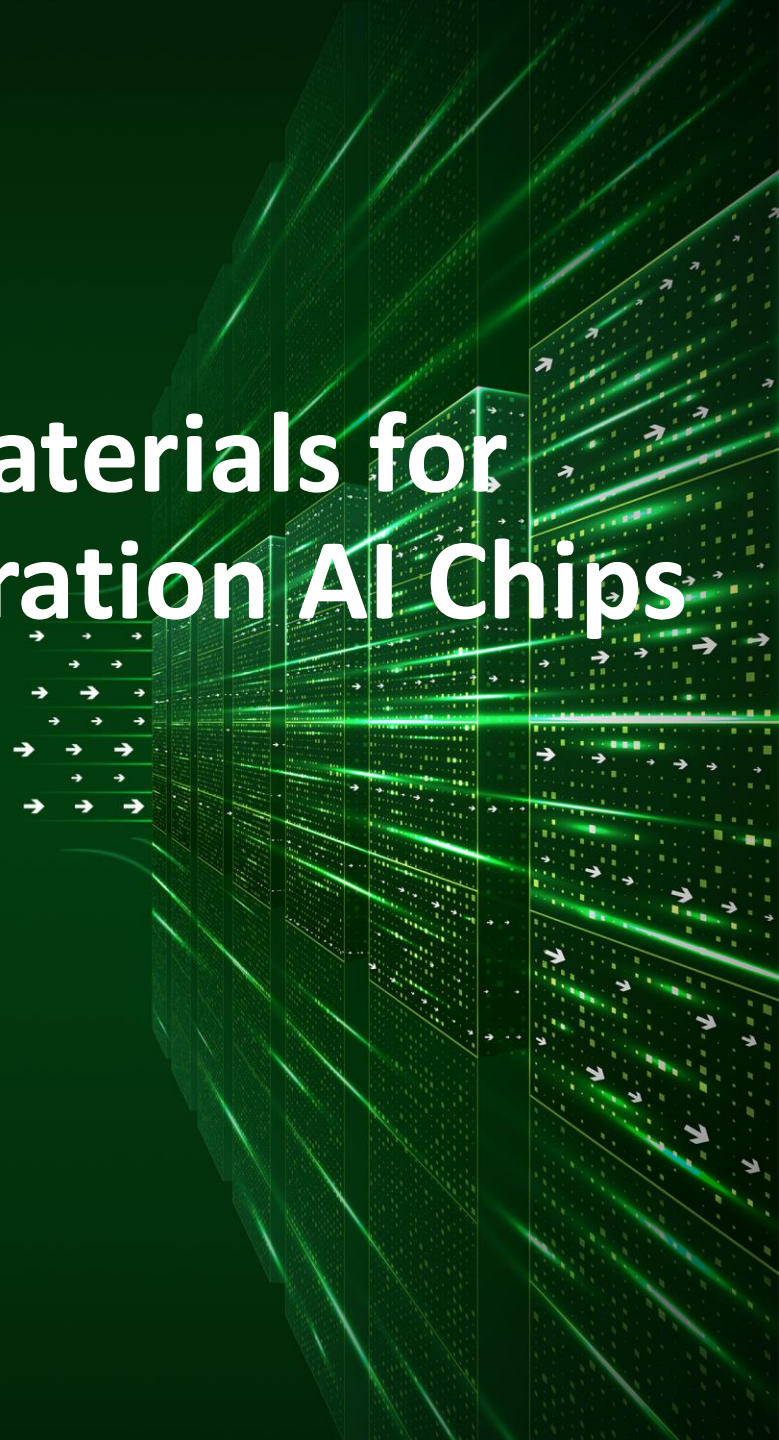
Investigation of Diamond-Based Materials for Direct Liquid Cooling of Next-Generation AI Chips

Nick Liu *Thermal Engineer, Wiwynn*

Jake Hsieh *Assistant Technical Manager, Wiwynn*



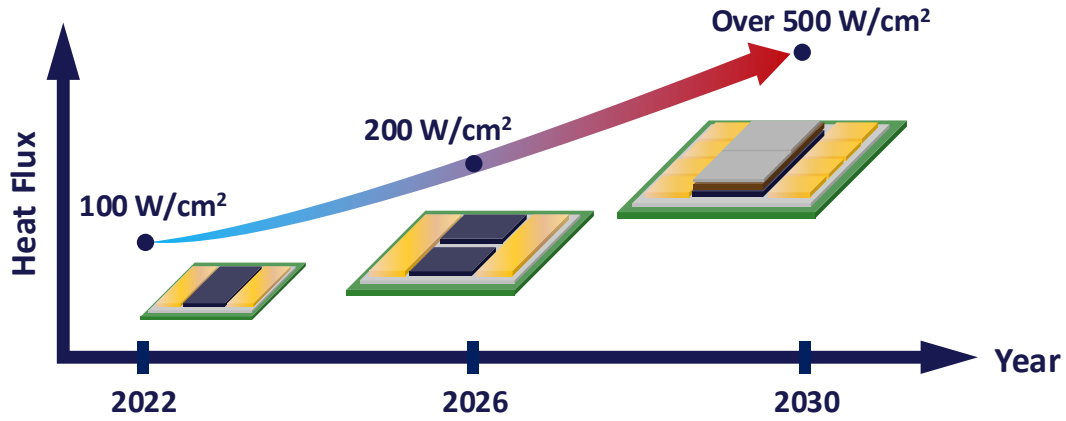
OCP FUTURE TECHNOLOGIES SYMPOSIUM

October 14, 2026
San Jose, California

Rising Chip Heat Flux Demands Lower Thermal Resistance

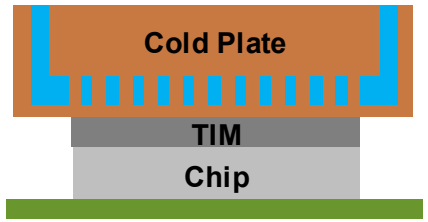
Background

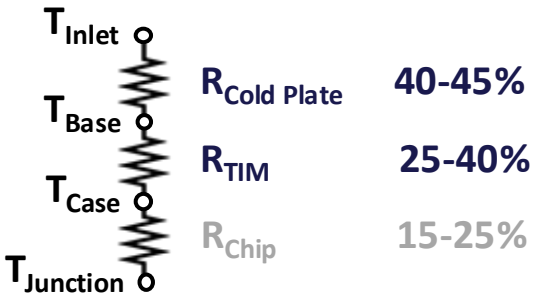
- Advanced packaging may push chip-level heat flux **beyond 500 W/cm²**
- **Minimizing R_{th}** is key for next-gen chips



Purpose

- **Cold plate** & **TIM** drive 65–85% of total R_{th}
  1. **High-conductivity material** lowers $R_{Cold\ Plate}$
  2. **Direct bonding** reduces R_{TIM}





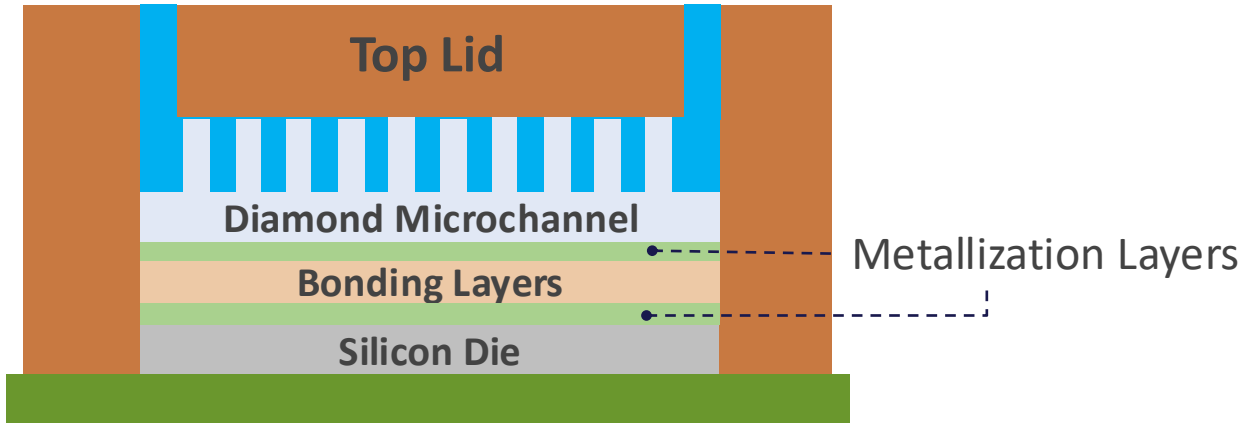
Diamond-Based Materials Potentially Improve Performance

- Diamond-based materials conduct heat better than copper
- Closer CTE match to silicon (CTE ~2.6 ppm/K) enables potential direct bonding
- SCD has the highest thermal conductivity, selected as the starting point

Material	Single Crystal Diamond	Diamond Copper	Diamond Silicon Carbide	Copper
Thermal Conductivity (W/m·K)	>2,000	600-900	500-800	~400
CTE (ppm/K)	~1.0	6.0-9.0	2.0-4.5	~17.0
Density (g/cm^3)	~3.5	5.0-6.0	3.30-3.45	~8.96

*CTE: coefficient of thermal expansion; SCD: single crystal diamond

Direct-Bonded Diamond Microchannel on Silicon

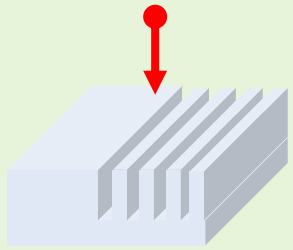


Metallization Layers
(Nanoscale Ti/Ni/Au stack)

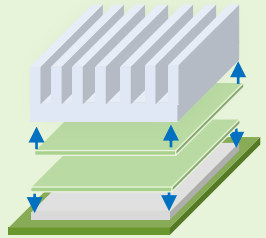
Bonding Layer
(Microscale Indium)

Metallization Layers
(Nanoscale Ti/Ni/Au stack)

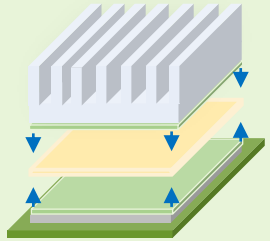
Experimental Setup Procedure



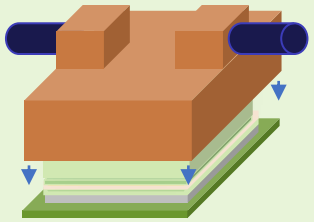
1. Laser-Cut Microchannels



2. Apply Metallization Layers



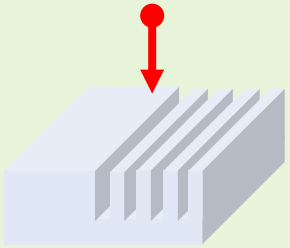
3. Reflow Indium for Bonding



4. Assemble Top Lid

Direct-Bonded Diamond Microchannel on Silicon

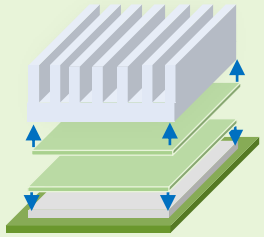
Experimental Setup Procedure



1. Laser-Cut Microchannels

Laser-cut SCD with microchannels:

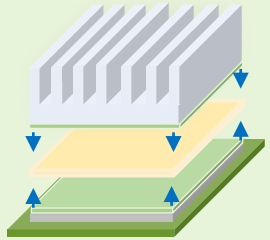
- Fin width & gap: 0.1 mm
- Fin height: 1 mm
- Base thickness: 0.5 mm
- Microchannel area: 32.2 x 25.7 mm^2



2. Apply Metallization Layers

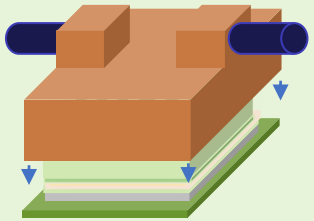
Apply metallization layers onto diamond & Si:

- Ti — Adhesion
- Ni — Diffusion Barrier
- Au —Wetting



3. Reflow Indium for Bonding

- Reflow indium solder
- Controlled temperature & pressure
- Bond diamond onto silicon

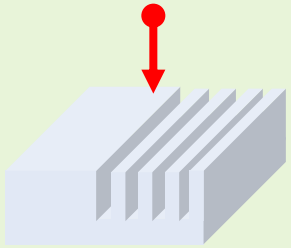


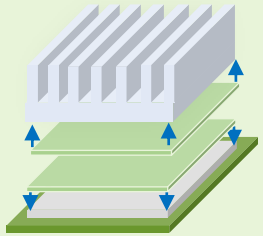
4. Assemble Top Lid

- O-ring seals coolant path
- Secure lid onto silicon TTV with screws

Direct-Bonded Diamond Microchannel on Silicon

Experimental Setup Procedure



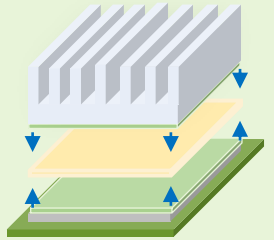


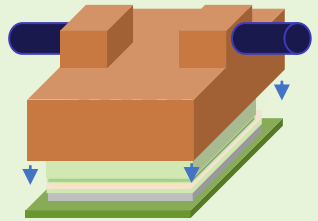
2. Apply Metallization Layers

Metallization Layers

- **Adhesion:** Ti improves metal adhesion to diamond/Si
- **Diffusion Barrier:** Ni prevents solder interdiffusion and reaction
- **Wetting:** Au enhances solder wettability, prevents oxidation

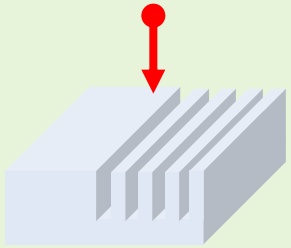
✓ **Ti/Ni/Au enable reliable, low R_{th} bonding**

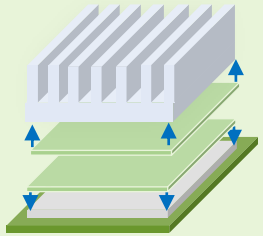


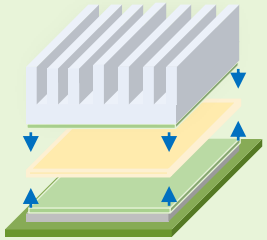


Direct-Bonded Diamond Microchannel on Silicon

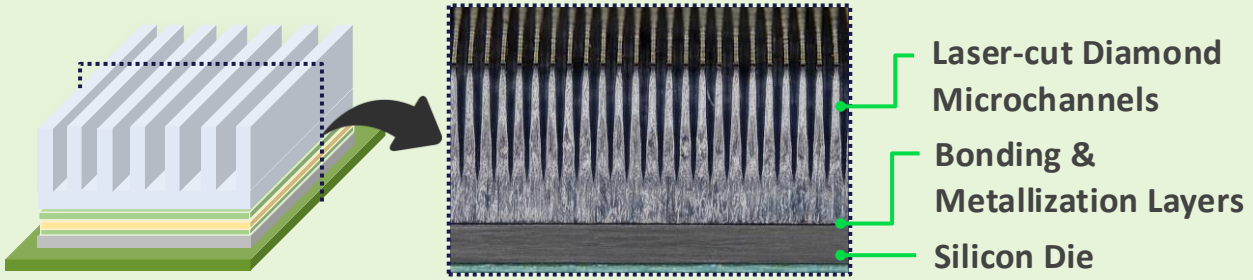
Experimental Setup Procedure

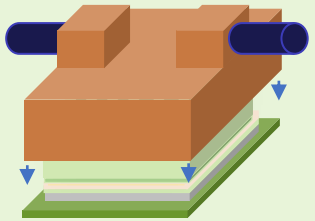






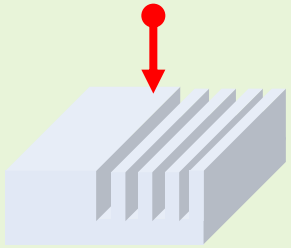
3. Reflow Indium for Bonding

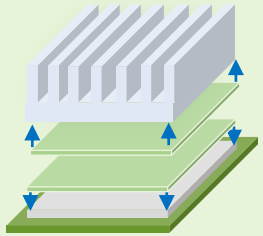


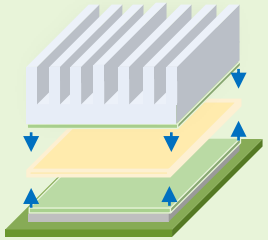


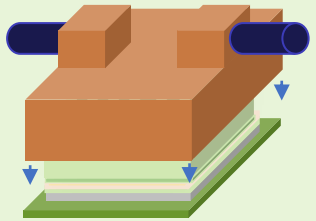
Direct-Bonded Diamond Microchannel on Silicon

Experimental Setup Procedure

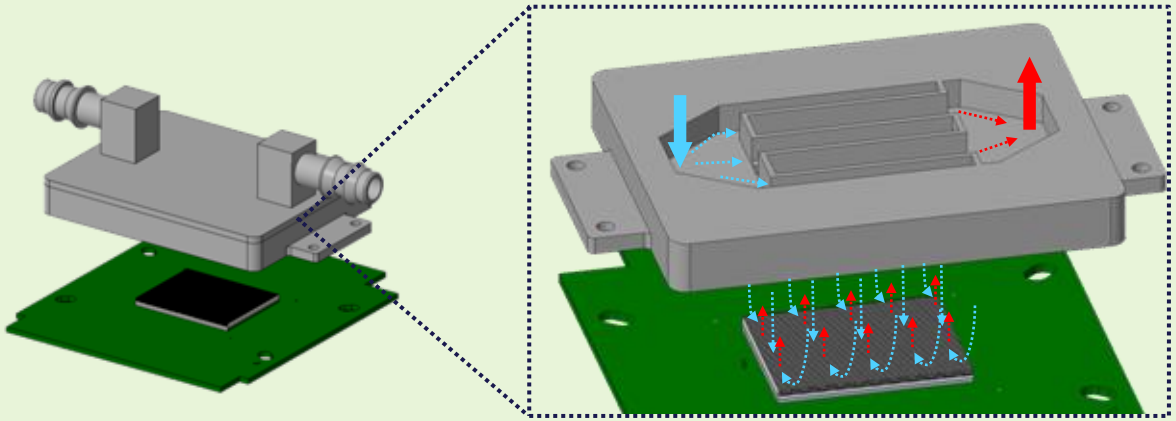








4. Assemble Top Lid



Direct-Bonded Diamond Microchannel Cooling Reduced Over 30% R_{th}

- At 360 W/cm², R_{th} was reduced by 38.2% vs. baseline (59.5% in simulation)
- Simulation-test gap likely due to interfacial R_{th} from non-ideal bonding quality

Cooling Solution	 Copper Cold Plate+ PCM TIM (Baseline)			 Direct-Bonded Diamond Microchannel Cooling		
Heat Flux (W/cm²)	**240**	**300**	**360**	**240**	**300**	**360**
Power (W)	2,000	2,500	3,000	2,000	2,500	3,000
Junction Max Temp. (°C)	84.3	95.0	**106.2**	64.9	70.8	**77.1**
R_{th} Junction to Inlet (°C/W)	0.0272	0.0260	**0.0254**	0.0175	0.0163	**0.0157 (-38.2%)**

*Test Conditions: PG25, Inlet 30°C, Flow rate: 2 LPM/kW

*Silicon thermal test vehicle with 9 Tjunction measurement points recorded (Heating area: 32.2 x 25.7 mm²)

Future Work

Collaborate with the community and industry to:

- Improve bonding quality to lower interfacial R_{th}
- Explore other diamond-based materials and other package-level cooling approaches
- Scale up the manufacturing process for next-gen AI chips

Learn More

- Visit us at Booth C74 to see our demos
- Wiwynn's White Paper: Advanced Microchannel Material - Diamond Composite Thermal Solutions

Scan for more Wiwynn's whitepapers

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