連産業
④原子力産業	⑪カーボンリサイクル・マテリアル産業		

Solutions: New Green Technologies

- New Material
  - Semiconductor bonded wafers / Engineering wafers



- New Devices / Module / Components
  - 3D integrated semiconductor devices, Power modules

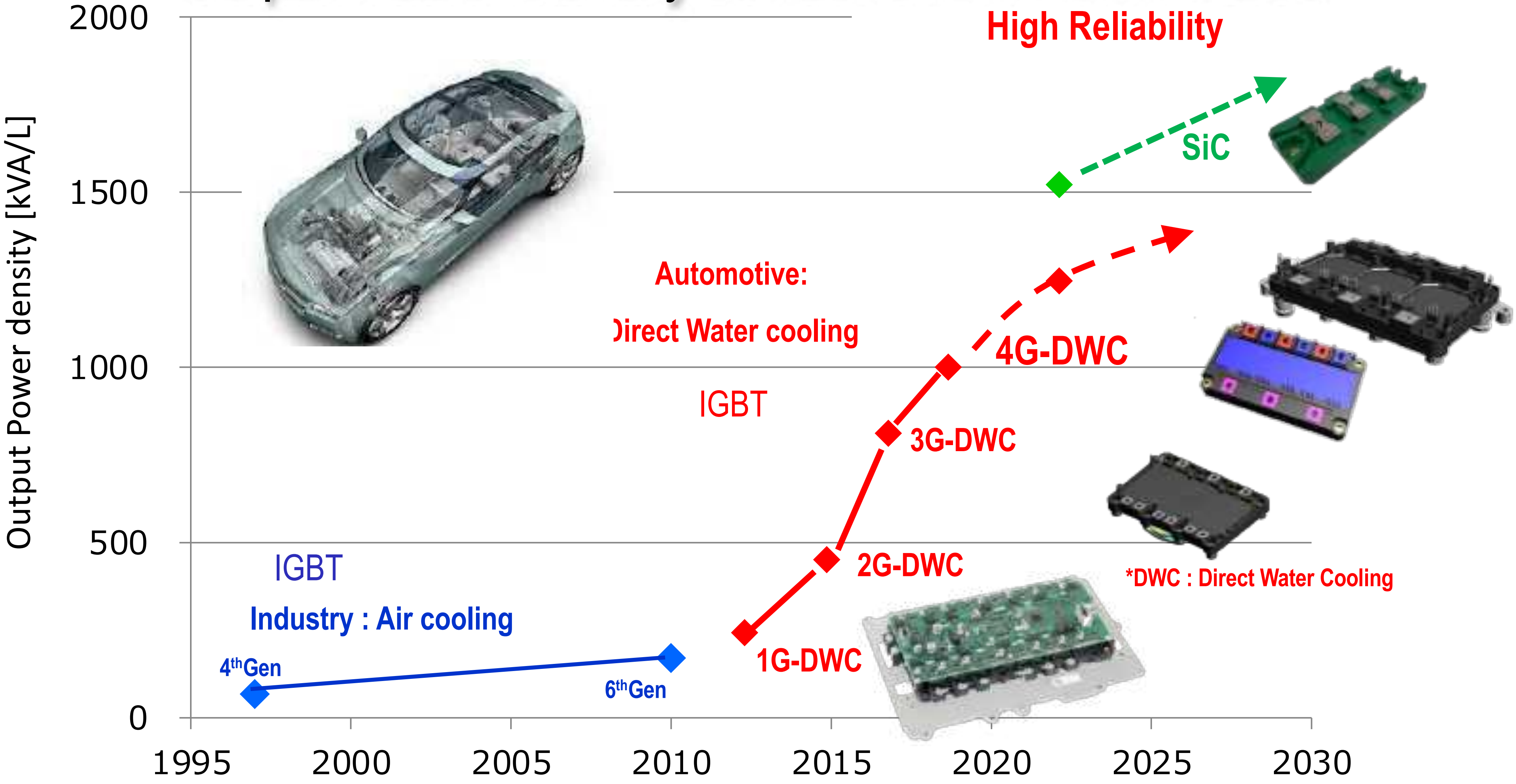


- New Process / Equipment
  - Innovative interconnect technology, Wafer bonder

新基建: New infrastructure
智能制造: Smart manufacturing
车联网/物联网: Internet of Vehicles/Internet of Things
AI智能视觉: AI smart vision
5G通讯: 5G communication
功率器件集成: Power device integration

Examples: Power electronics
for high power density and high frequency

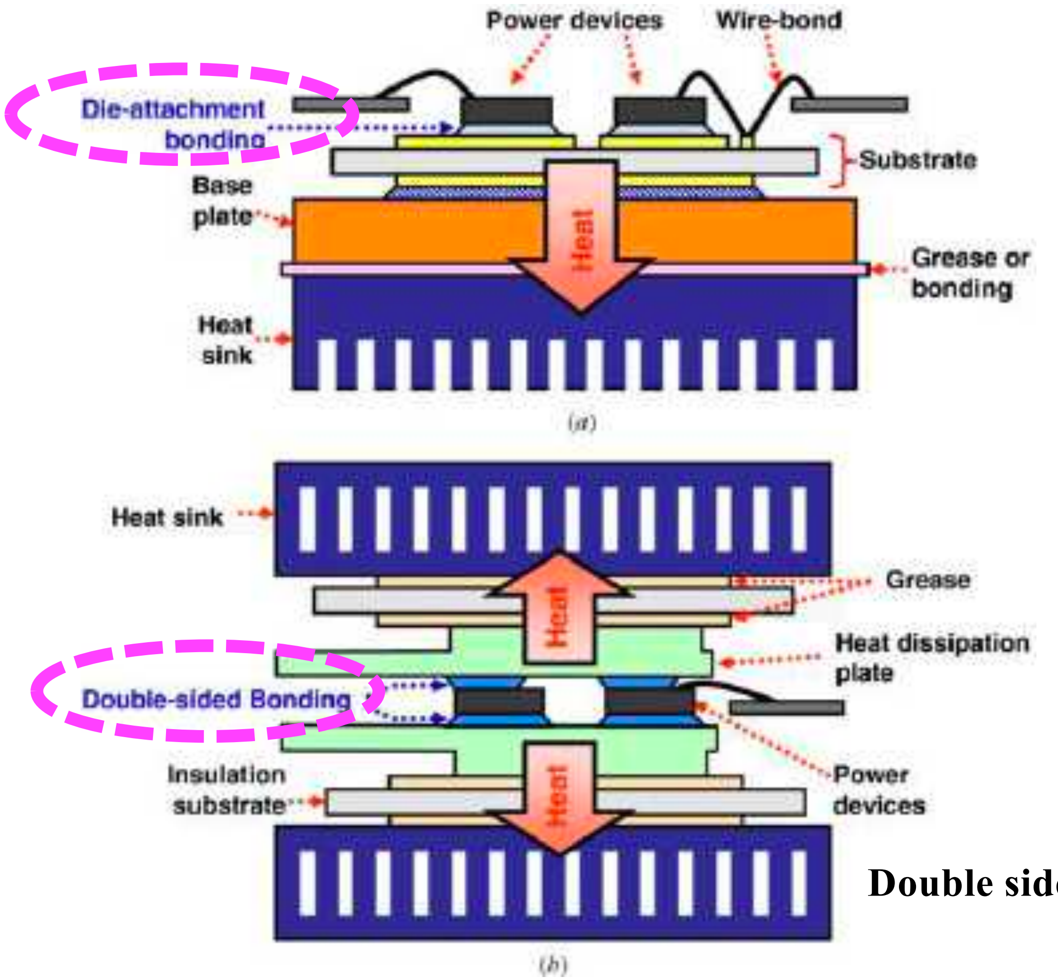
Output Power Density trends for EV/HEV/PHEVs



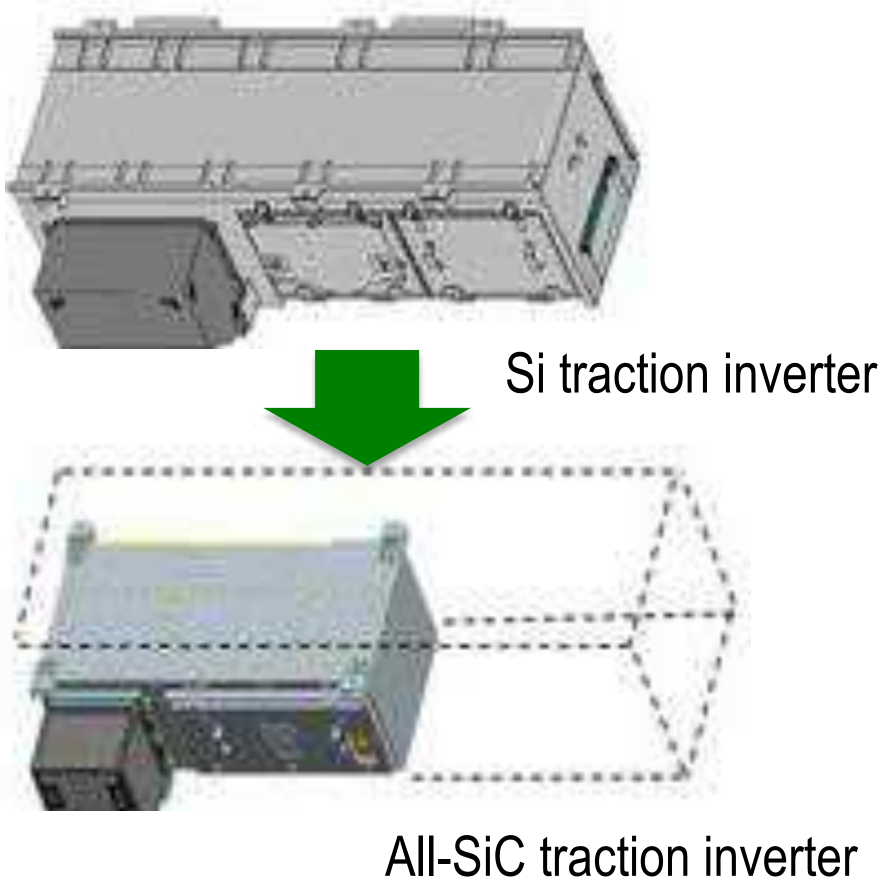
∗ Output Power density [kVA/L] = Max output power [kVA] / Module volume [L] in continuous

Power module

High power density, High reliability, High performance

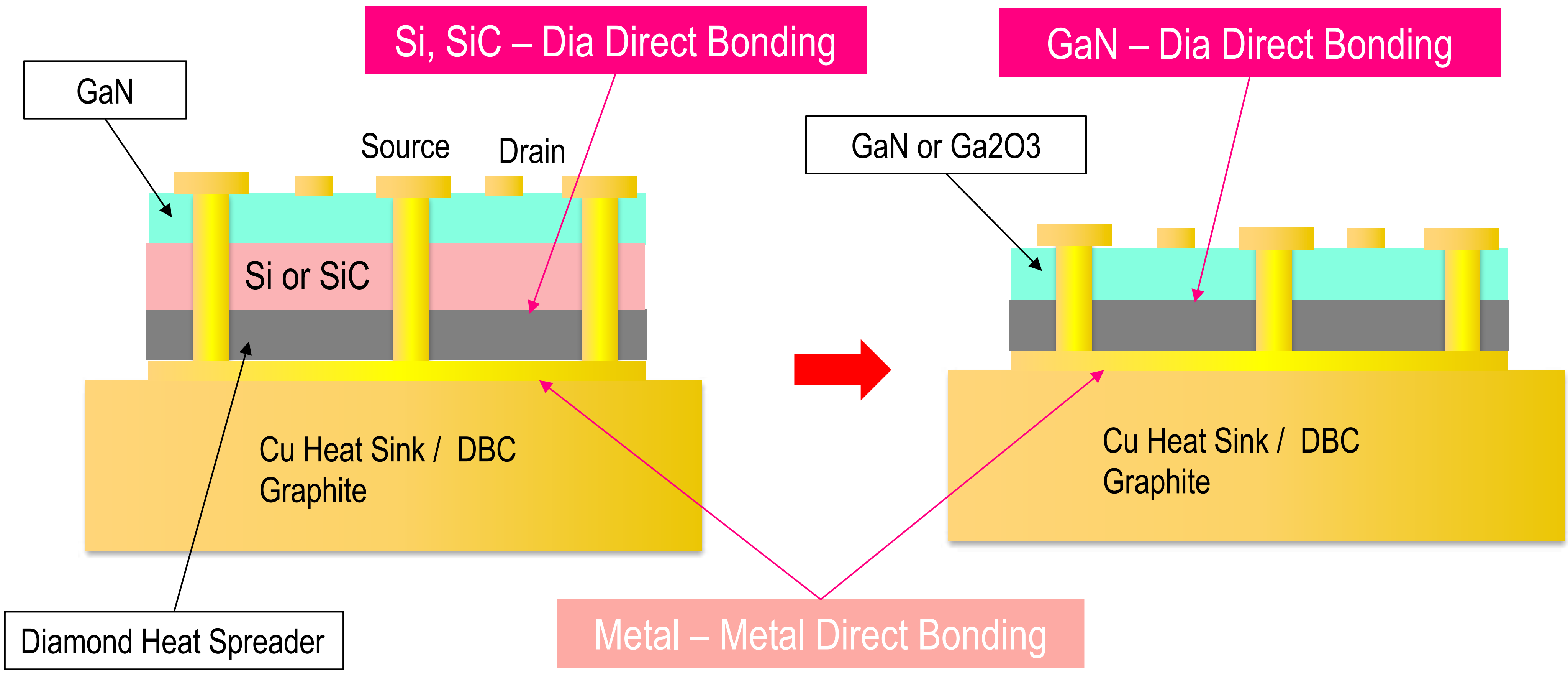


Double side cooling



Solution of Thermal Problems of High-Power Module

New Materials and New Interconnect technology



Solder → Sintering → Au-Au → Cu-Cu

Power Semiconductors

New Materials: Si → SiC → GaN → Ga_2O_3

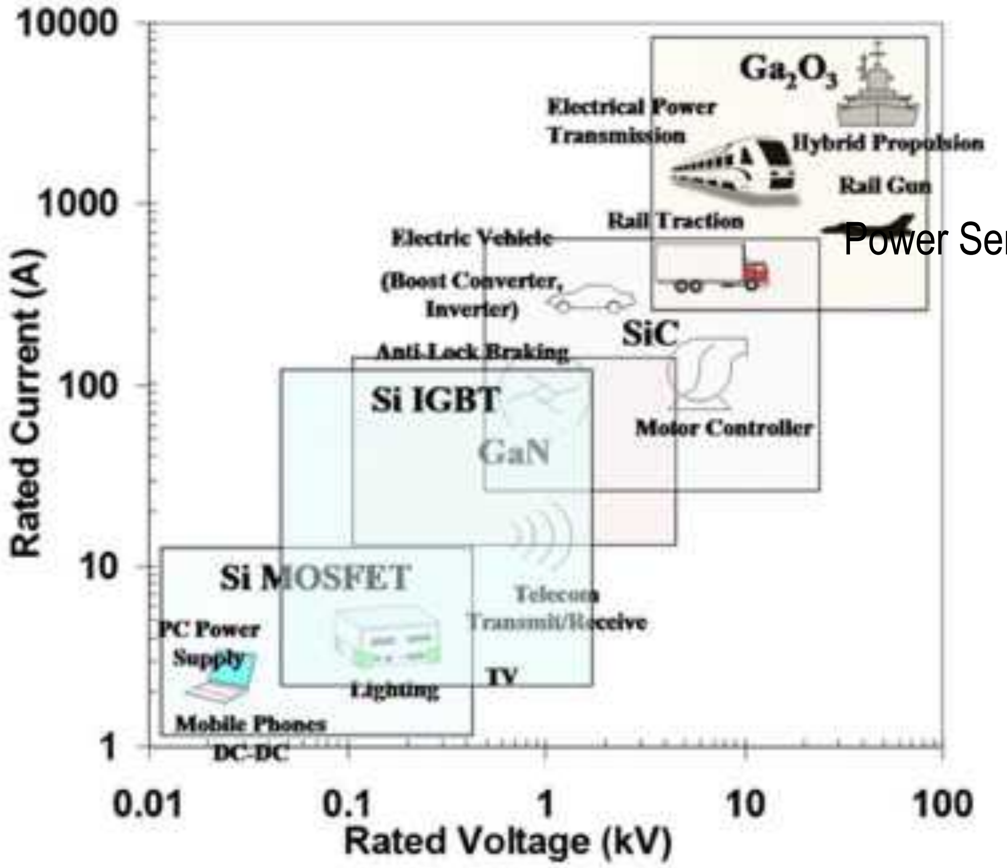


FIG. 4. Applications for Si, SiC, GaN, and Ga_2O_3 power electronics in terms of current and voltage requirements.

Power Semiconductors

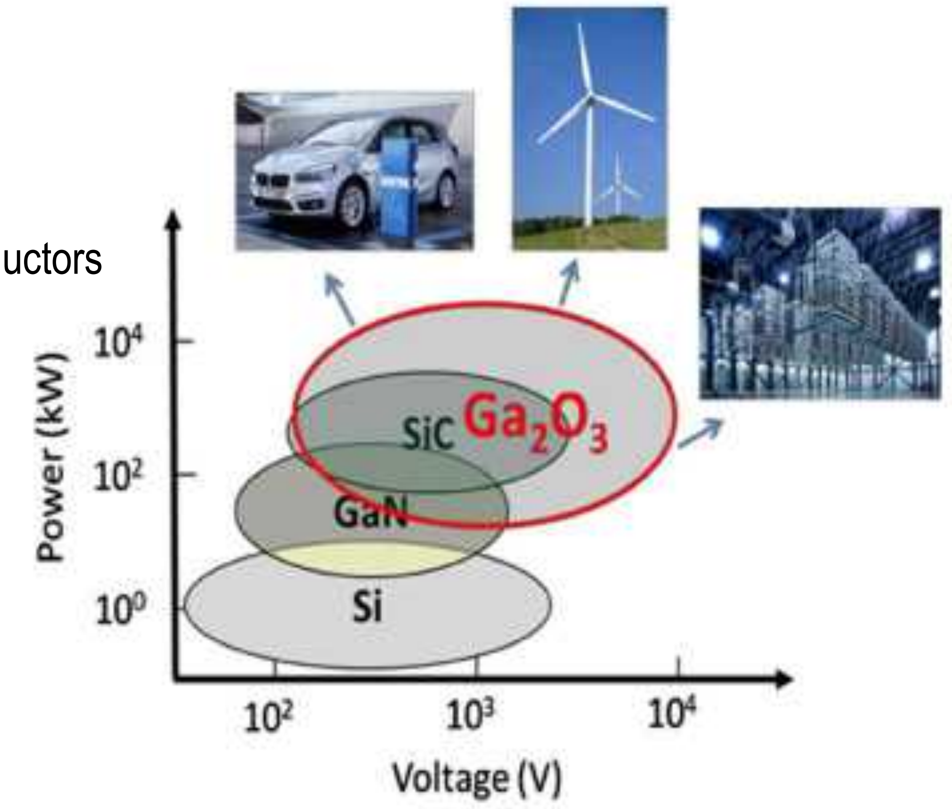
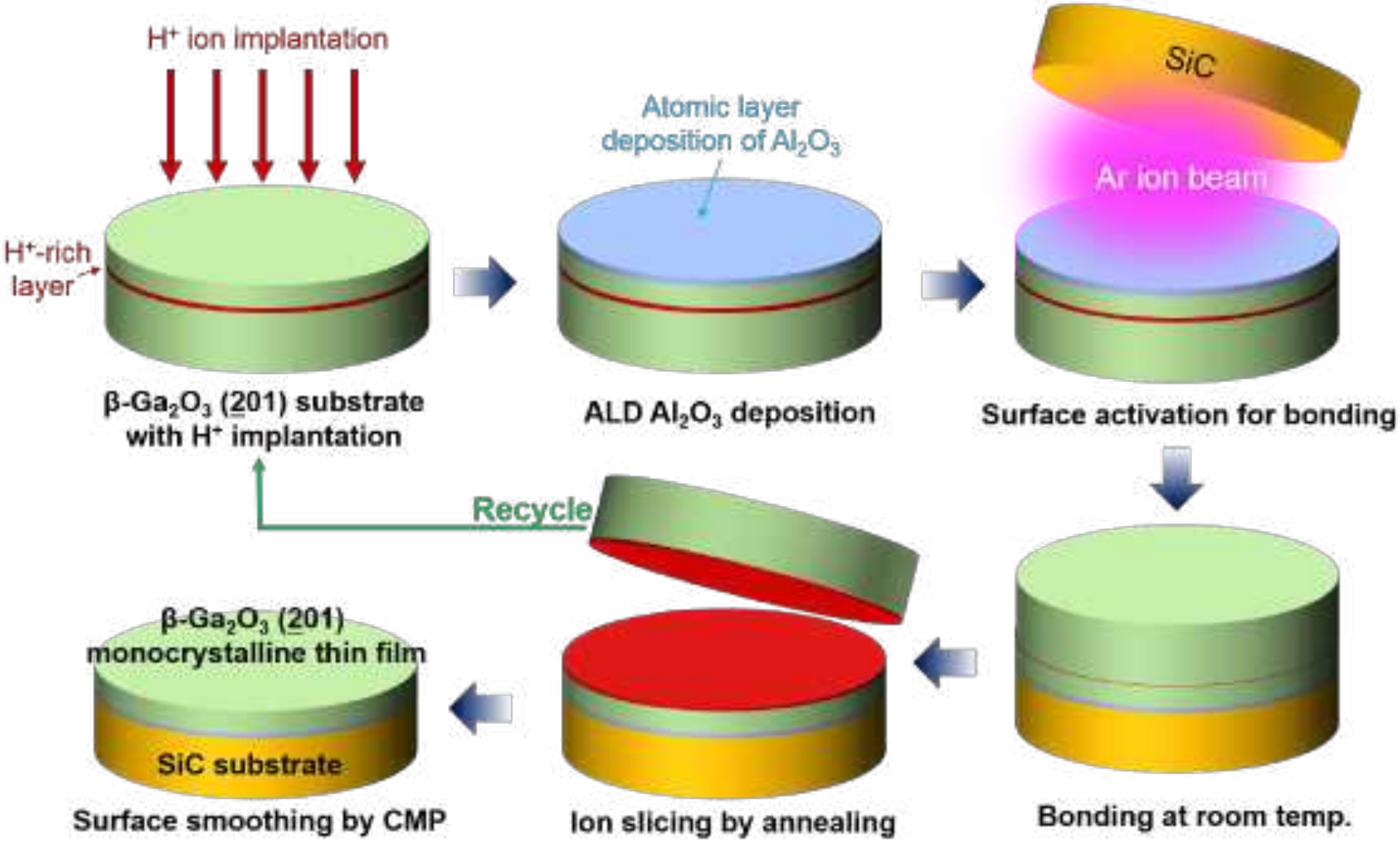


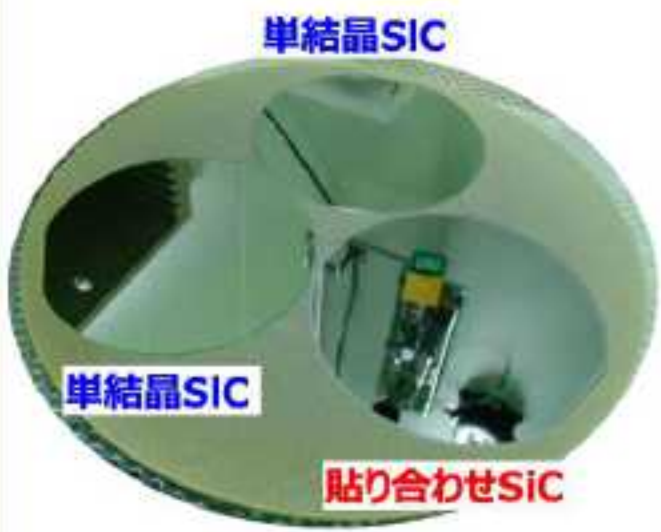
FIG. 5. Additional possible applications for Ga_2O_3 include fast chargers for electric vehicles, high voltage direct current (HVDC) for data centers, and alternative energy sources. These are used to interconnect separate power

doi.org/10.1063/1.5062841

Power Semiconductors

New Fabrication Process: SAB Wafer bonding

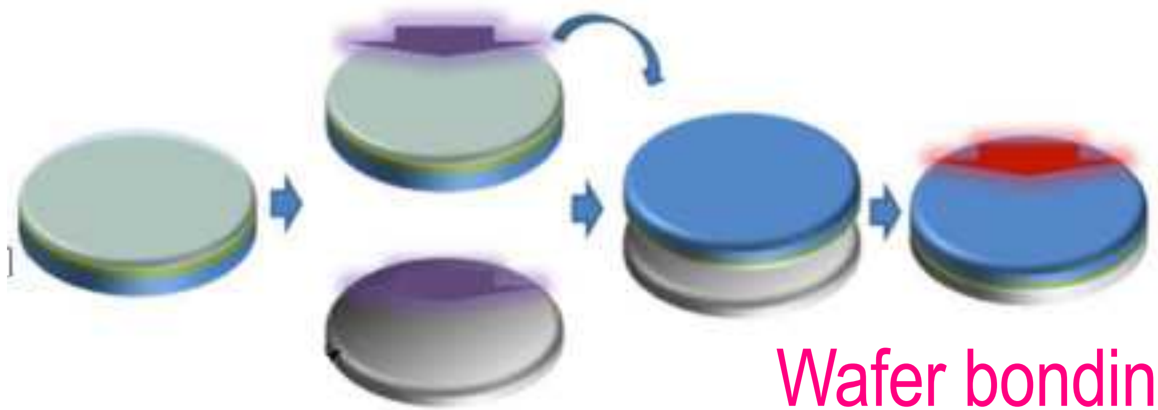




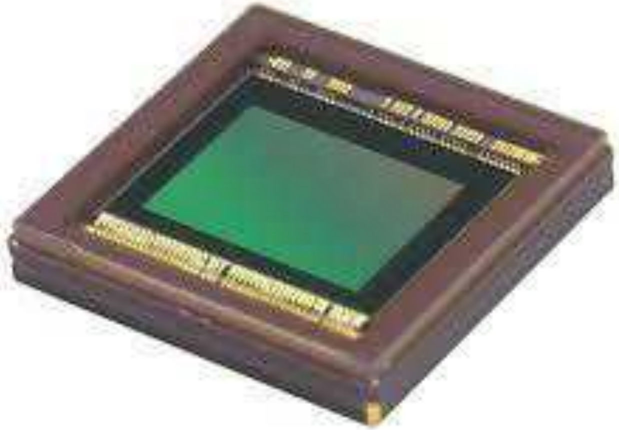
Cheng, Z, etal.: Thermal Transport across Ion-Cut Monocrystalline β-Ga_2O_3 Thin Films and Bonded β-Ga2O3–SiC Interfaces. *ACS Appl. Mater. Interfaces* **2020,**

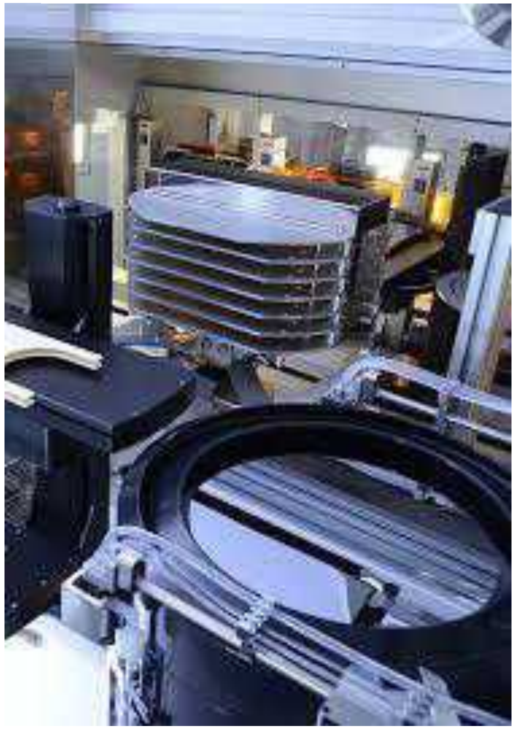
Examples: Semiconductor 3D Integration and Smart Sensors

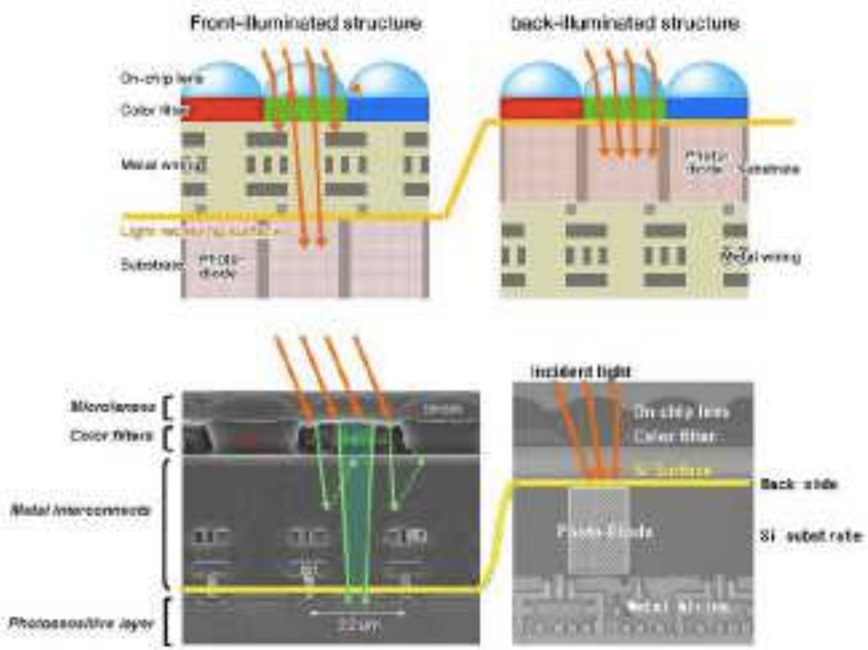
BSI-CMOS Image sensor



Wafer bonding





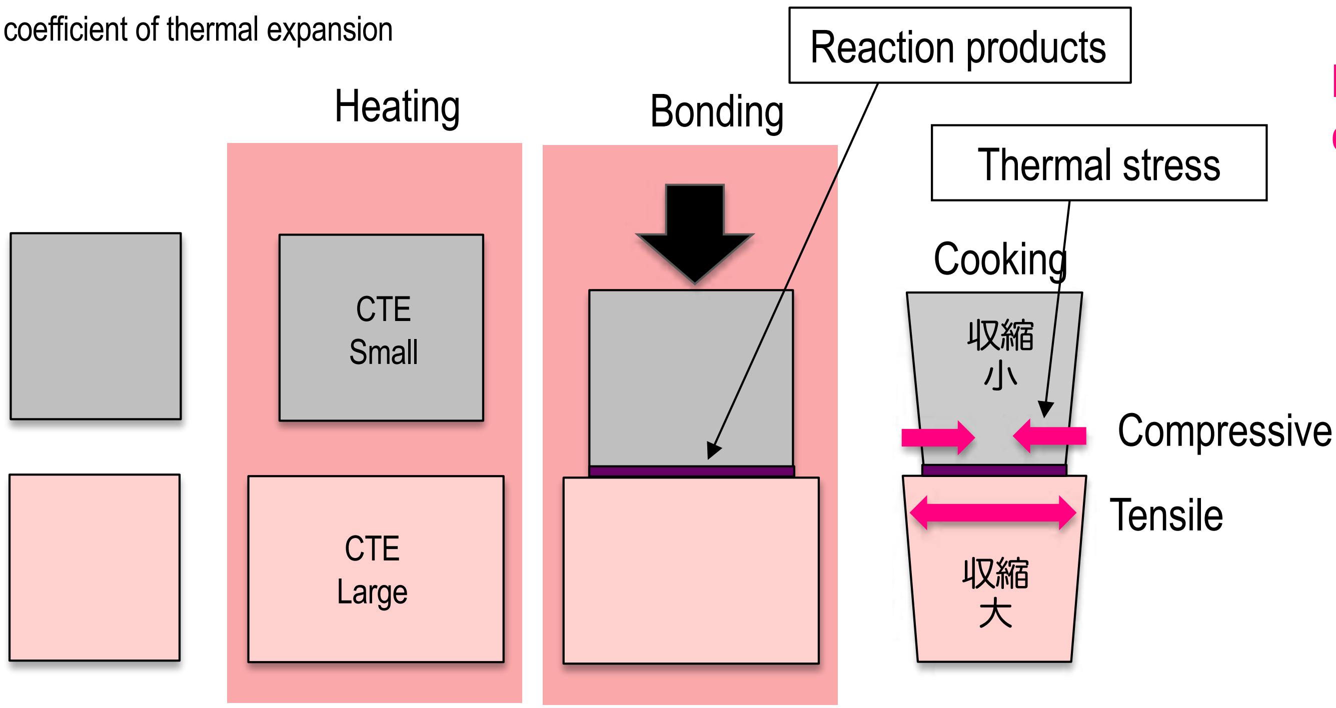


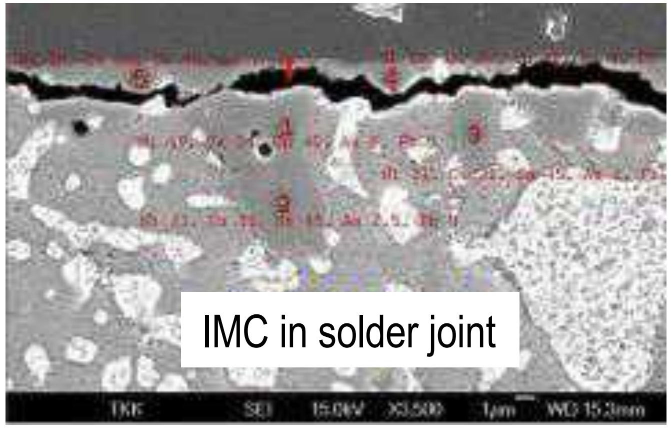
Hybrid bonding

Conventional bonding methods

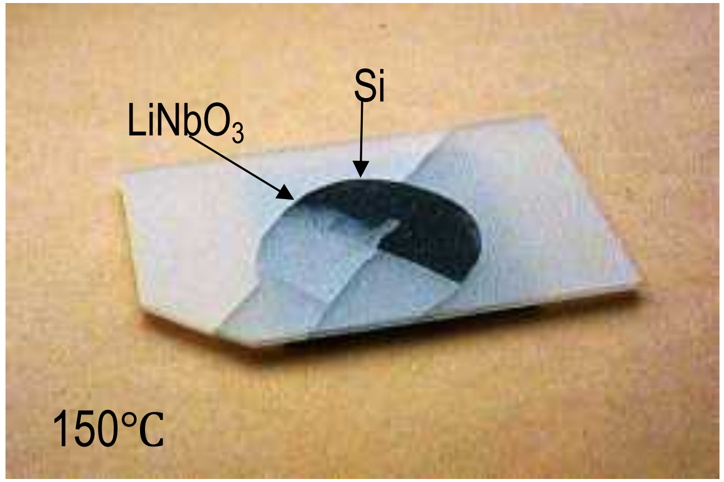
- High temperature process using bonding agents (solder, sintering agents, adhesives)
- Resulting to formation of brittle reaction layers, and/or thermal stresses / large warpage
  - Low yield, low reliability

Mismatch in CTE
coefficient of thermal expansion



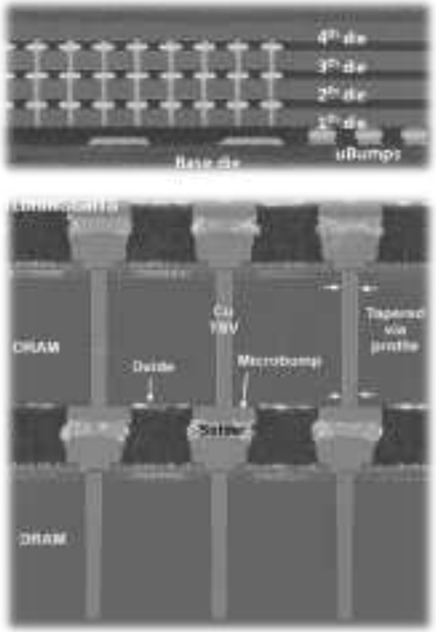


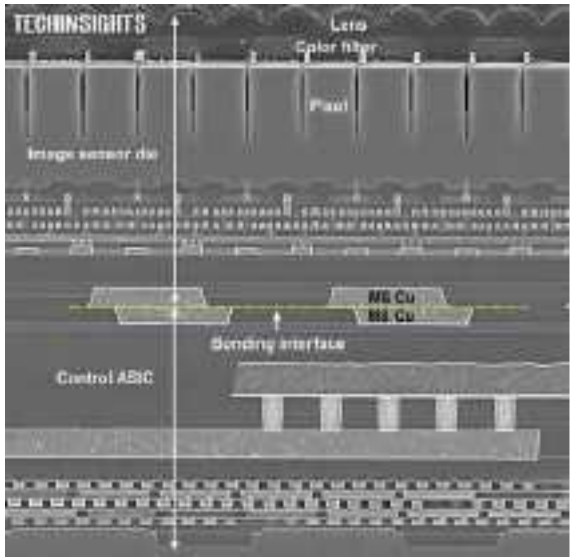
Low reliability due to IMC (intermetalic compound) formation



Warpage and cracks due to thermal stress

Trend of Semiconductor 3D Integration





Sony IMX260 Wafer Bonding

High density
Sub-micron boding

Bump bonding
Solder bonding

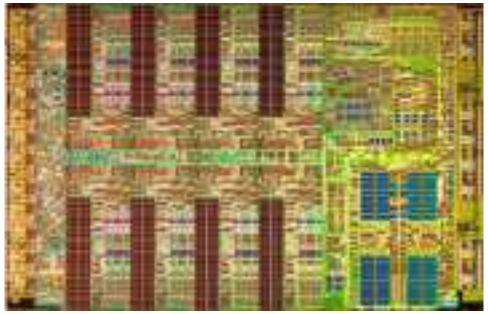
Bump-less bonding
Solder-less bonding

Direct bonding
at Room temperature

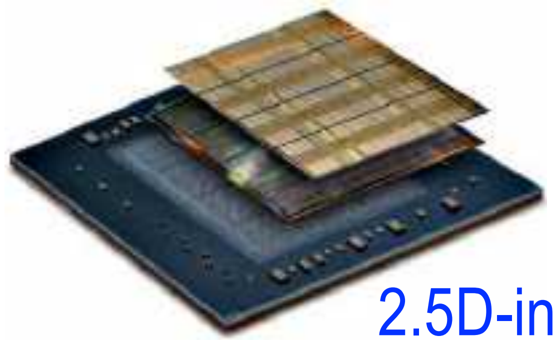
Future of 3D integration

Jack Kilby's pioneering integrated circuit (1958)

2D-integration

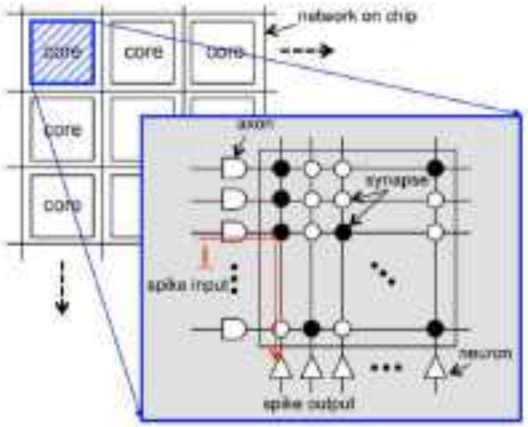


>10 million transistors (2012)



2.5D-integration

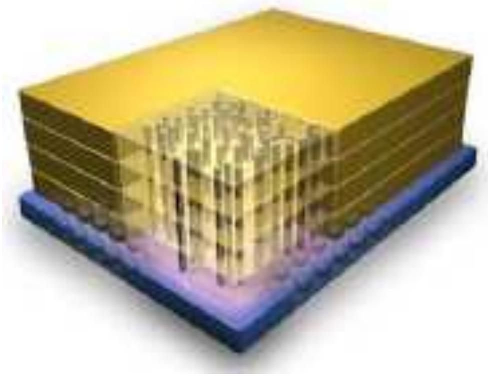
28nm 2.5D FPGA "Virtex-7 2000T" Xilinx (2011)



1 million Neurons
Neuromorphic Computing device (IBM 2014)

3D-integration

Currently only 10 tiers



Cognitive Computing
10 billion Neurons

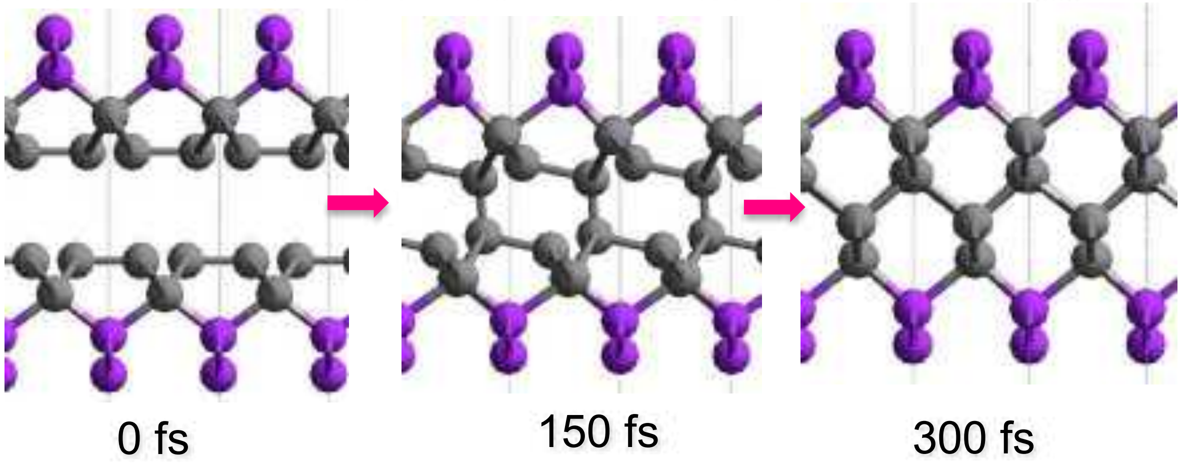
to go over 10,000 tiers (2^{14}=16,384)

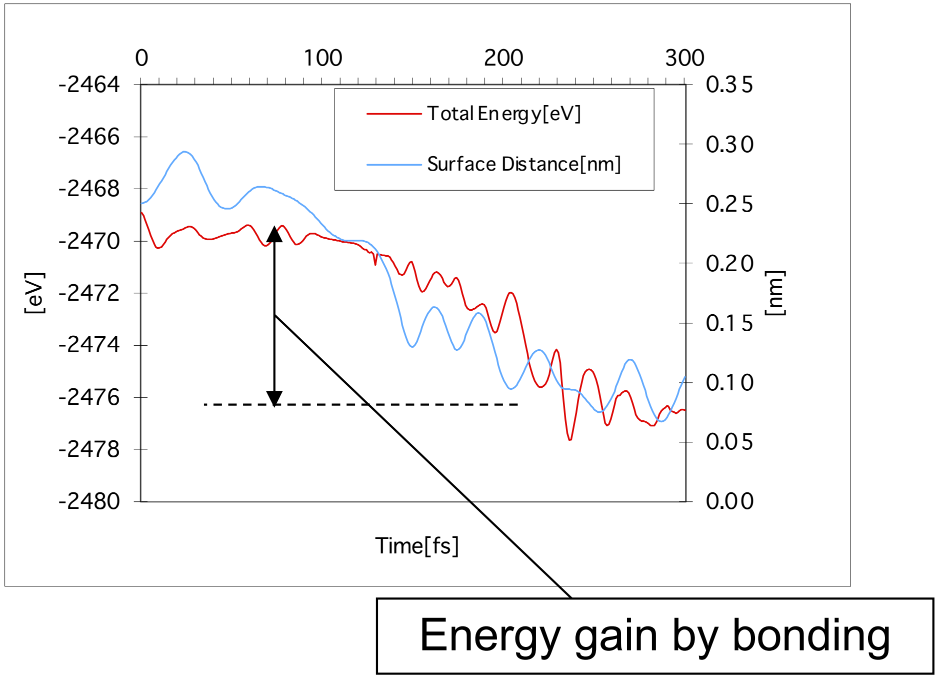
Core Concept: Key Technology

Surface Activated Bonding (SAB)
表面活性化常温接合

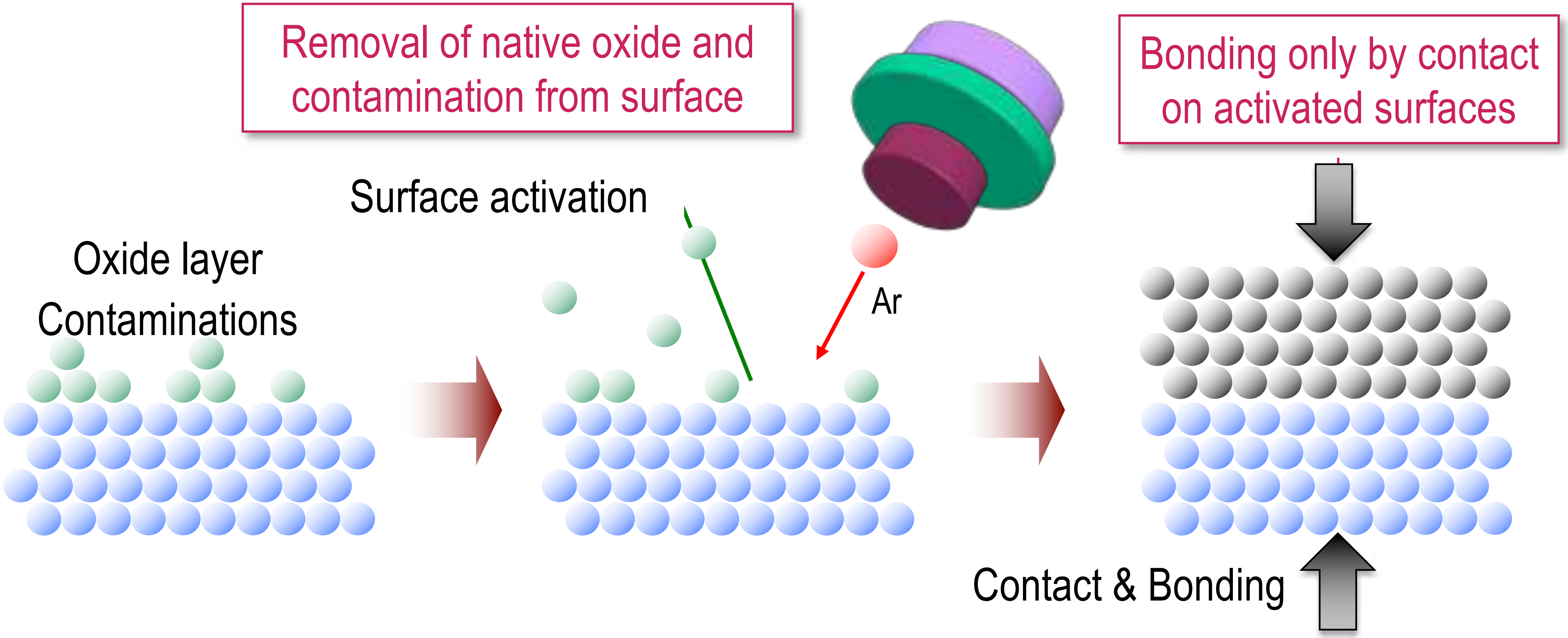
Solid state contact between two materials

Contact of diamond (001) surfaces 1st Principle MD Simulation





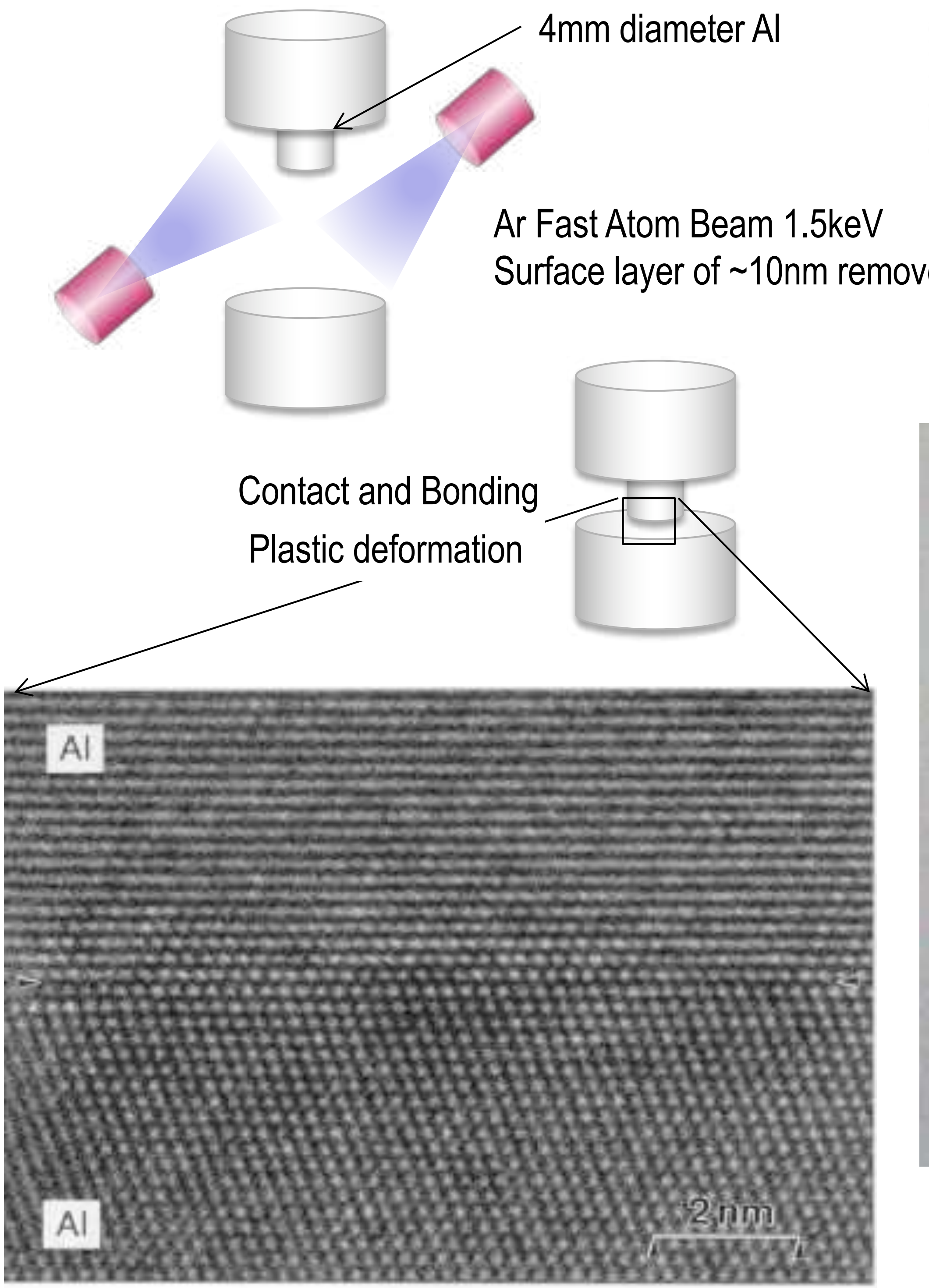
Surface Activated Bonding (SAB)

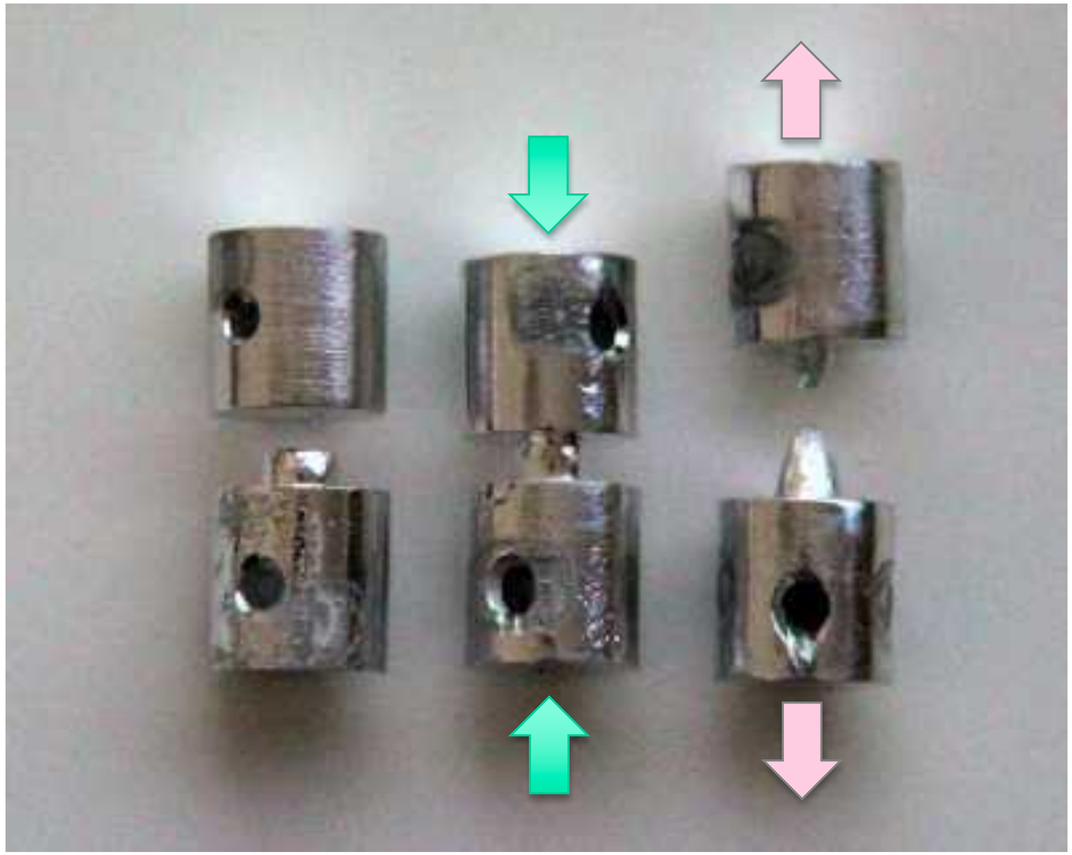


- Direct bonding at room temperature
  - High through put, High alignment accuracy
  - No thermal damage, no reaction layer, no void.
  - High flexibility in material selection
- Bonded pairs
  - Cu, Ni, Al, Au, Ti, etc
  - Si, Ge, GaAs, SiC, etc
  - Ga_2O_3, $LiNbO_3$, Sapphire

Room temperature the bonding of small aluminum rods in ultra-high vacuum chamber using 1.5 keV Ar atom beam irradiation for few minutes.
The result was ……. in the video clip.

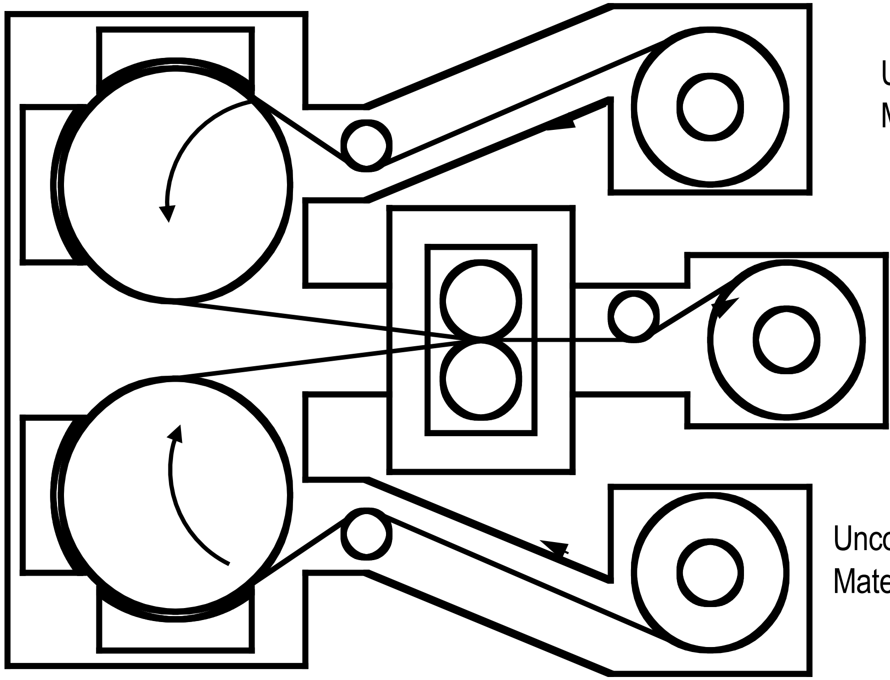
Room temperature bonding of Al-Al by Surface Activated Bonding (SAB)

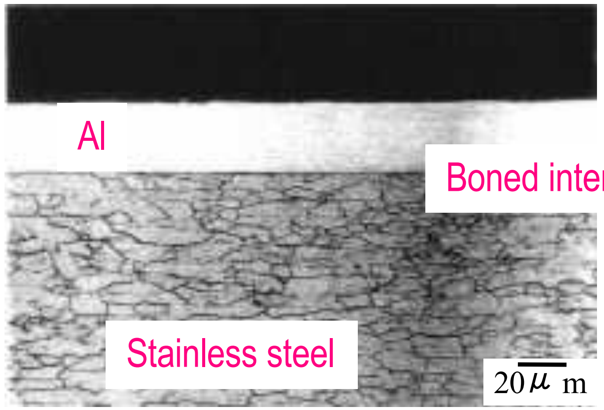




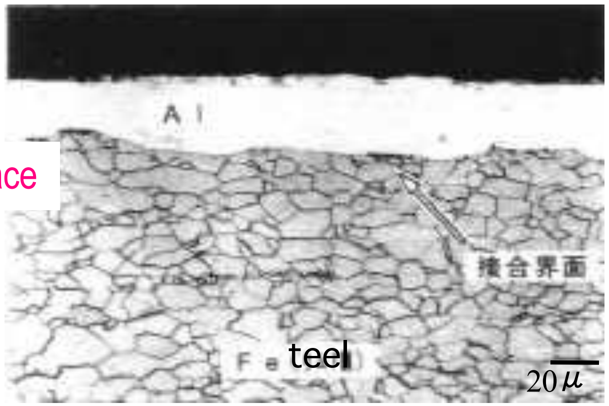
Applications of SAB in volume production

Metal laminates by SAB (FINE CLAD®)

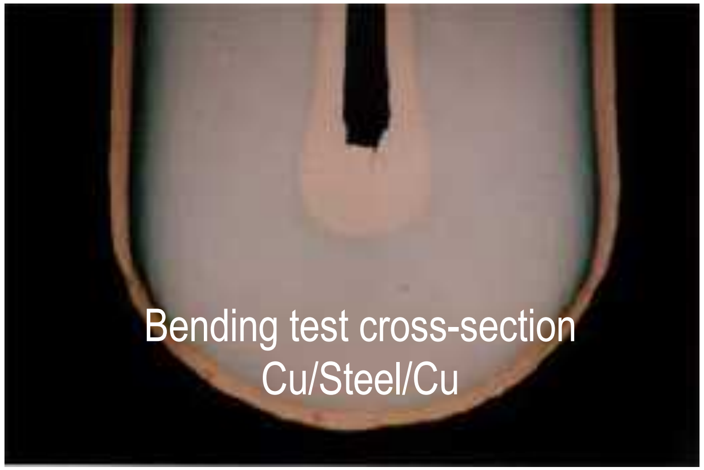




SAB



Cold rolling



华为nova 2 Plus魔镜版采用的是业界首创的双金属复合材质。

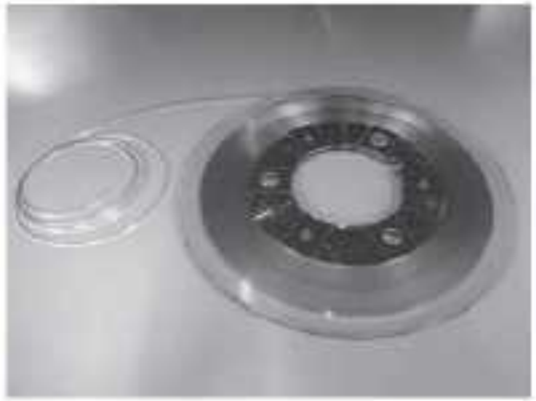
太阳雨科技
百家号 17-08-12 16:31

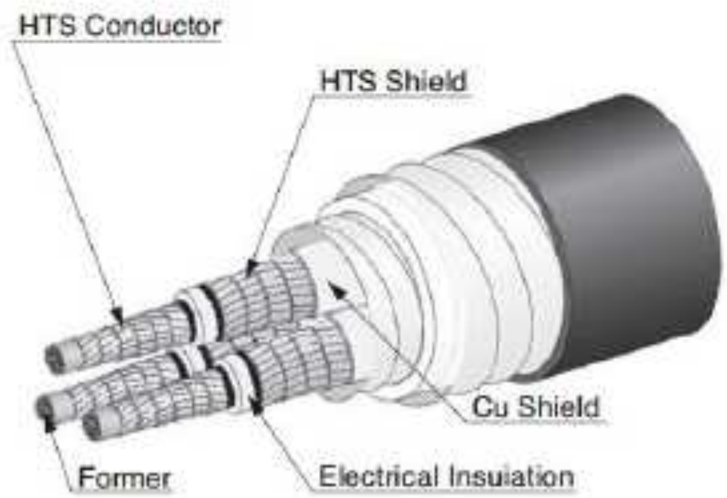
华为nova 2 Plus魔镜版采用的是业界首创的双金属复合材质，也就是说它的本质还是一部金属手机，这点一定不能混淆。华为nova 2 Plus魔镜版将250微米的高硬度精钢与内铝材质结合在一起，保证镜面亮度与材质的轻盈与坚固。

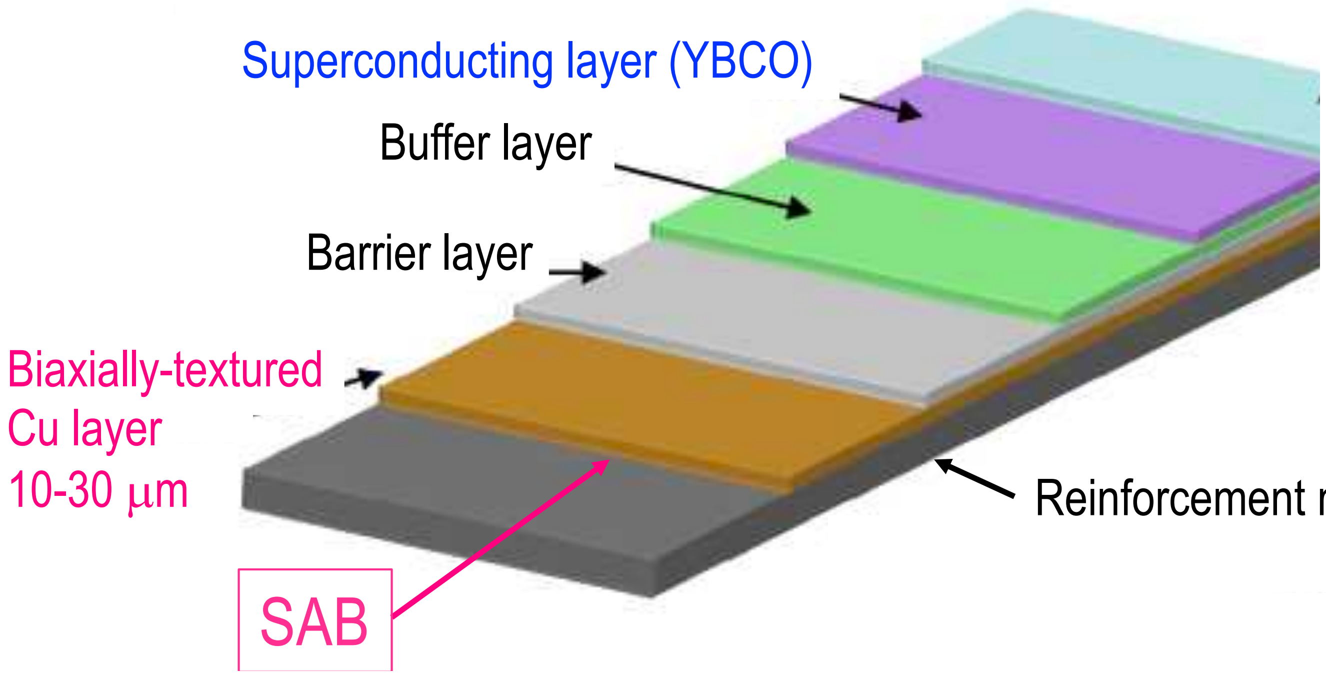
具体来说，所谓的双金属复合工艺和传统制造工艺不同，使用了低压与真空压延的方式，核心工艺就是真空环境下去氧化层，再进行低温低压压合。一般来说，传统的金属复合材料采用高温高压压合工艺，但这会导致金属变形和表面不平整。华为是在真空环境下实现低温压合的，将金属表面附着的氧化物进行表面活性化处理，再通过压接进行复合。

Substrate for High-Temperature Superconductors

High temperature superconductors (HTS) for power cables is made by pulsed laser deposition (PLD) on a biaxially-textured Cu layer, which is fabricated as a clad on a reinforcement material sheet by the SAB.



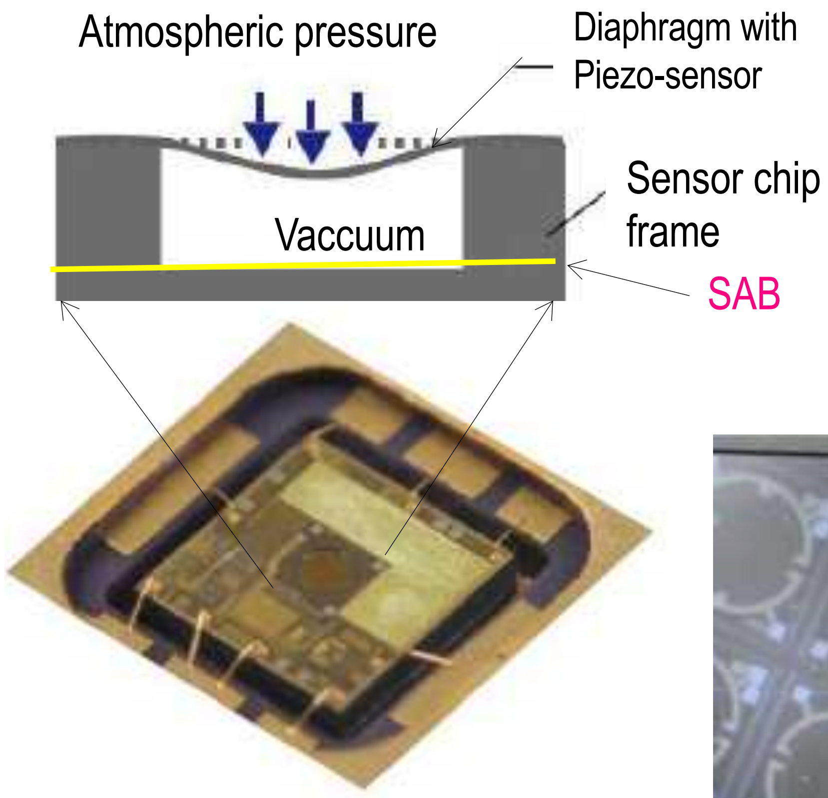




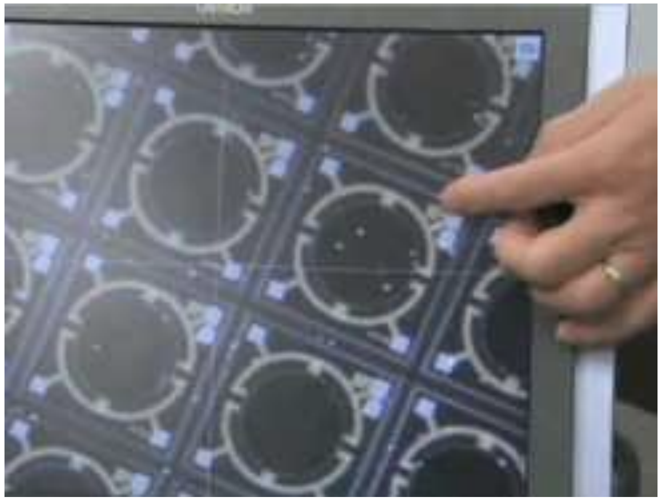
TOYO KOHAN CO.,LTD.

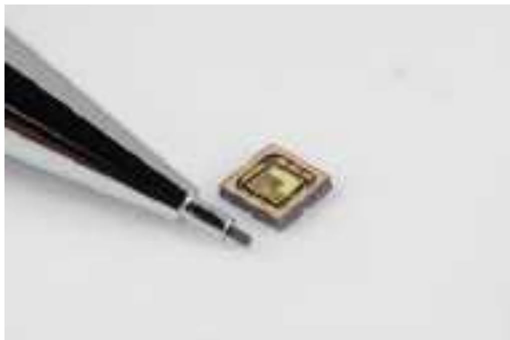
MEMS absolute pressure sensor fabricated by SAB wafer bonding

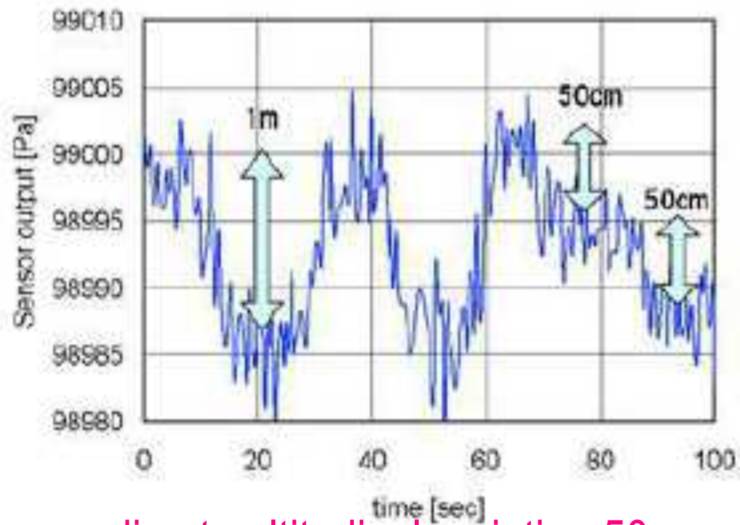
2012



The pressure sensor detects variation in atmospheric pressure relative to a vacuum cavity created inside the sensor chip by SAB. The resolution is 5 Pa, corresponding to altitudinal variation as small as 50cm. It is installed in a commercial **Pedometer** which can track the walking record also for the number of steps on stairs.

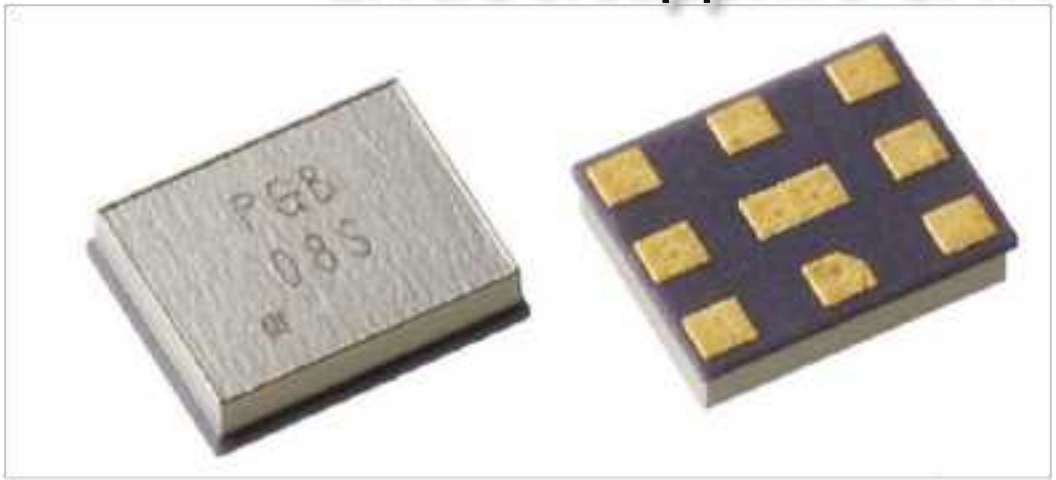


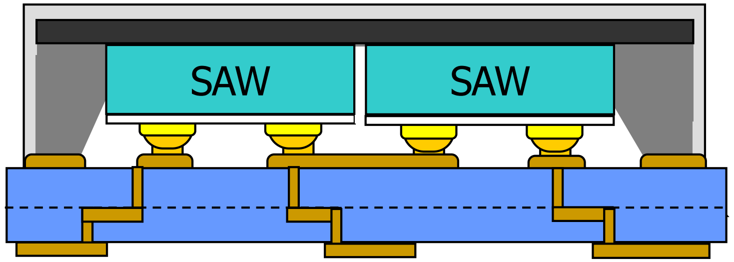


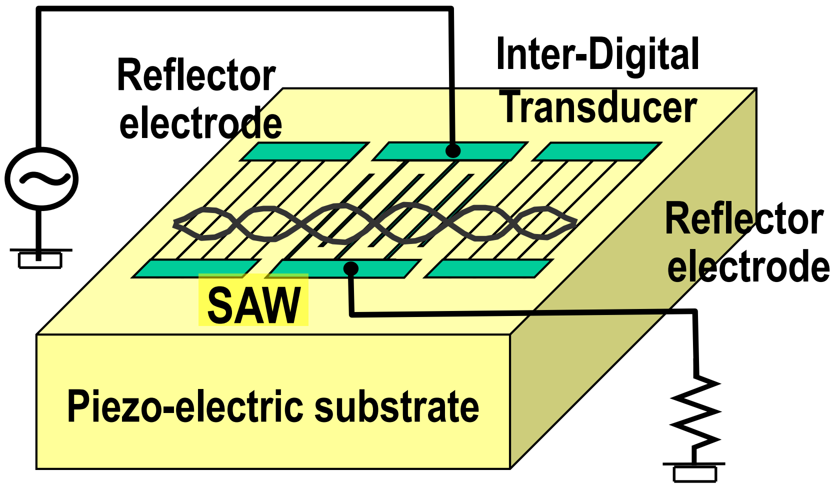


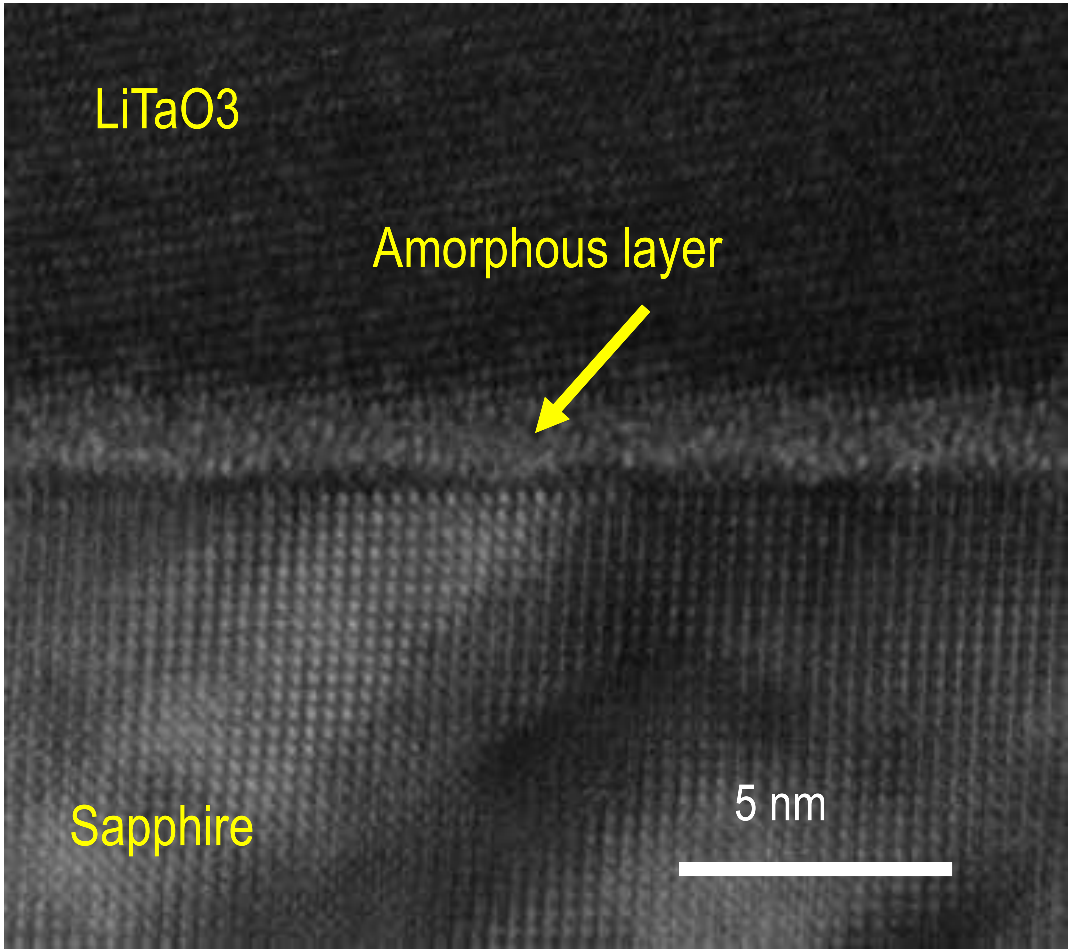
The resolution is 5 Pa, corresponding to altitudinal variation 50cm.

LiTaO3/sapphire SAW device fabricated by SAB









SAB Applications for Photovoltaic Devices

- Multi-junction Solar Cells: Semiconductor wafer bonding

World Record Solar Cell with 44.7% Efficiency

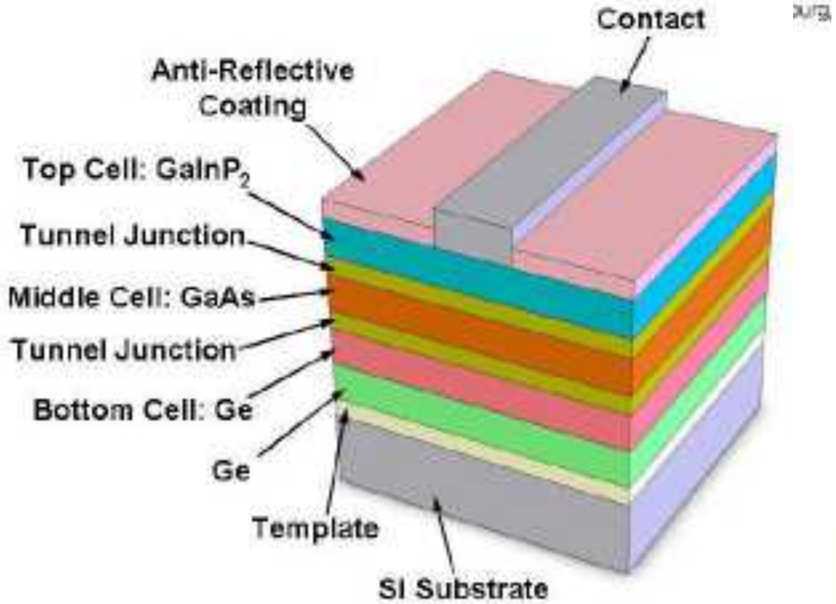
Fraunhofer ISE

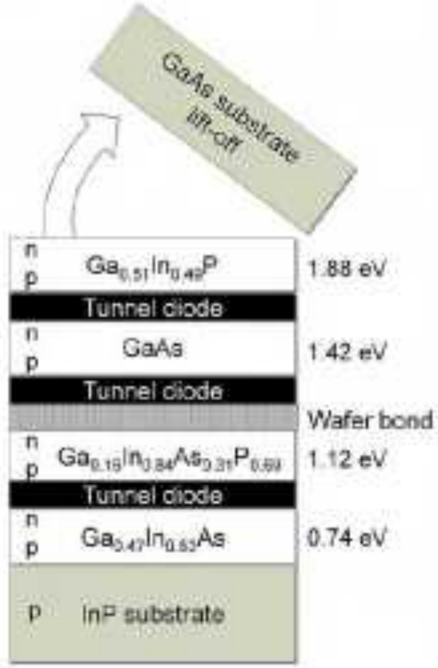
Press Release 22/13, September 23, 2013

World record solar cell with 44.7% efficiency, made up of four solar subcells based on III-V compound semiconductors for use in concentrator photovoltaics. ©Fraunhofer ISE

Wafer bonded four-junction GaInP/GaAs//GaInAsP/GaInAs concentrator solar cells with 44.7% efficiency

Frank Dimroth[1*], Matthias Grave[1], Paul Beutel[1], Ulrich Fiedeler[1], Christian Karcher[1], Thomas N. D. Tibbits[1], Eduard Oliva[1], Gerald Siefer[1], Michael Schachtner[1], Alexander Wekkeli[1], Andreas W. Bett[1], Rainer Krause[2], Matteo Piccin[2], Nicolas Blanc[2], Charlotte Drazek[2], Eric Guiot[2], Bruno Ghyselen[2], Thierry Salvetat[3], Aurélie Tauzin[3], Thomas Signamarcheix[3], Anja Dobrich[4], Thomas Hannappel[4†] and Klaus Schwarzburg[4]





Collaboration in China

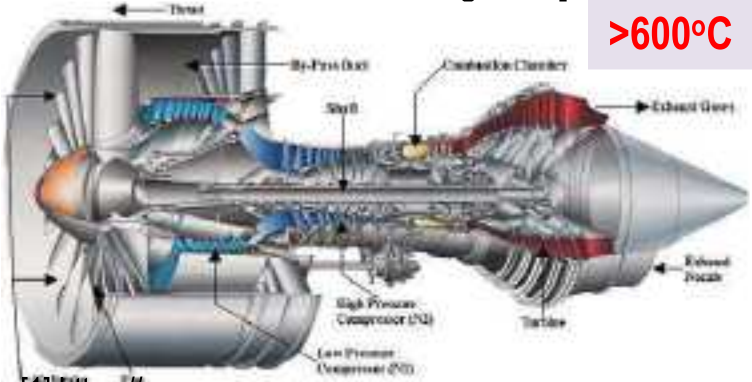
All-SiC pressure sensor fabrication using SAB of SiC wafer at room temperature

中国科学院微电子研究所
INSTITUTE OF MICROELECTRONICS OF THE CHINESE ACADEMY OF SCIENCES

MEMS for Harsh Environmental Applications

- **Harsh Environments** includes extremes of temperature, pressure, shock, radiation and chemical attack.

Gas turbines/Aircraft engines [1]



[1] https://rampages.us

Automotive engines [2]

[2] http://buster1951.cgsociety.org

Efficient & Safe

Geothermal [3]

[3] http://www.greenpeace.org

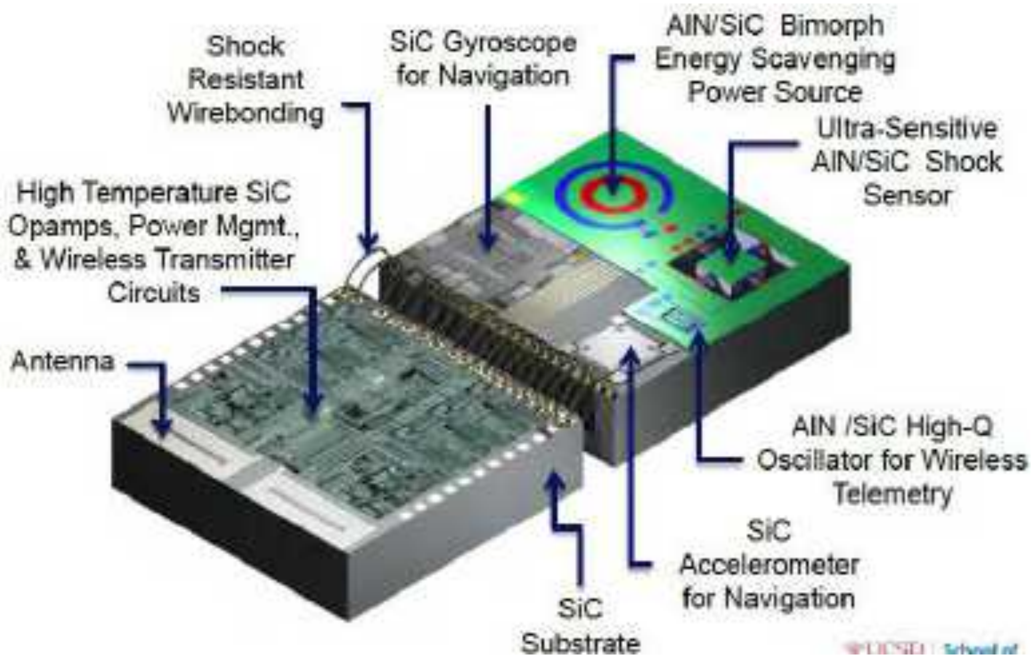
Space exploration [4]

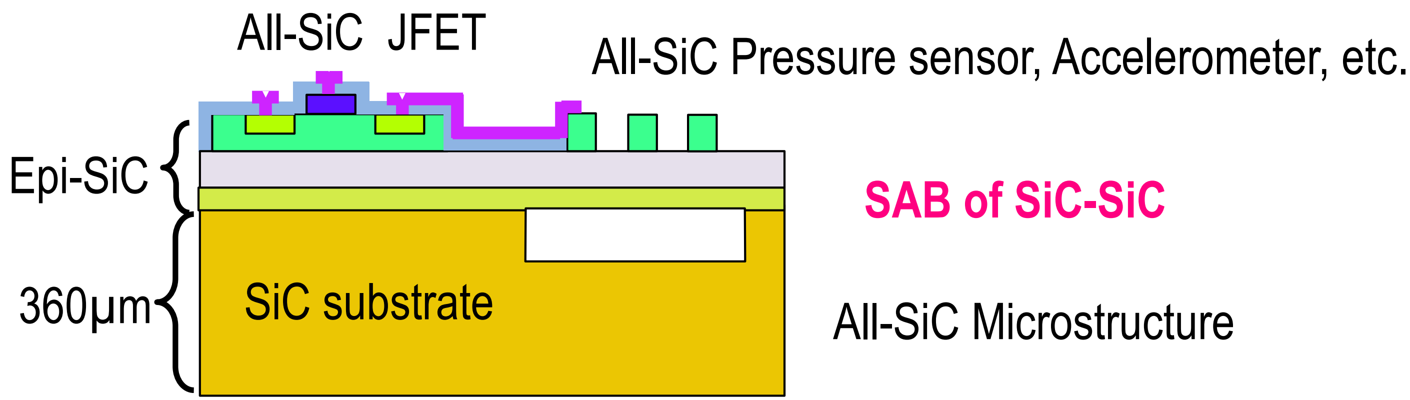
[4] www.wallcoo.com

- **Real-time sensing in harsh environments** enables monitoring of combustion, subsurface environments, and critical components.

Integrated SiC Sensors & Electronics

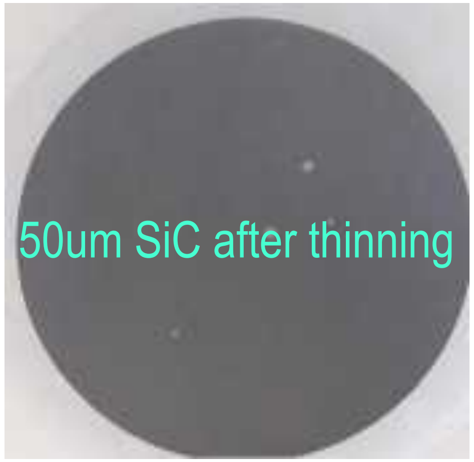
- Requirement for MEMS Devices
  - High temperature operation
  - Harsh environment
  - Real time sensing
- Solution
  - All-SiC MEMS
- Key technology
  - SiC wafer bonding using SAB





All-SiC piezo-resistive pressure sensor

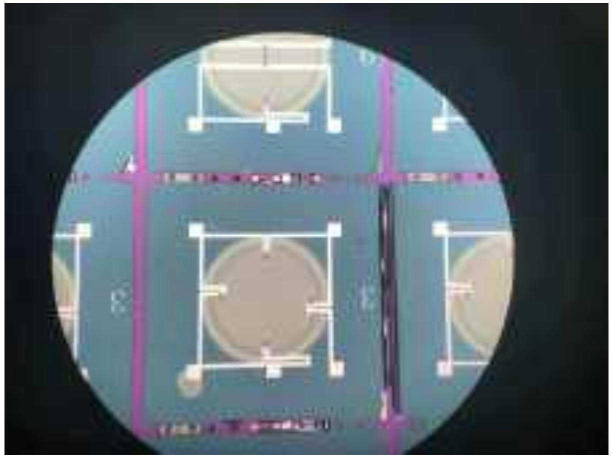
- Wafer thinning

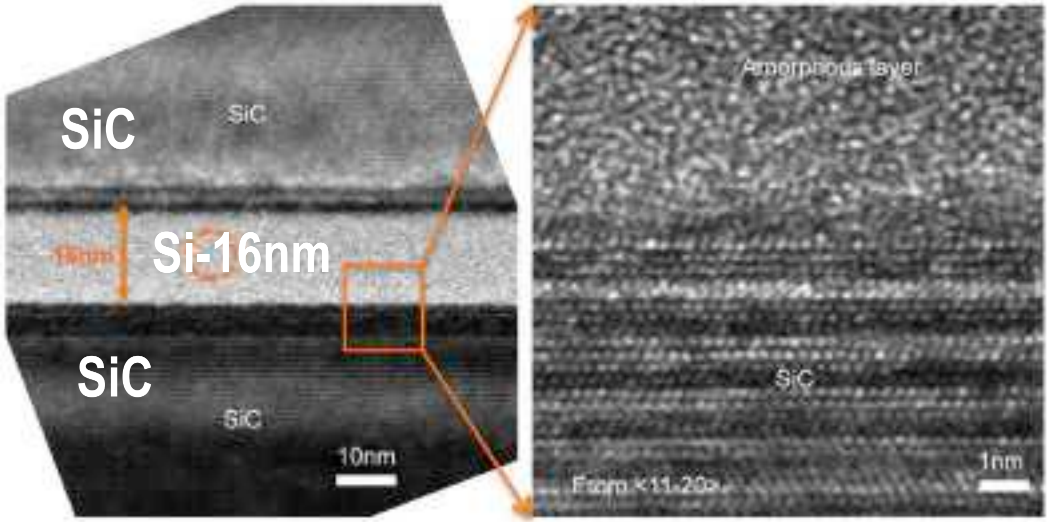


- Patterned wafer

- Alignment bonding of thin epi-SiC wafer

- Piezo-resistors fabrication





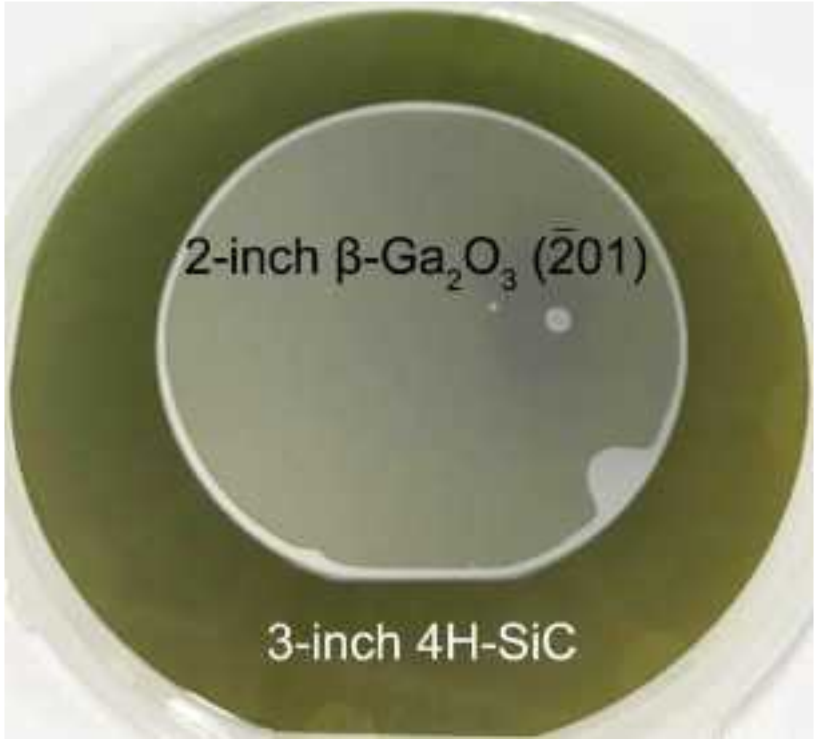
SAB of SiC wafers

- Hermeticity test: the lowest leak rate is < 2 10^{-12} Pa·m^3/s, <<MIL-STD-883H .

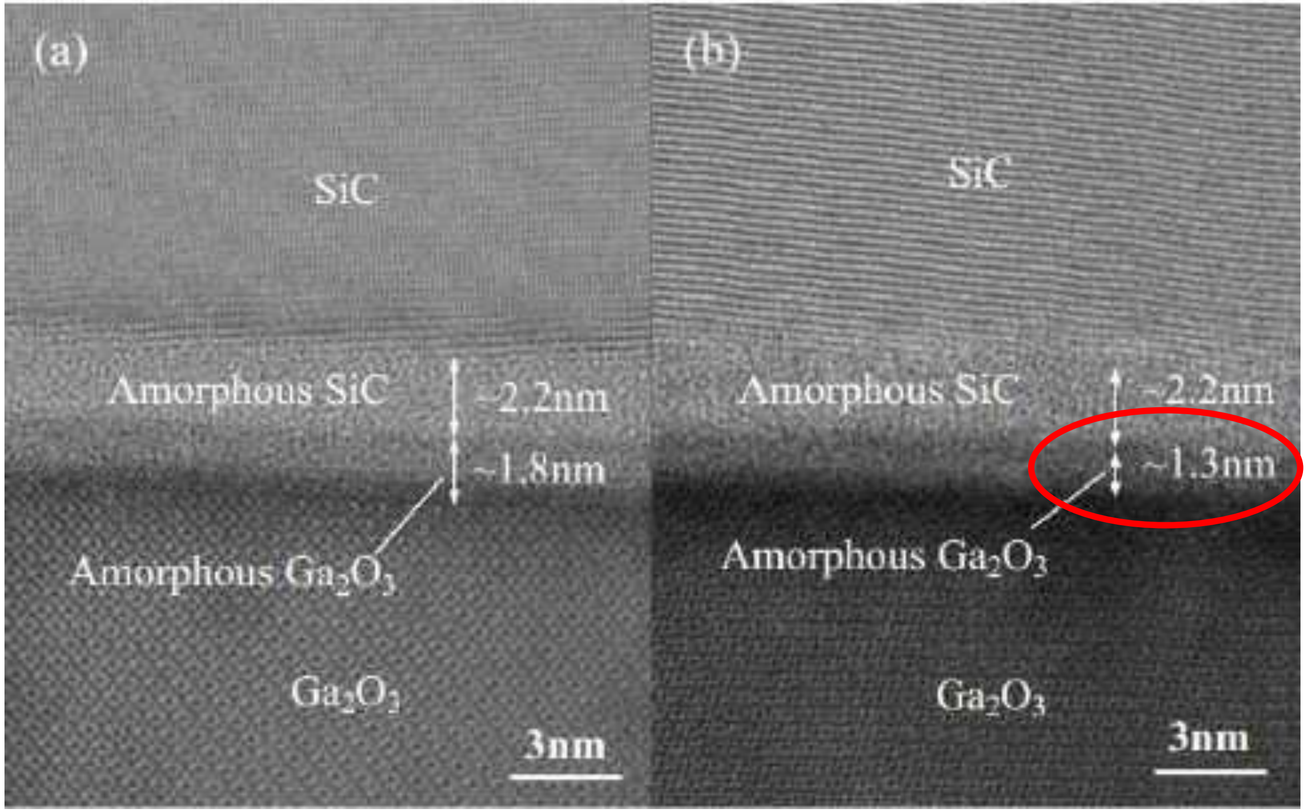
Ga_2O_3 - SiC bonding

collaboration
with
Xin Ou. (Shanghai Institute of Microsystem and Information Technology, CAS)
Mark S. Goorsky (UCLA)
Samuel Graham (GIT)

Ga2O3 – SiC bonding using Si-doped SAB



- Room temp. bonding of βGa$_2$O$_3$-SiC by Si-doped SAB
- High bond strength: 2.3 J/m^2



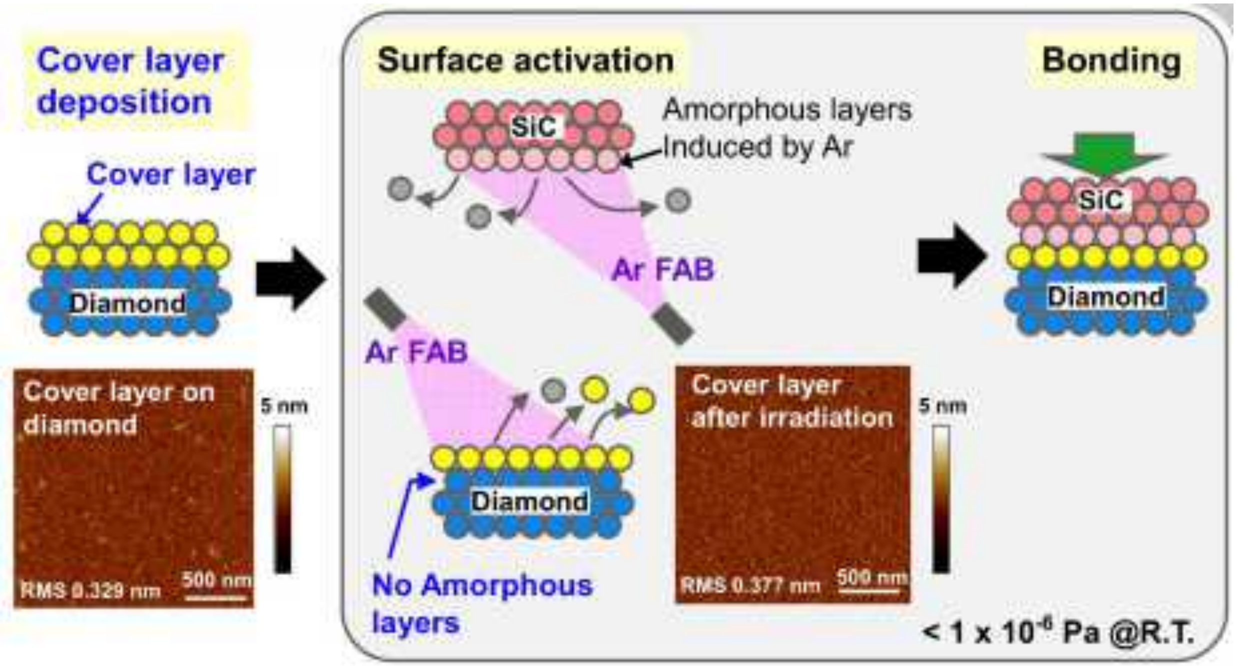
BF STEM images of the Ga_2O_3-SiC bonding interface
(a) before annealing (b) after annealing

Amorphous layer shrank by interfacial diffusion

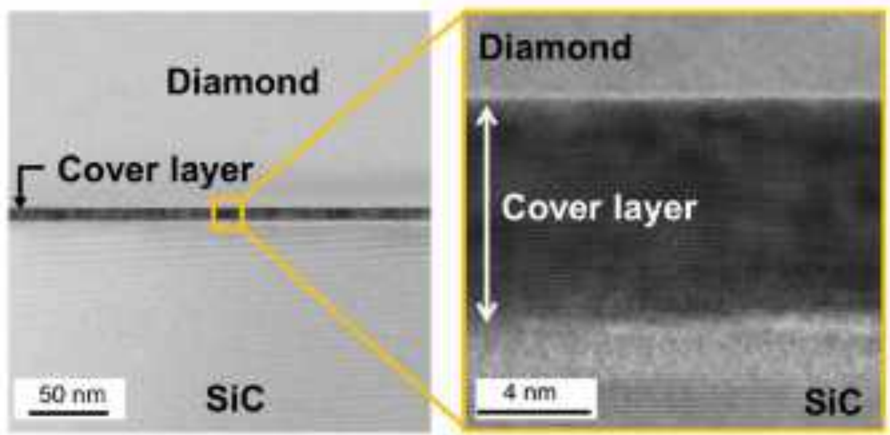
Xu Y, et al. Direct wafer bonding of Ga_2O_3–SiC at room temperature. Ceramics International, 2019

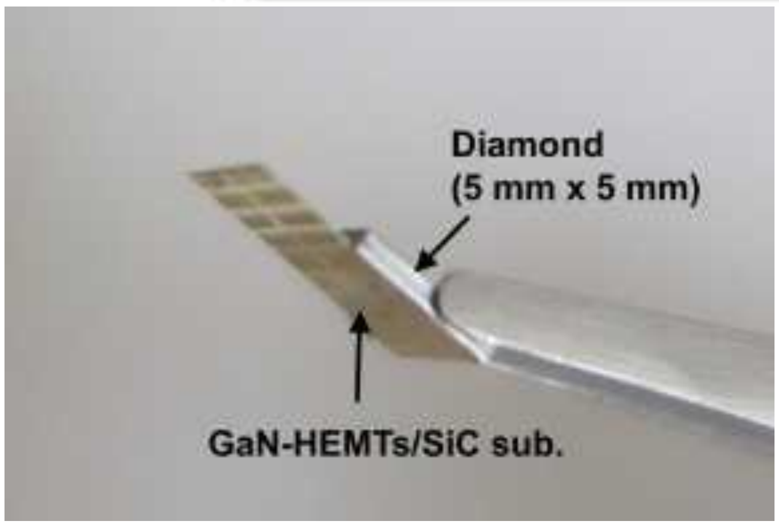
GaN-HEMT- Diamond Substrates

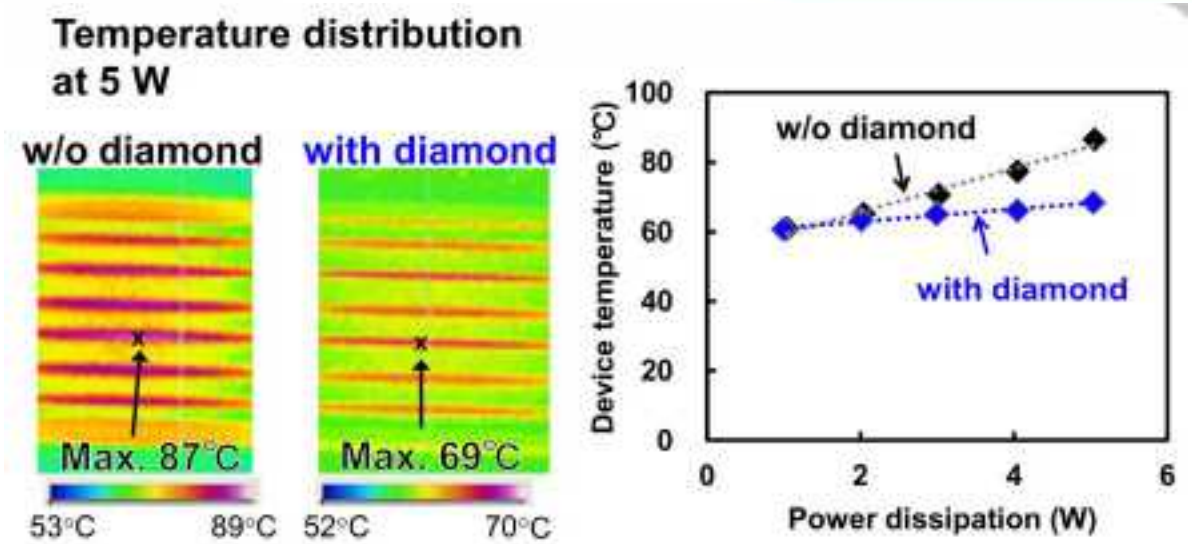
Bonding Single-crystal Diamond and SiC at Room Temperature by modified SAB



TBC

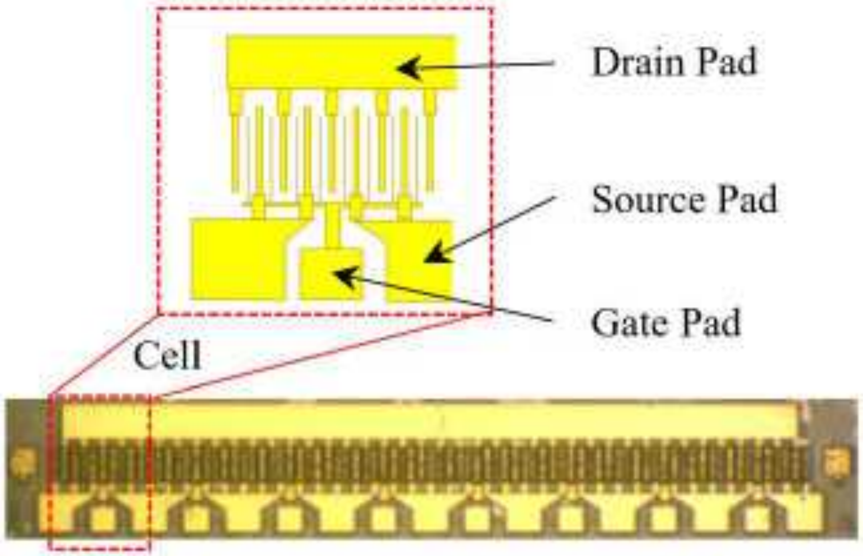


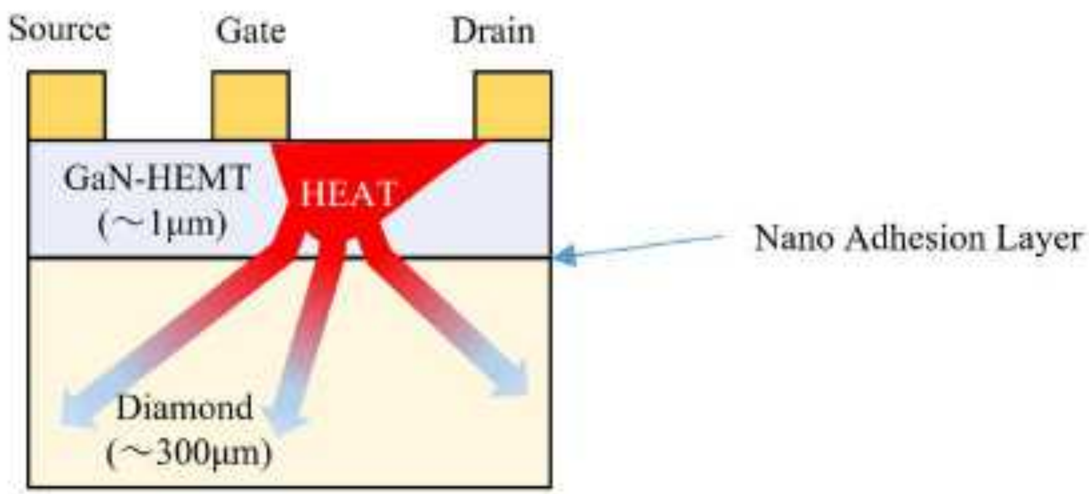




Mitsubishi Electric Develops World's First Multi-Cell GaN-HEMT Bonded Directly to Diamond Substrate

News release: September 2, 2019
Published in SSDM 2019, Nagoya, in collaboration with the Research Center for Ubiquitous MEMS and Micro Engineering, National Institute of Advanced Industrial Science and Technology (AIST)

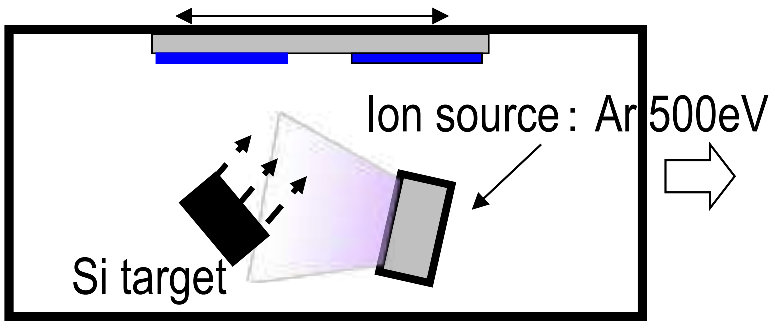


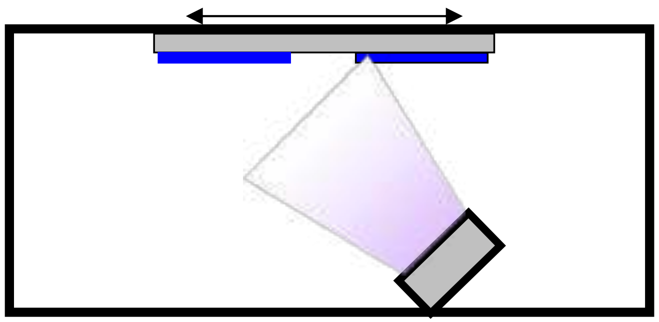


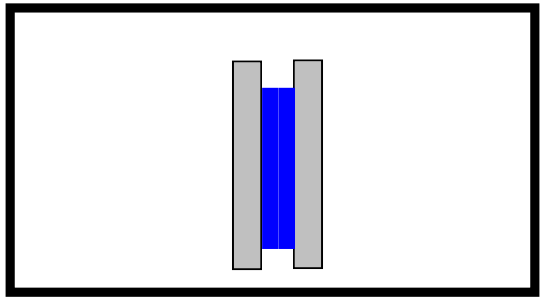
The temperature rise of the GaN-HEMT decreased from 211 to 35 degrees Celsius.
The output per gate width improved from 2.8 W/mm to 3.1 W/mm as well as the power efficiency raised from 55.6 to 65.2 %

Bonding process

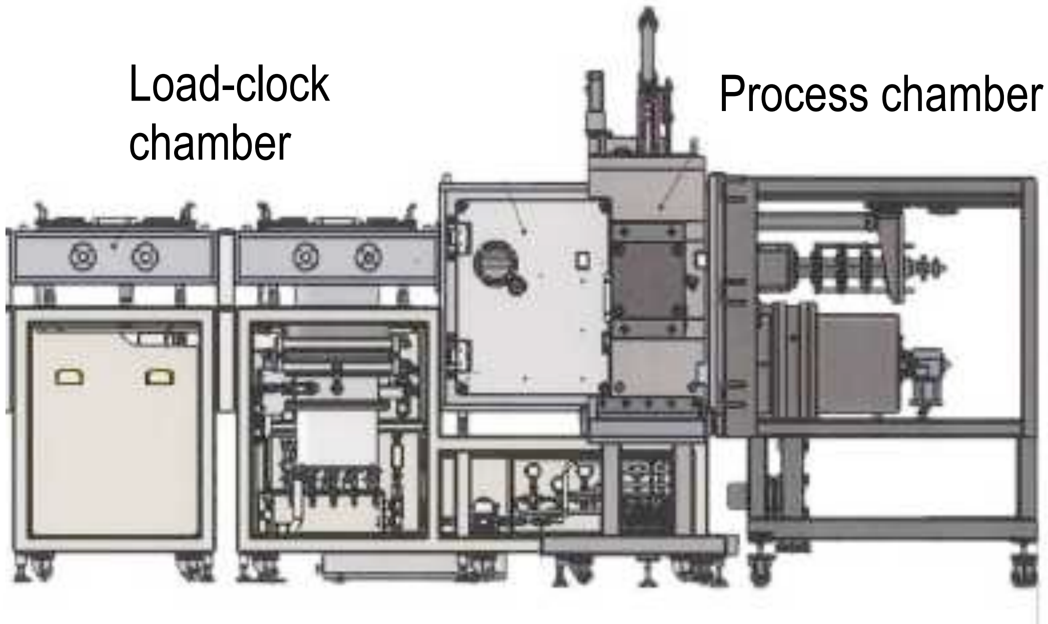
Si, metal, SiC deposition → Surface activation → Bonding



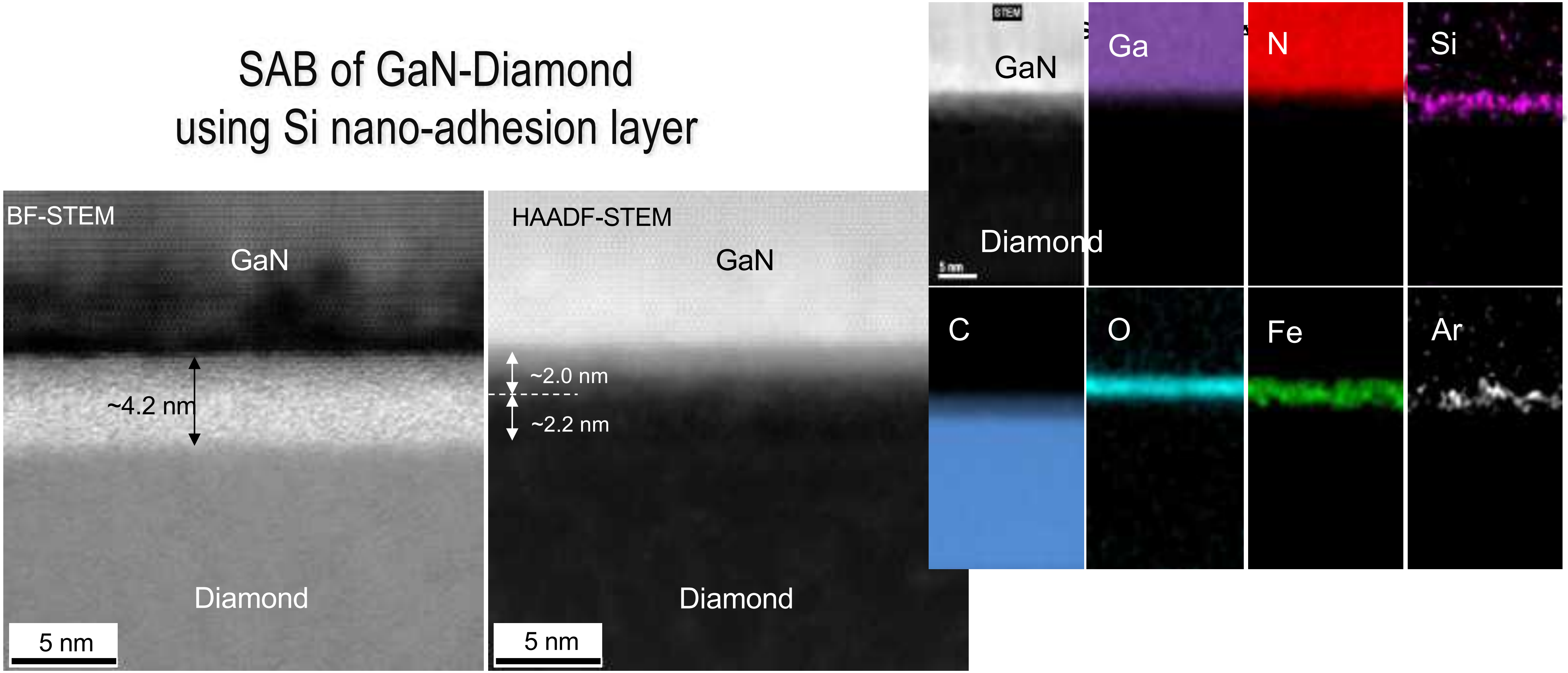




- in vacuum ~10^{-7}Pa
- bonding load 20 kN



SAB of GaN-Diamond using Si nano-adhesion layer



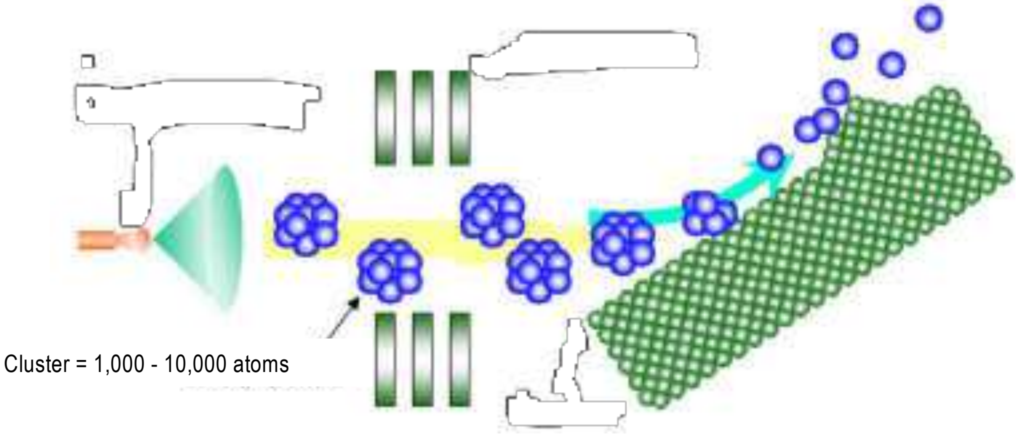
TBC (thermal barrier conductance) by TDTR* method

J. Cho et al.	Bonding (AlGaN-diamond)	~700°C	3-42nm SiNx (**142nm Al0.5Ga0.5N**)	TDTR	~37 MW/m^2K (just SiNx layer)
L. Yates et al.	CVD growth (Diamond on GaN)	. >600°C	~5nm SiNx	TDTR	>100 MW/m^2K
Suga et al.	**SAB**	**Room temp.**	**<10 nm Si**	**TDTR**	**~53** MW/m^2K
Suga et al.	**SAB**	**Room temp.**	**< 2 nm Si**	**TDTR**	**~92** MW/m^2K

world highest 2019

Polishing and bonding of diamond using GCIB

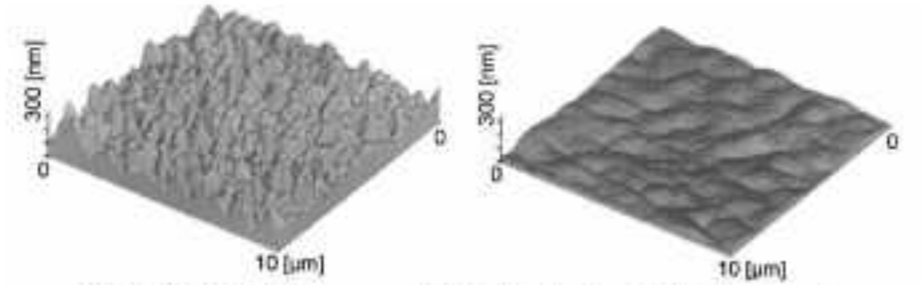
Polishing and bonding of diamond using GCIB



IIPT Inc.

Gas-cluster ion beam (GCIB) irradiation

- High removal rate
- Low damage
- Reactive gas



(a) Before irradiation
Ra=40nm

(b) Ar cluster ion ($1\times10^{17}cm^{-2}$) and O_2 cluster ion irradiation ($1\times10^{15}cm^{-2}$)
Ra=10nm

N. Toyoda, N. Hagiwara, J. Matsuo, I. Yamada, (1999)

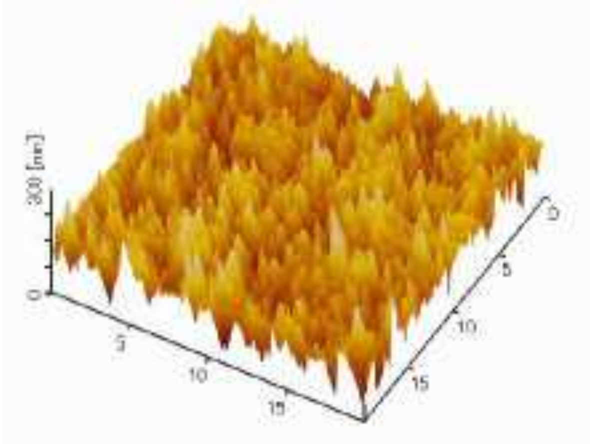
Bonding diamond

- only possible by Extended SAB
- Surface roughness Ra <0.5 nm
- Warpage < 10 um

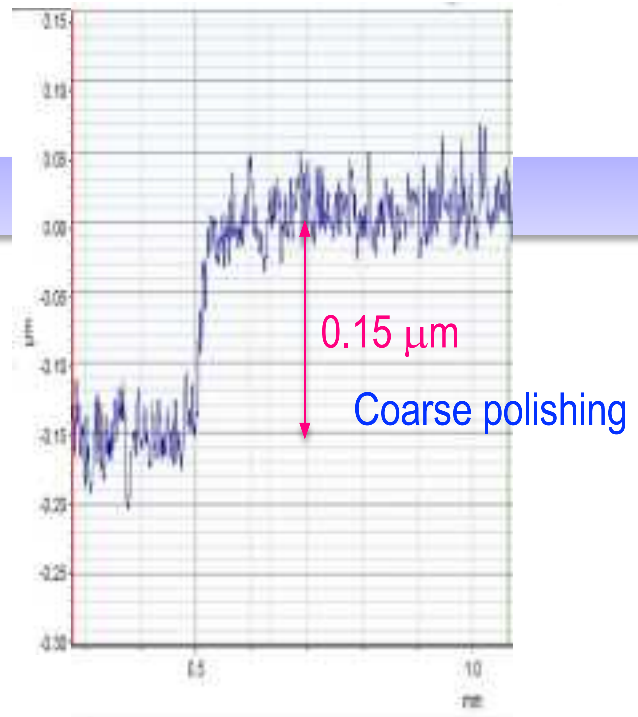
Combined bonding process: GCIB-SAB

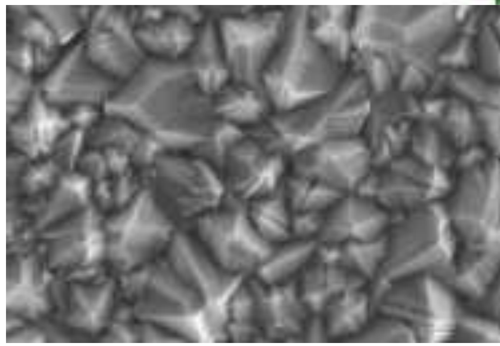
- Seamless process of polishing and bonding
- Low damage bonding

Polishing of Diamond wafer by GCIB



After GCIB irradiation for 20 min
Ra ～ 40 nm





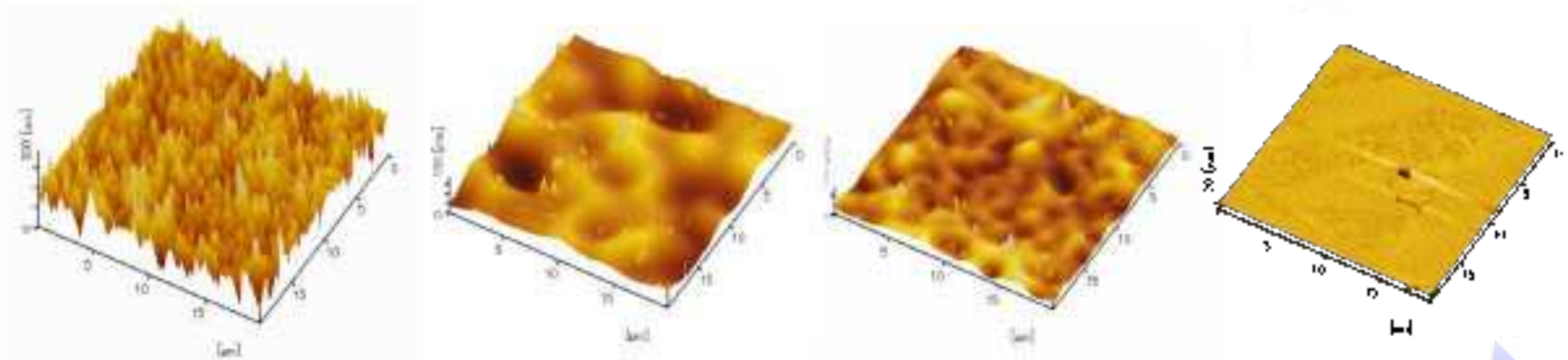
CVD diamond as grown on Si
Ra ～ 200 nm

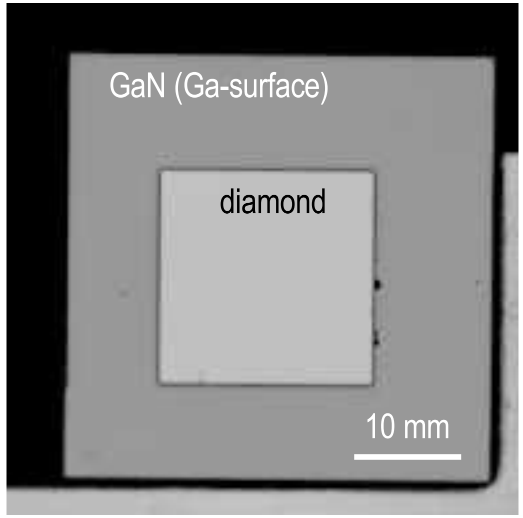
Optimized GCIB conditions

- Gas: Ar-SF6, He-SF6
- GCIB 30keV, 10^{14} ～ 10^{16} ions/cm^2

Fine polishing

RMS:~50 nm Ra: ~40 nm → RMS:~25 nm Ra: ~20 nm → RMS:~10 nm Ra: ~8 nm → RMS:~3 nm Ra: ~0.5 nm





SAM image of CVD diamond bonded to GaN by extended SAB with 10 nm Si nano-adhesion layer

Industry – University Collaboration

Institute for Advanced Micro-system Integration

一般社団法人
電子実装工学研究所
Institute for Advanced Micro-system Integration

URL http://www.imsi.jp/

- Founded in December 1997 by 11 semiconductor enterprises. Currently 41 company members run the 8th stage (3 years for each stage).
- Scope
  - Promotion of R&D for next generation
  - Global communication and standardization
  - Networking researchers and engineers
  - Cooperation with academia (Contract research)
- Project working group
  - WG1- High speed signal transmission system
  - WG2 - SAB - Room temperature bonding
  - WG3 - GaN power module integration
- Research committee
  - Application of Deep-Learning Concept on electronic systems.
  - Innovative Interface Bonding Technology - SAB

URL http://www.imsi.jp/ Since 1997

ImSI

2021.10

Institute for Advanced Micro-system Integration

一般社団法人

電子実装工学研究所

Institute for Advanced Micro-system Integration

TOSHIBA Panasonic NEC

KIOXIA Fuji Electric SONY

NTT SHINKO OLYMPUS

TAIYO YUDEN muRata INNOVATOR IN ELECTRONICS SUMITOMO ELECTRIC Nikon

KYOCERA AGC azbil Denka LINTEC Linking your dreams

Hitachi High-Tech NICHIA ADAMANT Namiki NLM

ALPHA DESIGN CO.,LTD. YAMAHA Yamaha Robotics Holdings Co., Ltd. ACCRETECH D-Process CMP,Bonding,Grinding Total solution

EVG TEL TOKYO ELECTRON Canon CANON ANELVA CORPORATION ME Ayumi INDUSTRY CO.,LTD.

SUSS MicroTec bondtech LAN Nidec NIDEC MACHINE TOOL

SAB equipment manufacturers

Standard SAB

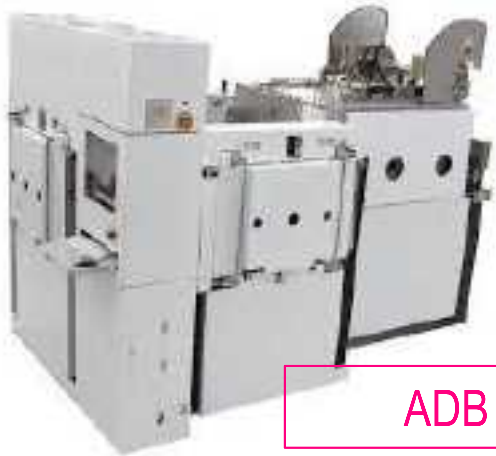
NIDEC MACHINE TOOL

bondtech

Plasma AB

Standard SAB

Modified SAB



ADB

Canon

CANON ANELVA CORPORATION

Ayumi

Standard SAB

LAN

Standard SAB

Modified SAB
OLED sealing

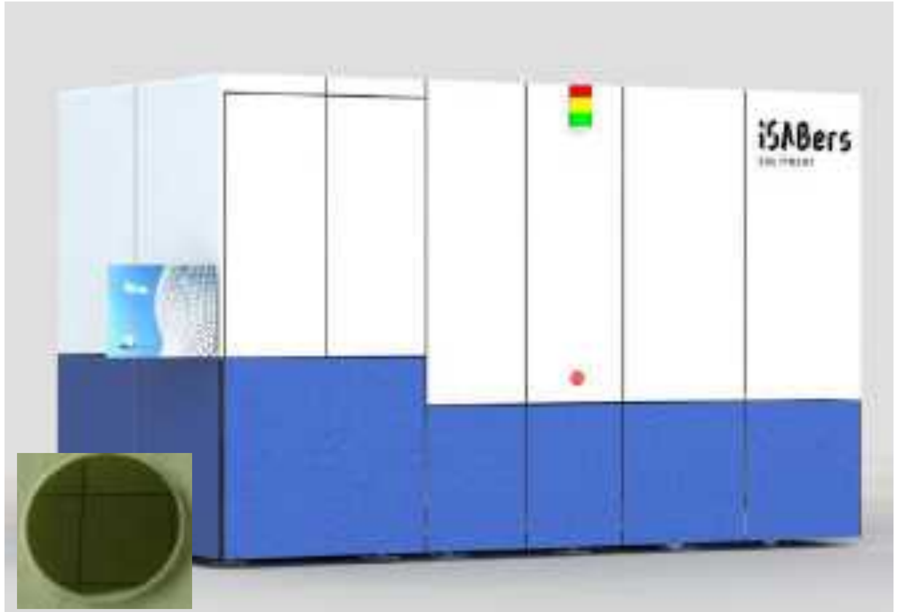
Standard SAB

ADB

天津中科晶禾电子科技有限责任公司

SABers Co.,Ltd.   Dr. Fengwen Mu (母风文)

- 核心产品：室温晶圆键合设备&低温烧结互连设备&半导体材料



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海内存知己，天涯若比邻

开拓和建立科技合作

■ 1988年-上海冶金所

～32年前第一次到中国参加 日中科学技术交流协会在 中国科学院上海冶金研究所 组织的“Sino-Japanese Symposium on Metal Physics and Physical Metallurgy”的学术会议

Japan-China Symposium on Interface and Bonding of Dissimilar Materials Tokyo, 1990

■ 1990年-东京

左より、諸住正太郎先生(東北大)、坂田君子先生(金材研)、筆者、橋口隆吉先生、石田洋一先生(東大)

■ 1993年-沈阳金属所

■ 1995-1997年-中国科技大学

和黄文浩教授共同指导 博士生
-褚家如（现中科大教授）

开拓和建立科技合作

■ 2003年-从东京大学先端技术研究所牵头在无锡设立交流机构

■ 2005年-东京大学无锡代表处

～2005年从东京大学工学院牵头在无锡设立东京大学无锡代表处开展和中国的产学研合作。

开幕式@无锡, 2005年11月4日

■ 2009年-东京大学国际产学研合作中心

～2009年在无锡设立东京大学国际产学研合作中心， 开展中日间在半导体、物联网、环境和其他工程领域的产学研合作。

第二期合作协议@东京, 2009年6月

开拓和建立科技合作

■ 2003-2014年-产学研交流及共同研究

東京大学 THE UNIVERSITY OF TOKYO
EcoDeNet ECOPAC Research Institute
无锡新区

Eco-design
MEMS, IC Design & Devices
IC Packaging MEM-IC Integration
Quality Control
Green IC, Green MEMS Sensor Network etc…
Packaging Materials
Electroplating …
Solder paste etc.

FUJITSU
JAPAN PURE CHEMICAL
SMIC


UV/VIS Spectrophotometer U-2900

MINAMI Co.,Ltd. Printing Technology

中国科学技术大学 University of Science and Technology of China
上海交通大學 SHANGHAI JIAO TONG UNIVERSITY
清华大学 Tsinghua University
IMECAS 中国科学院微电子研究所 Institute of Microelectronics of Chinese Academy of Sciences
Opticoat
CIT-CHINA
中国物联网研究发展中心（筹）
中国科学院物联网研究发展中心
江苏物联网研究发展中心




ICP-OES SPS-8000


Ball Placer MK-BP2000

Reflow Oven MKR-1200

USHIO USHIO LIGHTING


甩胶机

光刻机

■ 2011-2016年：中国科学院微电子所

2011. 6

同东大师生访
问微电子所

2011.10

在无锡东大代表处
和微电子所与物联
网中心技术交流

2012. 2

微电子所访
问东京大学

2012.7

第二届UT Eng- CIT-China技
术研讨会（无锡）

2012.12

受聘微电子所
“荣誉教授”

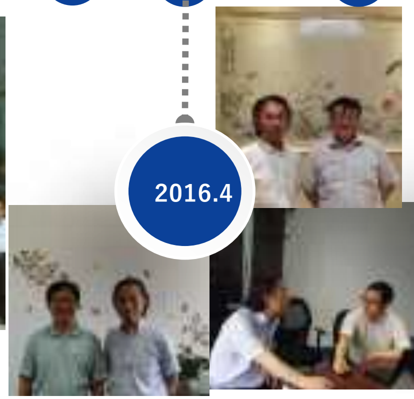
2013.9

参加第三届中日信息及电
子材料研讨会

2014. 4

协助02专项副总师王
曦院士访问东京大学

2016.4



获中科院国际访问学者计划资助
提案SiC高温压力传感器研发新方案

2016.9

第三届全球传感器论
坛并做大会特邀报告

2016.10

协助02专项叶甜春
总师访问东京大学

■ 2017年-2021年：微电子所昆山分所

2017.10

铂催化甲酸处理铜及氧化银粉低温烧结项目提案及立项

2018.2

昆山市高新区人才奖励大会

2018.4

派研究生赴日联合培养

2018.4

与华为技术有限公司交流并做报告

2018.4

与微电子所续聘荣誉教授

2019.1

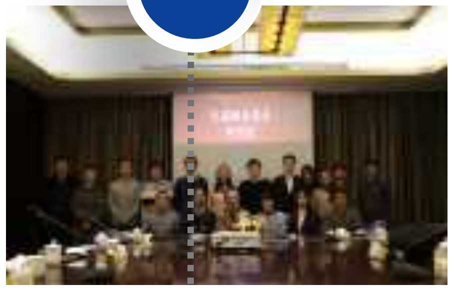
与昆山维信诺科技有限公司签署联合实验室协议

2019. 7

参加第二届亚太碳化硅及相关材料国际会议并做邀请报告

2019.10

在昆山组织国际专家工作室校企对接会

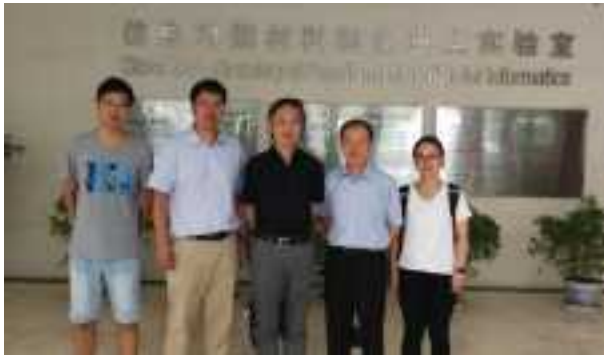


2019. 12

在昆山组织低温键合研讨会

国内院校合作交流

和国内各高校院所进行合作交流，为所需 **共性关键技术** 提供咨询及指导并探讨合作



中国科学院上海微系统研究所

复旦大学

清华大学

西安交通大学

中北大学

学会及联盟的交流

IEEE ELECTRONICS PACKAGING SOCIETY　JIEP　ICEP 2018

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