Preliminary study on ultra-light composite cold panel

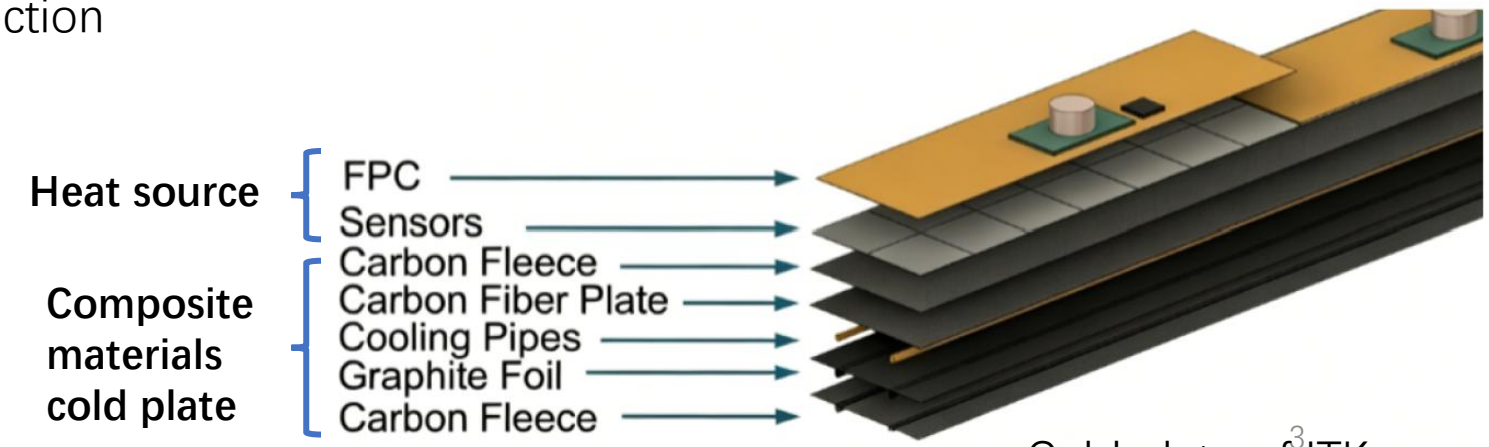
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From IHEP
@CEPC2026
202610

Content

- Motivation
- Mold design
- Conductivity preliminary test
- Cold panel preliminary test
- Conclusion

Motivation

- Some collider sub-detectors need a cold panel
  - Cool sensor efficiently
  - **Low material budget** of cooling panel
  - ITK/OTK, TPC, Cherenkov detector and so on
- Cold panel characteristic (initial goal: better than aluminum)
  - **Density <2.7 g/cm^3**
  - **Thermal conductivity : > 200 W/m*K** —— hope better than copper: > 390 W/m*K
  - Thin thickness of heat transfer surface of cold panel: <1 mm, More focused on the in-plane thermal conductivity rather than the thickness direction
- Cold plate of ITK:
  - Thickness: ~0.3 mm
  - Cooling pipes:
  - Cold plate: CF+graphite foil



Cold plate of ITK

Material in this preliminary study

Carbon fiber

- PAN-based CF: **M40J**, thermal conductivity along the fiber direction 10.5 - 155.7 W/(m·K), the other direction(vertical fibers): <5 W/(m·K)
- MPCF (Mesophase Pitch-based Carbon Fiber): >600 W/(m·K)

Cooling tube

- **Aluminum tube**: D2X0.2
- Titanium tube: much stronger, 0.2mm thickness is not a standard size

Graphene

- Thickness: 25um, thermal conductivity in plane: ~1400 W/(m·K)
- Other thickness

Glue

- **Epoxy resin**
- Phenolic resin, diaminopropyl resin: **good radiation resistance performance**

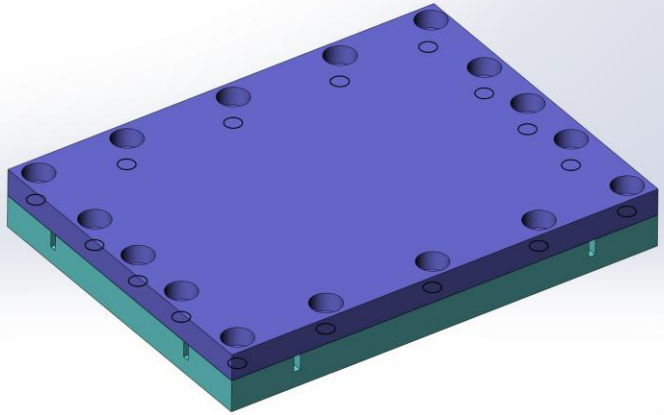
Table: graphene properties of diff. thickness

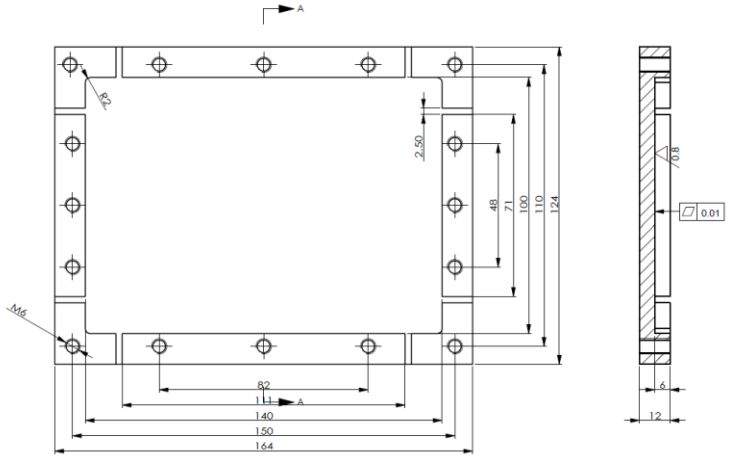
性能参数	HXGTS-10	HXGTS-50	HXGTS-70	HXGTS-100	HXGTS-150	HXGTS-200	HXGTS-300	测试方法
厚度(μm)	10±1	50±5	70±7	100±10	150±15	200±20	300±30	ASTM D374
纵向导热系数	≥19	≥19	≥19	≥19	≥19	≥19	≥19	ASTM E1461
综合导热系数（W/m·K）	≥1500	≥1400	≥1300	≥1300	≥1200	≥1050	≥800	ASTM E1461
综合热扩散系数 (mm^2/s)	≥850	≥800	≥750	≥750	≥700	≥600	≥500	ASTM D5470
密度（g/cm^3）	2.0±0.1	2.0±0.1	2.0±0.1	2.0±0.1	2.0±0.1	2.0±0.1	2.0±0.1	ASTM D792
比热容（J/g·K）	0.85	0.85	0.85	0.85	0.85	0.85	0.85	ASTM E1269
拉伸强度（MPa）	35	35	35	35	35	35	35	GB/T 1040.3-2018
抗弯折次数(R1/180°)（times）	> 100000	> 10000	> 5000	> 1000	>500	>100	>10	ASTM F152
导电系数（s/m）	2x10^5	2x10^5	2x10^5	2x10^5	2x10^5	10^5	10^5	GB/T1551-2009

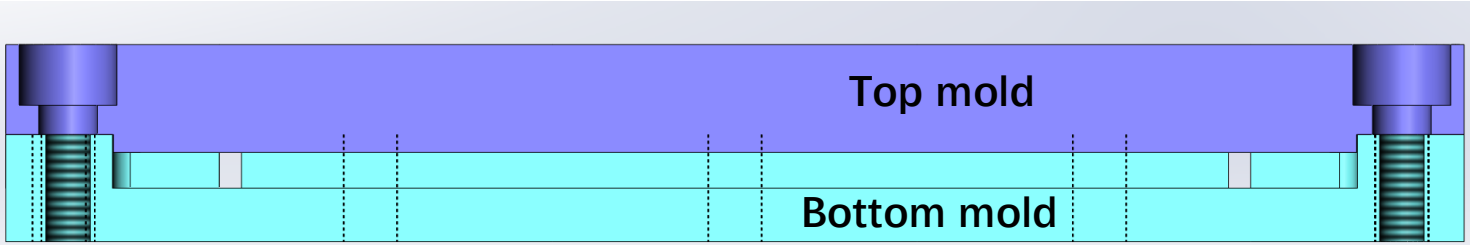
The Materials mainly come from market that is easy purchasing.

Mold design

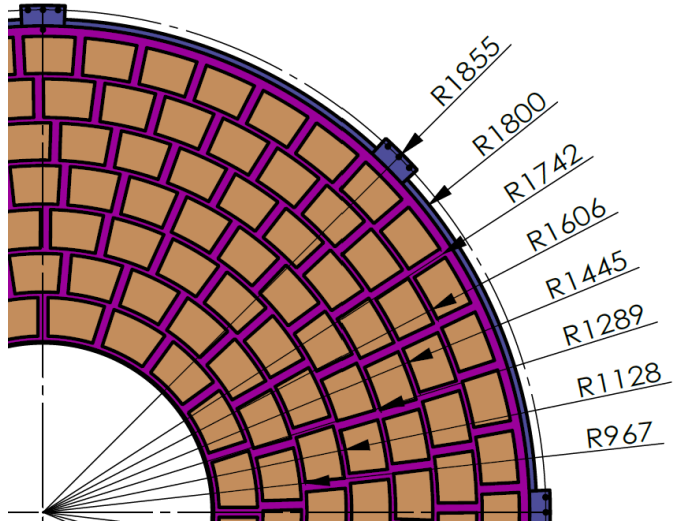
- Base on TPC module size: sample size 100X140mm
- Pressure adjustment: thickness of silicone sheet
- 2 mm aluminum tube



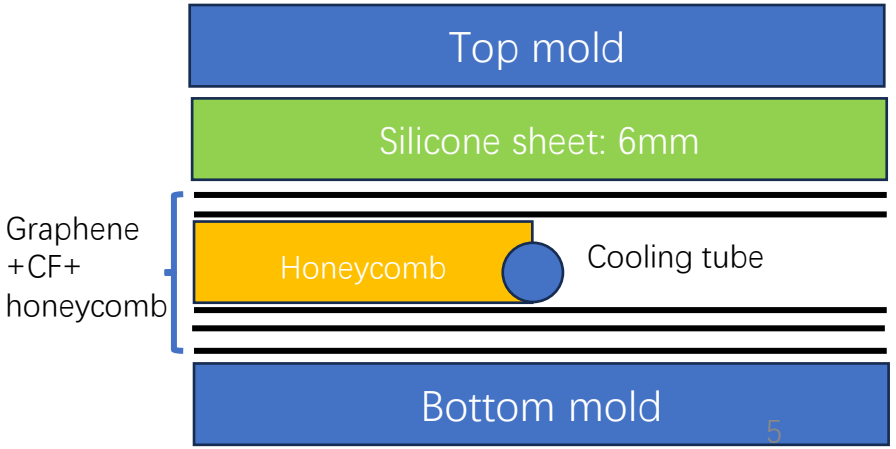




Mold design

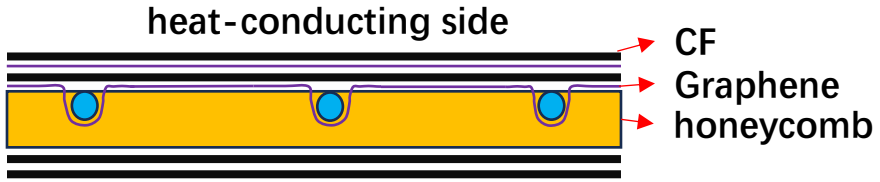


TPC end flange size

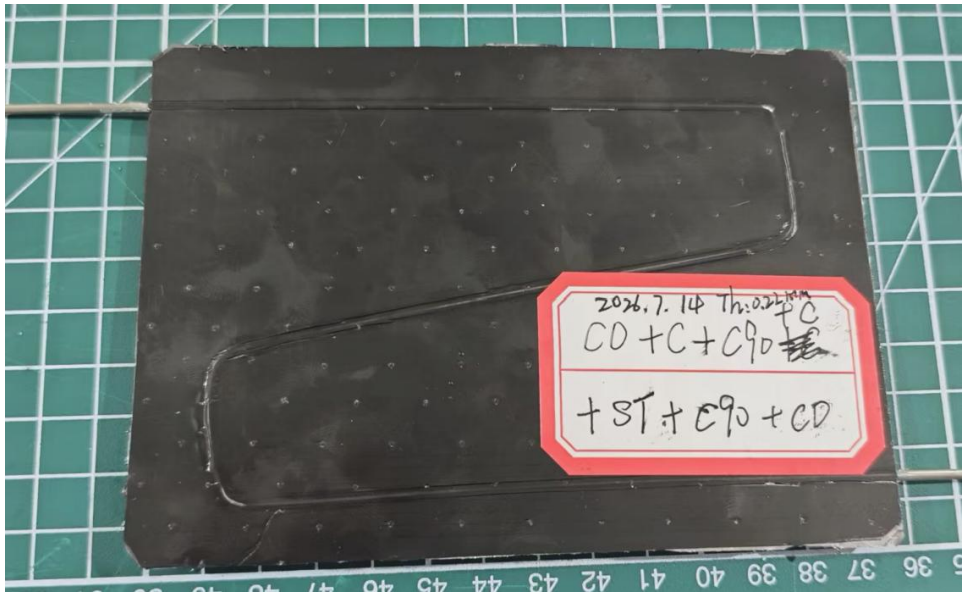


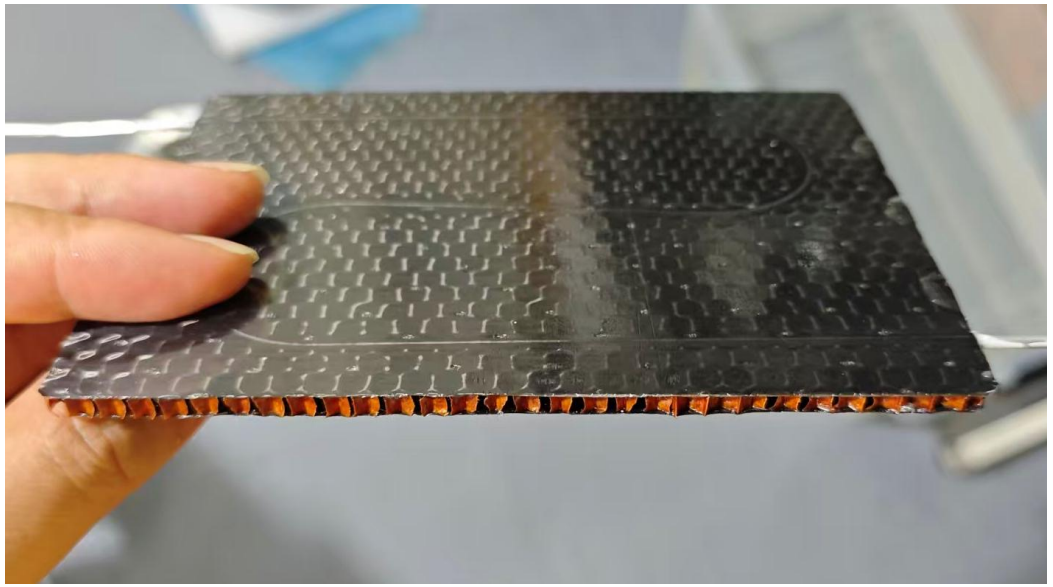
First samples produced

- The thickness could be optimized according to the requirements.
- Need to understand the in-plane thermal conductivity of the cold sheet.







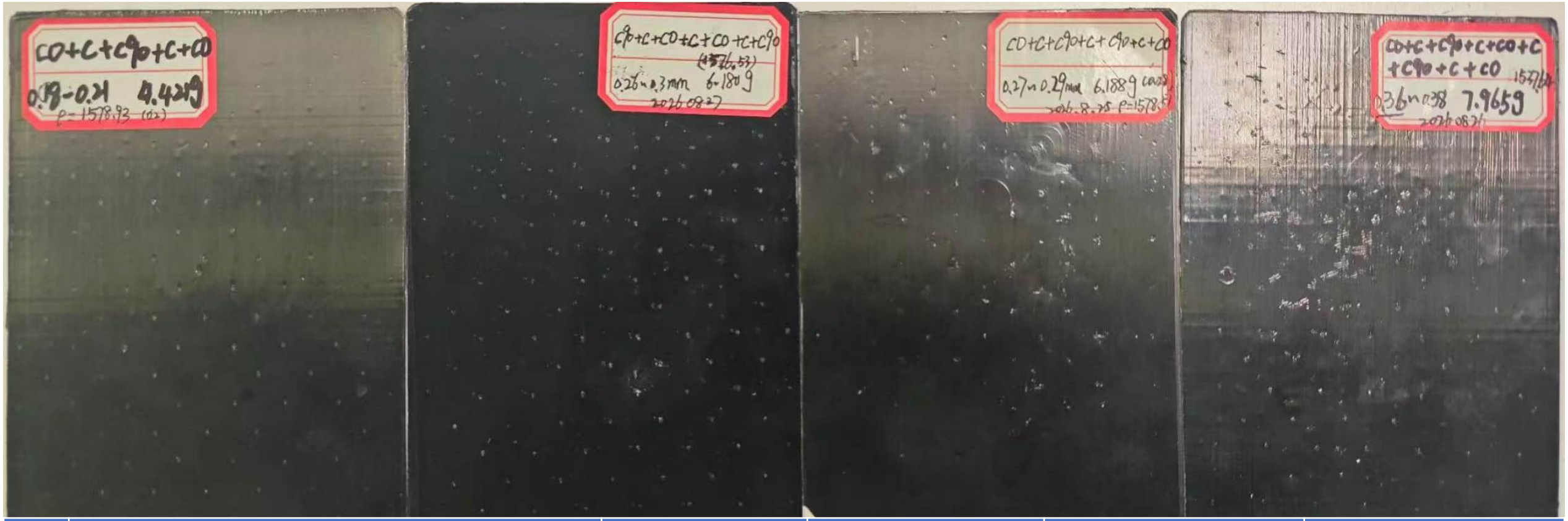


Cold sheet (CF+Graphene)
- Thickness: ~0.3mm
- heat-conducting sheet
- Density: ~1.6 g/cm^3

Cold sheet with cooling pipe:
- sheet thickness: ~0.3mm

Cold panel: Cold sheet with cooling pipe and aramid honeycomb panel:
- Panel thickness: ~4 mm.
- heat-conducting sheet on the top: ~0.3mm
- Single-sided heat conduction
- Density: <0.4 g/cm^3

Cold sheet for thermal conductivity measurement



	layup sequence (CF60um+Graphene25um)	thickness (mm)	Weight （g)	Density(kg/m^3)	Thermal conductivity
1	C0+G+C90+G+C0	0.18~0.21	4.421	1578.93	?
2	**C90+G+C0+G+C0+G+C90**	0.26~0.30	6.180	1576.53	
3	**C0+G+C90+G+C90+G+C0**	0.27~0.29	6.188	1578.57	
4	C0+G+C90+G+C0+G+C90+G+C0	0.36~0.38	7.965	1537.64	

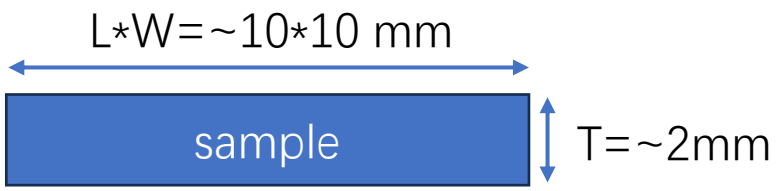
Cold sheet for thermal conductivity measurement

- GB/T 42919.4-2023 plastics-determination of thermal conductivity and thermal diffusivity- part 4: laser flash method: **also suited for composite material sample**
- Commercial products
- Our sample is too thin to measure the thermal conductivity

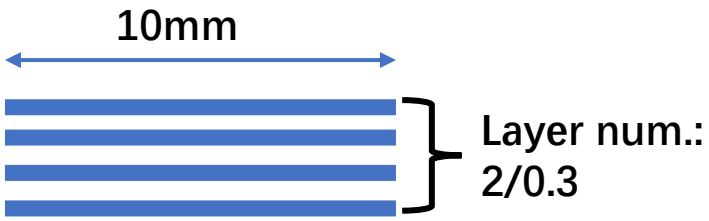




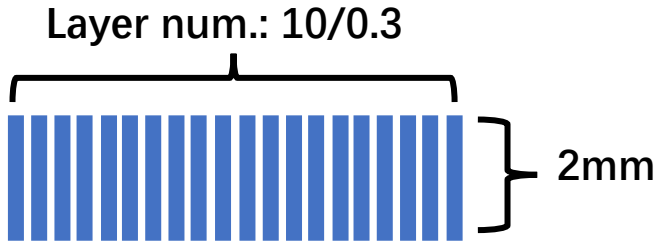
Commercial products and its sample house



Normal sample size



In thickness direction Thermal Conductivity sample



In plane direction thermal conductivity sample

Thermal conductivity measurement

Characteristic attenuation coefficient (m): how fast the temperature decays along the length.

$$m = \sqrt{\frac{hP}{\lambda A}} = \sqrt{\frac{2h(w+t)}{\lambda w t}}$$

when $w \gg t$

$$m \approx \sqrt{\frac{2h}{\lambda t}}$$

Where

$\boldsymbol{w}$: Width of sample

$\boldsymbol{t}$: *T*hickness of sample

$\boldsymbol{\lambda}$: Thermal conductivity

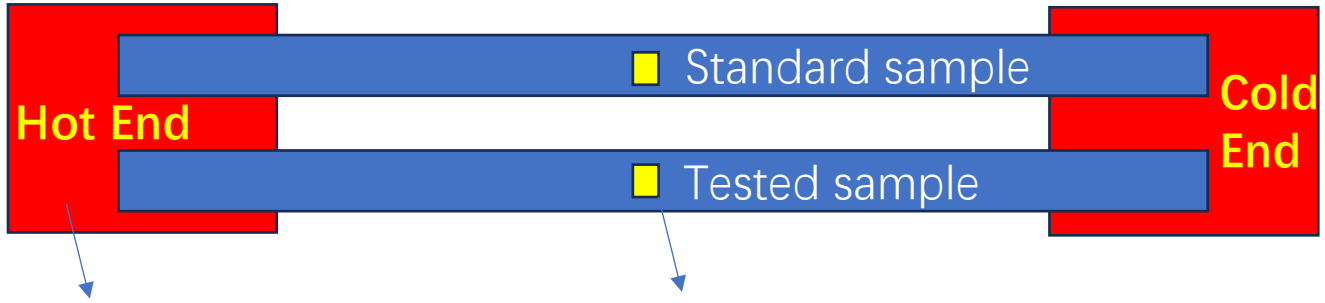
$\boldsymbol{h}$: Equivalent surface heat dissipation coefficient, including radiation and air conduction/convection.

Thermal conductivity measurement

Isothermal boundary midpoint thermometry

- Sample length: 100~150 mm， using same width
- TEC plate to get exact temperature: <0.1℃
- Only need to understand three position temperature:

- hot end: $\theta_h = T_h - T_{air}$
- Cool end: $\theta_c = T_c - T_{air}$
- Center point: $\theta_{mid} = T_{mid} - T_{air}$



Measurement model

$$m = \frac{2}{L} \cdot \operatorname{arcosh}\left(\frac{\theta_h + \theta_c}{2\theta_{\text{mid}}}\right)$$

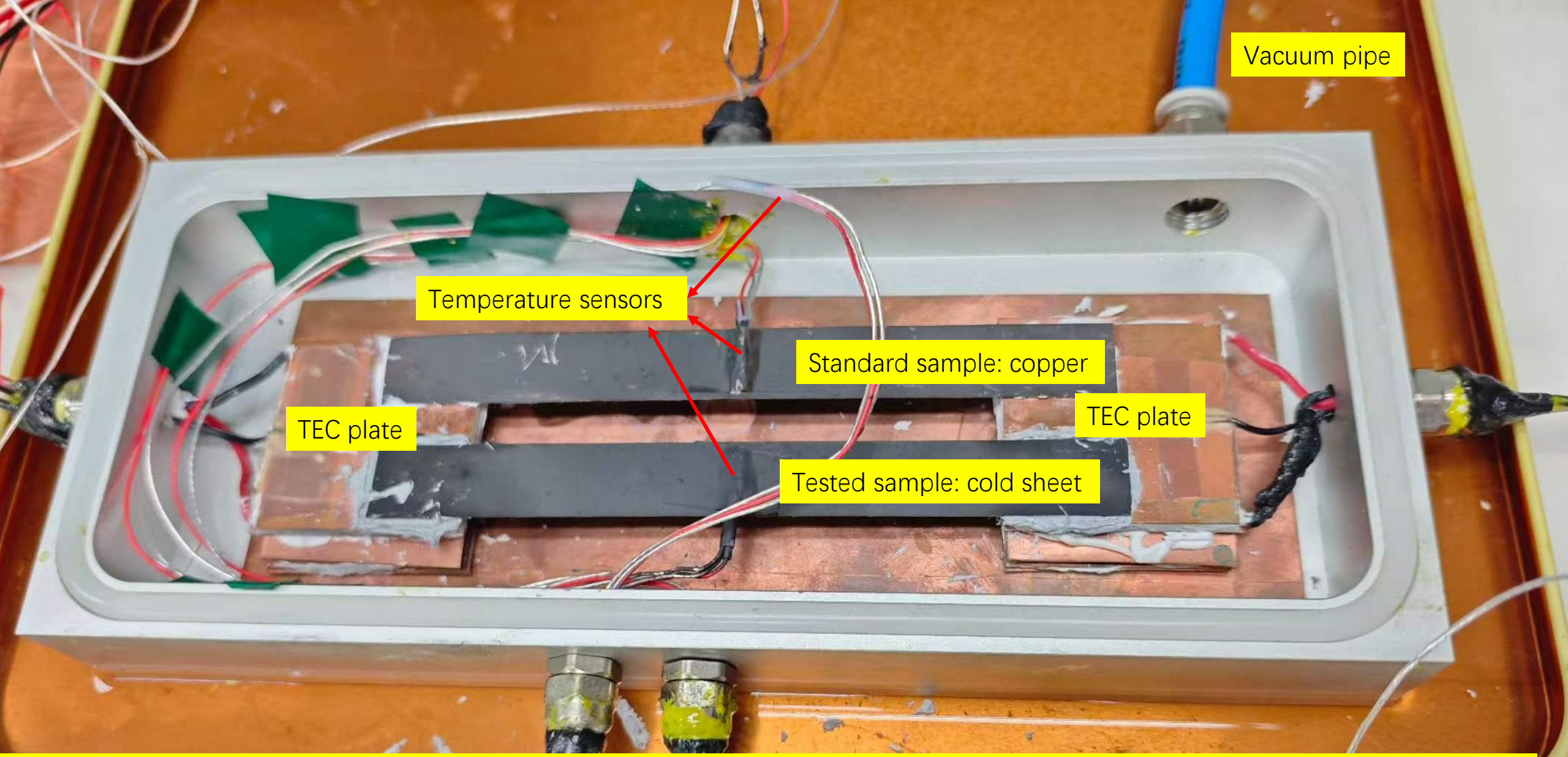
$$m = \sqrt{\frac{hP}{\lambda A}} = \sqrt{\frac{2h(w+t)}{\lambda w t}}$$

$$\lambda_x = \lambda_s \cdot \frac{t_s}{t_x} \cdot \frac{w + t_x}{w + t_s} \cdot \left(\frac{m_s}{m_x}\right)^2$$

when $w \gg t$

$$\lambda_x \approx \lambda_s \cdot \frac{t_s}{t_x} \cdot \left(\frac{m_s}{m_x}\right)^2$$

Thermal conductivity of tested sample (λx) could be obtained through already known standard sample conductivity (λs).



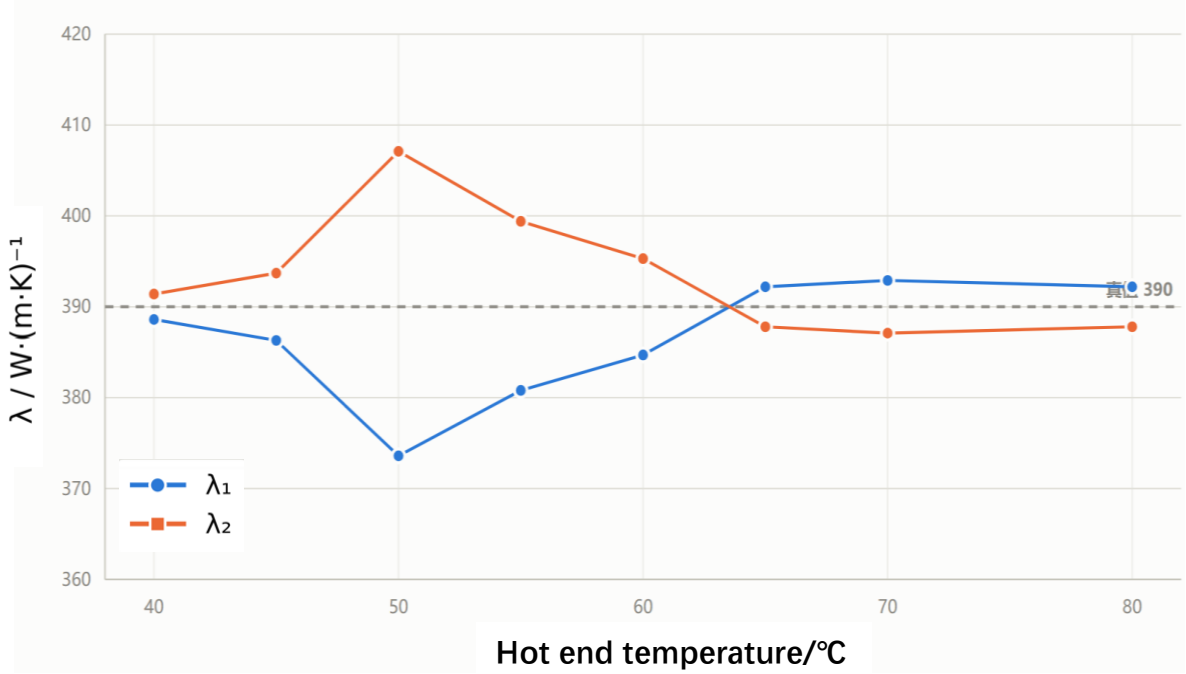
- The samples surface was sprayed with graphite to ensure same thermal radiation.
- Samples in vacuum environment
- Verify principle method worked: both samples are copper but different thickness.

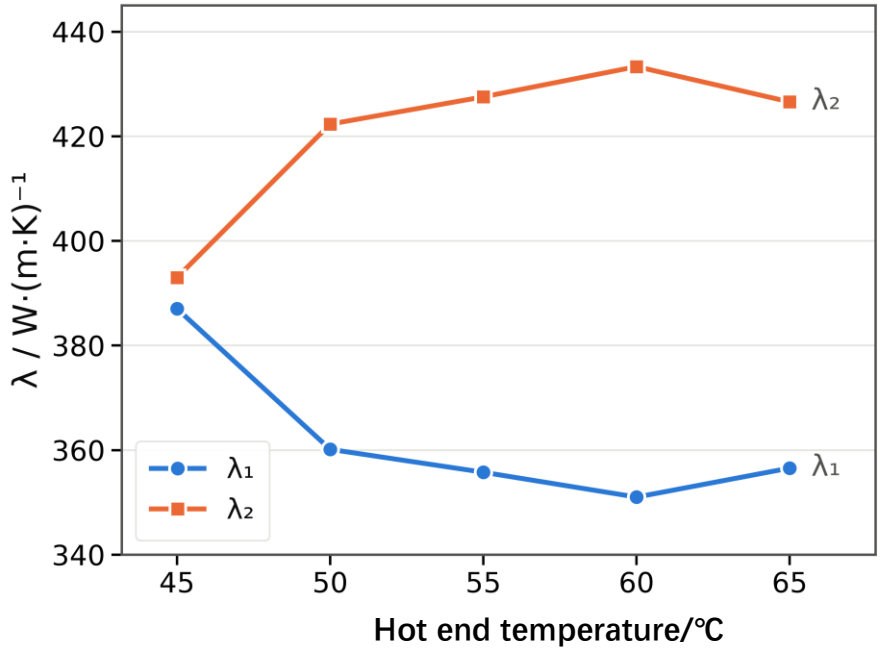
PID temperature control for TEC plate



Thermal conductivity measurement——Principle verification

- Standard samples:
  - Material: copper, 390 W/m*K
  - Different thickness



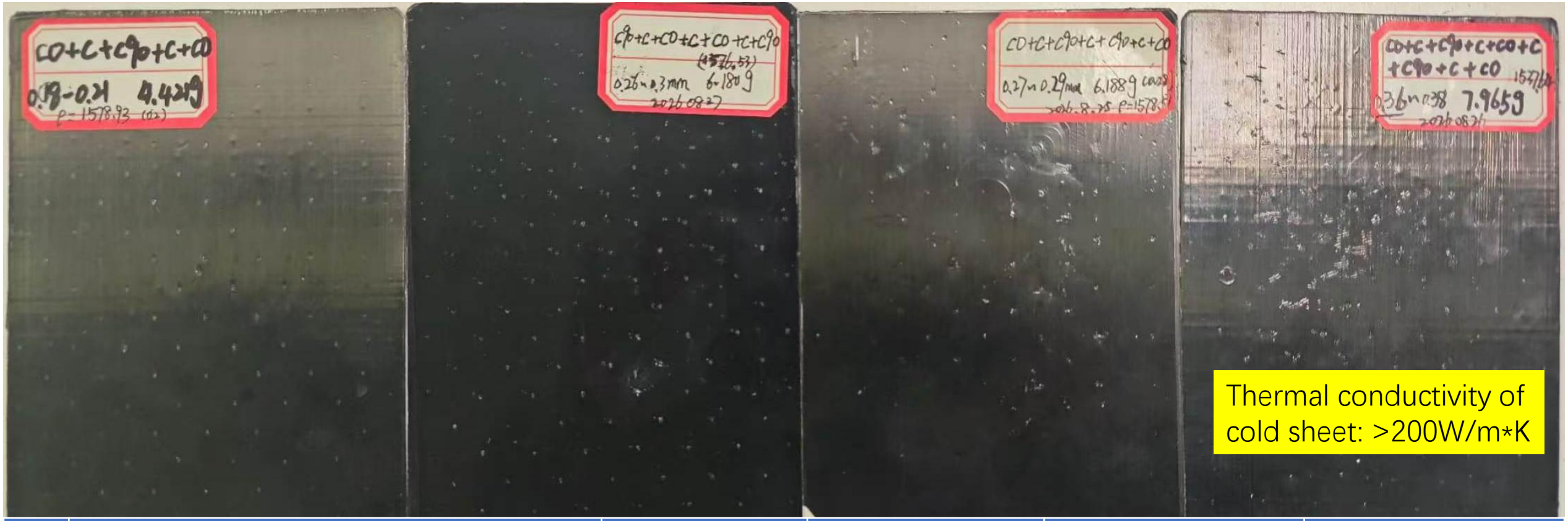


	Thickness of sample/mm	Result W·(m·K)⁻¹	Deviation/%
Sample1	0.1	393.7 ± 6.9	+0.9%
Sample2	0.2	386.4 ± 6.7	−0.9%

	Thickness of sample/mm	Result W·(m·K)⁻¹	Deviation/%
Sample1	0.4	362.1 ± 14.3	-7.8%
Sample2	0.2	420.6 ± 15.9	+7.2%

The result of principle verification looks not very good.

Cold sheet for thermal conductivity measurement

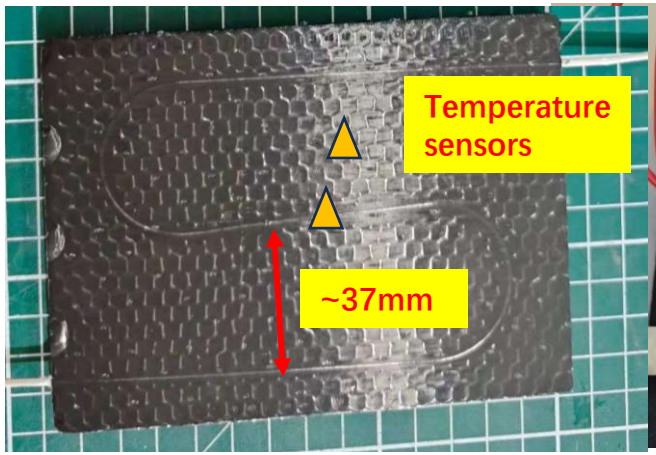


	layup sequence (CF 60um+Graphene25um)	thickness (mm)	Weight （g)	density(kg/m^3)	Thermal conduc. (W/m*K)
1	C0+G+C90+G+C0	0.18~0.21	4.421	1578.93	**259.29±1.77**
2	**C90+G+C0+G+C0+G+C90**	0.26~0.30	6.180	1576.53	—
3	**C0+G+C90+G+C90+G+C0**	0.27~0.29	6.188	1578.57	**333.32±1.74**
4	C0+G+C90+G+C0+G+C90+G+C0	0.36~0.38	7.965	1537.64	**281.68±7.94**

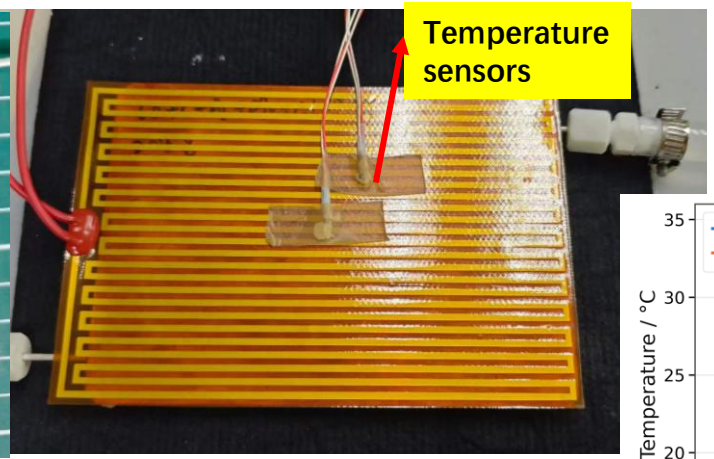
Cold panel preliminary test

	Voltage V	Current A	Resistance Ω	Power W	power density W/m^2	Point 1 temperature	Point 1 temperature
1	0	0	——	0	**0**	**15.94**	**15.72**
2	5.0	0.161	31.06	0.81	**57.86**	**16.38**	**16.11**
3	10	0.320	31.25	3.20	**228.57**	**17.83**	**17.50**
4	15	0.480	31.25	7.20	**514.29**	**20.35**	**19.86**
5	20	0.638	31.35	12.76	**911.43**	**23.83**	**23.09**
6	25	0.792	31.57	19.80	**1414.29**	**28.36**	**27.25**
7	30	0.947	31.67	28.41	**2029.29**	**33.82**	**32.27**

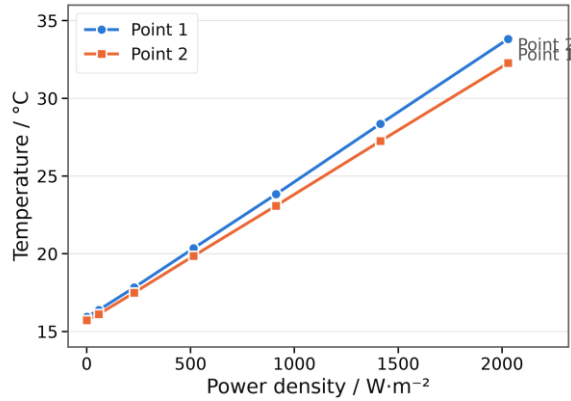
- Thickness of cold sheet: 0.3mm
- Distance between cooling pipes: 37mm
- Temperature of cooling flow: 15 ±1 ℃
- Velocity of cooling flow: unknow.
- Heat source: PI heating sheet
- Optimize: reduce distance between cooling pipes



Cold panel



Cold panel with PI heating sheet



Conclusion

- This is very preliminary study about the cold panel
  - Thermal conductivity of cold sheet could be larger than Aluminum's, >200W/m*K
  - Density of cold sheet is about 1.5 g/cm^3, cold panel <0.4 g/cm^3, lighter than Aluminum's
- A lot work to be done:
  - Exactly measure the thermal conductivity of the cold sheet
  - Improve the cold panel's thermal conductivity, larger than copper