Multiscale Modeling and Closure-Boundary Parameterization of Vapor–Liquid Coplanar Ultrathin Vapor Chambers

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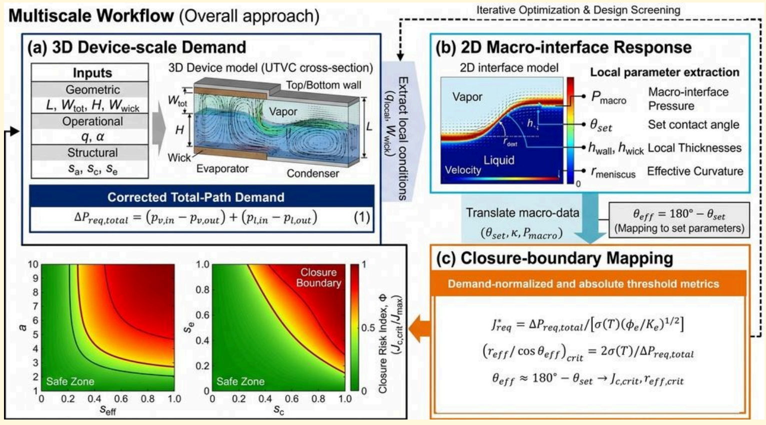
Presenter: Xiangwen Tan Keywords: UTVC, vapor–liquid coplanar structure, closure-boundary parameter, liquid-film management

Central message: wick width is a coupled hydraulic–thermal–interfacial–closure matching problem; 1.4–1.5 mm is the preferred window and 1.5 mm is the center solution.

1. Introduction

In ultrathin vapor chambers, wick width cannot be selected from thermal performance alone. Hydraulic demand, macro-interface morphology and closure accessibility evolve together; therefore the preferred width is identified by coupling device-scale demand, macro-interface response and closure-boundary metrics.

2. Multiscale framework



Corrected multiscale workflow: 3D total-path demand → 2D macro-interface response → closure-boundary mapping.

3. Corrected demand & closure variables

Corrected total-path pressure demand:

$$\Delta P_{req,total} = (p_{v,in} - p_{v,out}) + (p_{l,in} - p_{l,out})$$

Demand-normalized capillary requirement:

$$J^*_{req} = \Delta P_{req,total} / [\sigma(T)\cdot(\varphi_e/K_e)^{1/2}]$$

Effective contact-angle approximation:

$$\theta_{eff} \approx 180^\circ - \theta_{set}$$

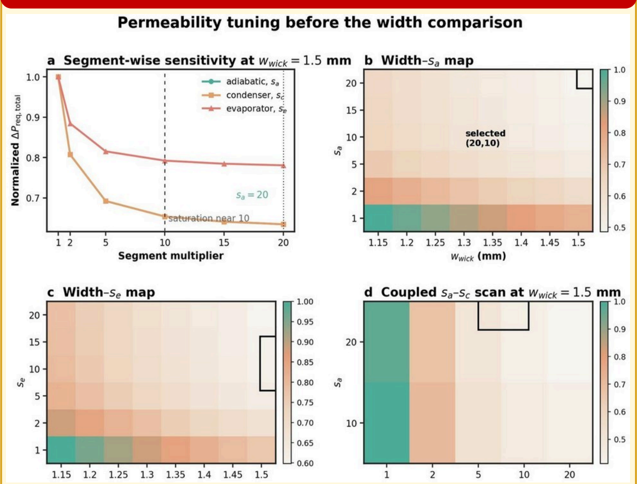
Derived thresholds:

$J_{c,crit}$ (critical capillary coefficient)
$r_{eff,crit}$ (critical effective pore radius)

4. Main settings used for comparison

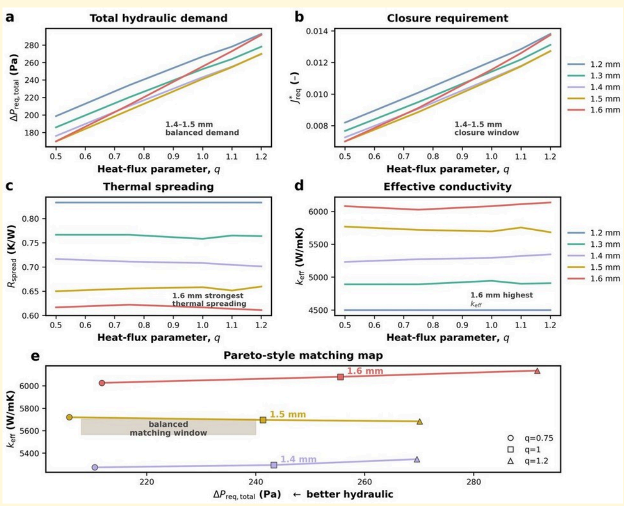
Setting	Value
L_e/L_a/L_c (mm)	3 / 2 / 5
W_total/H (mm)	4 / 0.4
K_e/K_a/K_c (m²)	5e−12 / 4e−12 / 1e−11
φ_e/φ_a/φ_c	0.65 / 0.60 / 0.65
Width scan w_wick (mm)	1.2 – 1.6
q (normalized)	0.5 – 1.2
Final tuning	s_a = 20, s_c = s_e = 10

5. Permeability tuning evidence



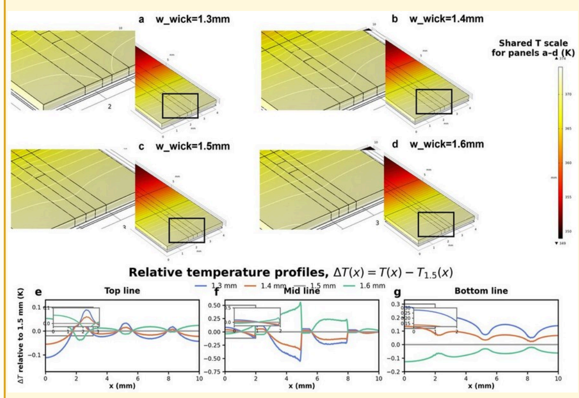
Segment-wise permeability enhancement reduces demand with diminishing returns; selected setting: s_a = 20, s_c = s_e = 10.

6. Hydraulic–thermal matching across widths (q = 1.0)



1.6 mm is thermally strongest; 1.4–1.5 mm are hydraulically preferable; 1.5 mm offers the best overall match.

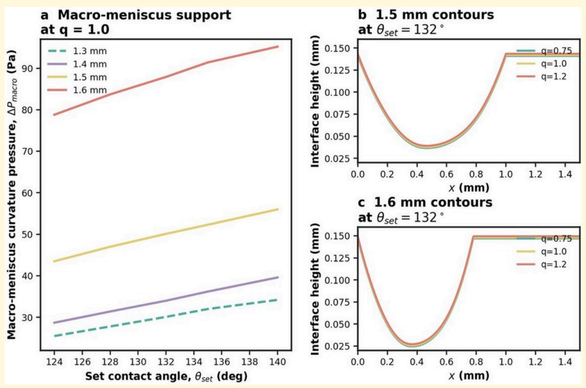
7. Representative thermal evidence (q = 1.0)



Thermal fields and ΔT(x) profiles consistently show the 1.6 mm layout as thermally favorable. However, the difference relative to 1.5 mm remains modest, so the final width selection should be governed by coupled hydraulic–closure matching rather than thermal spreading alone.

Relative ΔT(x) confirms limited thermal gain beyond 1.5 mm.

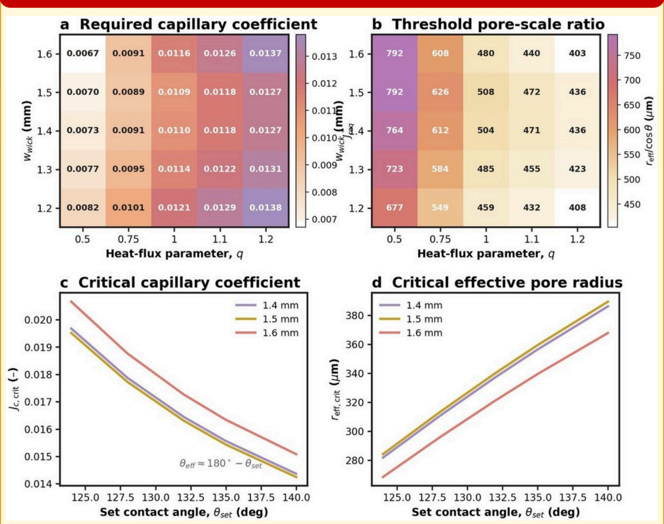
8. Macro-meniscus & liquid-film management



The 2D phase-field results are treated as macro-interface evidence. Wider wick layouts improve meniscus support and liquid-film accommodation, but this advantage must be interpreted together with the corrected total-path hydraulic demand.

Macro-interface support improves with width, but does not by itself define the optimum.

9. Stronger closure-boundary parameterization



After applying the effective-angle approximation, the wider 1.6 mm case shifts toward stricter $J_{c,crit}$ and $r_{eff,crit}$ requirements. This indicates reduced closure accessibility despite its stronger thermal and interfacial response.

1.6 mm imposes the strongest closure burden.

10. Conclusions

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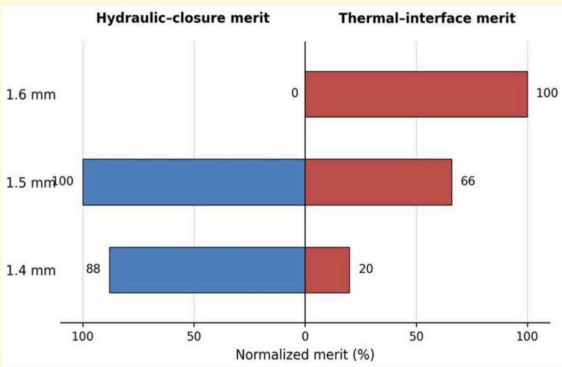
- Corrected total-path demand retains the adiabatic contribution.
- Permeability tuning supports s_a = 20 and s_c = s_e = 10.
- Thermal and hydraulic optima do not coincide.
- 1.6 mm is thermally strongest, but it also raises closure burden.
- 1.4–1.5 mm better preserve hydraulic and closure margins.
- 1.5 mm is the center solution of the preferred matching window.

12. Integrated summary



1.4 mm leans hydraulic–closure; 1.6 mm leans thermal–interface; 1.5 mm is the most balanced solution.

11. References

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The selected references cover UTVC confinement, vapor-core/wick optimization, wettability patterning, heterogeneous vapor–liquid channels and recent ultrathin chamber fabrication strategies.