組別: 熱流組

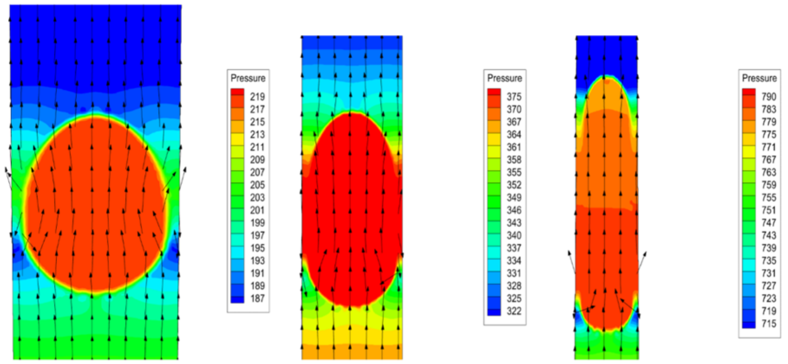
研究領域: 二相流熱傳 (Two-Phase Heat Transfer)、微尺度與微通道傳輸現象 (Microscale & Microchannel Transport)、電子與晶片散熱 (Electronics & Chip Cooling)、高功率微波與能量傳輸 (High-Power Microwave & Energy Transport)、數值模擬與傳輸物理建模 (Computational Transport Physics)、降階模型與資料驅動方法 (Reduced-Order Modeling & Data-Driven Methods)

實驗室(EE307): 傳輸與相變物理實驗室 Transport and Phase-Change Physics Laboratory

研究方向: (a) 二相流與微尺度相變之基礎傳輸物理(b) 微先進數值方法與物理導向模型發展(c) 晶片與封裝層級之熱管理與系統整合(d) 高功率微波系統之物理解析與硬體實作

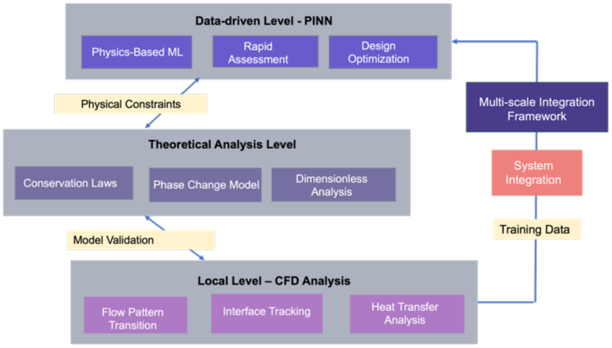
研究內容簡介:

(a) **二相流與微尺度相變之基礎傳輸物理:** 二相流與相變熱傳是高熱通量系統中最具潛力、同時也是最具挑戰性的傳輸問題之一，其複雜性源自於界面動力學、流動結構與相變穩定性之高度耦合。本研究聚焦於微尺度與受限幾何條件下的沸騰與冷凝行為，系統性探討界面演化、氣泡動力學與熱傳機制之交互影響。透過控制體法與界面追蹤數值模型（如VOF），分析流動條件、幾何尺度與操作參數如何影響熱傳效能、不穩定行為與臨界操作極限，目標在於建立具物理一致性且可推廣的傳輸物理模型，而非僅止於特定系統的經驗描述。(Two-phase flow and phase-change heat transfer represent one of the most promising yet challenging transport mechanisms for high heat-flux systems, owing to the strong coupling among interfacial dynamics, flow structures, and phase-change stability. This research focuses on boiling and condensation phenomena under microscale and confined geometries, aiming to elucidate the interactions among interface evolution, bubble dynamics, and heat transfer mechanisms. Using finite-volume-based numerical frameworks with interface-tracking methods such as the volume-of-fluid (VOF) approach, we systematically examine how flow conditions, geometric scales, and operating parameters influence heat transfer performance, flow instabilities, and critical operating limits. The ultimate goal is to develop physically consistent and generalizable transport models, rather than system-specific empirical descriptions.

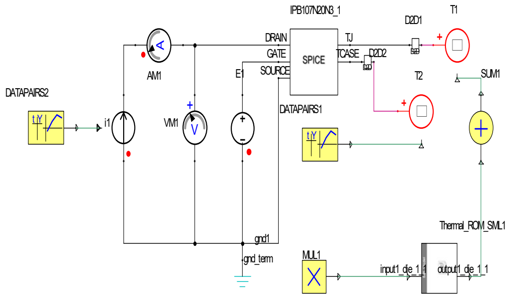


Geometric effect on single bubble boiling

(b) **先進數值方法與物理導向模型發展:** 本研究之先進數值方法發展並非獨立於物理問題之外，而是服務於二相流、相變熱傳與高功率微波系統中之高維度傳輸問題。針對高解析度多相流與熱流模擬計算成本高昂的限制，本研究發展降階模型（Reduced-Order Models）與物理導向的資料驅動方法（如 Physics-Informed Neural Networks, PINNs），在保留主要傳輸物理機制的前提下，大幅降低計算複雜度。研究重點在於將守恆定律、邊界條件與關鍵無因次參數系統性地納入模型建構流程，使模型簡化與數值效率提升不以犧牲物理可解釋性為代價。 (The development of advanced numerical methods in this research is not pursued independently of physical problems, but is instead driven by high-dimensional transport phenomena arising in two-phase flow, phase-change heat transfer, and high-power microwave systems. To address the prohibitive computational cost of high-fidelity multiphase and thermo-fluid simulations, reduced-order models (ROMs) and physics-guided data-driven approaches, such as Physics-Informed Neural Networks (PINNs), are developed to significantly reduce computational complexity while preserving essential transport physics. Emphasis is placed on systematically embedding conservation laws, boundary conditions, and key dimensionless parameters into the modeling framework to ensure that improved numerical efficiency does not compromise physical interpretability.)

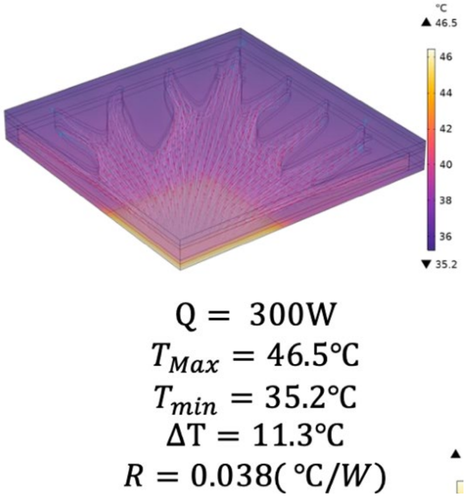


PINNs-based model development for thermo-fluid systems



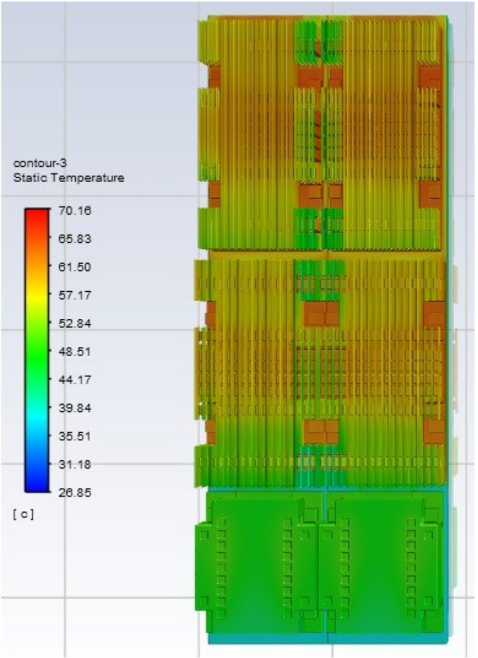
Rapid electro-thermal coupling analysis

(c) 晶片與封裝層級之熱管理與系統整合: 研究聚焦於晶片、封裝與系統之間的跨尺度熱流耦合問題，包含矽蒸氣腔、浸沒式冷卻與多層結構中的熱傳限制。透過數值模擬分析不同整合策略在真實操作條件下的可靠度與熱穩定性，回應高效能運算與先進製程對散熱技術的實際需求。 (With the rapid advancement of semiconductor technologies and heterogeneous integration, thermal coupling across chip, package, and system levels has become increasingly critical. This research focuses on heat transfer limitations at chip and packaging scales, including silicon vapor chambers, immersion cooling, and multilayer structures. Numerical simulations are conducted to evaluate the thermal stability, reliability, and feasibility of different integration strategies under realistic operating conditions.)



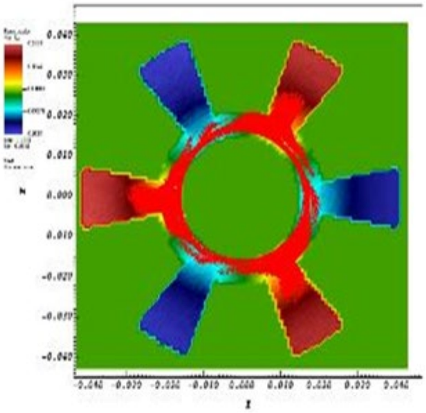
$$Q = 300\text{W}$$
$$T_{Max} = 46.5℃$$
$$T_{min} = 35.2℃$$
$$\Delta T = 11.3℃$$
$$R = 0.038(℃/W)$$

Vapor chamber design

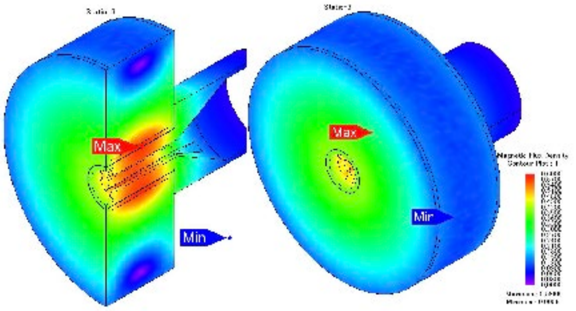


Immersion cooling system

(d) 高功率微波系統設計與製造：本研究聚焦於高功率微波源之核心物理，主要以 A6 磁控管為平台，利用粒子式模擬方法（Particle-in-Cell 等）解析電子運動、空間電荷效應與腔體電磁場之交互作用，進而探討微波振盪模式（mode）、輸出功率與工作點穩定性之形成機制。除源端的電磁—粒子耦合外，亦建立冷陰極之場發射特性學習與評估能力，釐清陰極材料與局部電場分佈對發射電流與啟動行為的影響。同時，本研究具備電磁鐵設計與製造能力，針對磁路配置與磁場均勻性進行工程化實作，以支撐磁控管操作所需之磁場條件並連結到整體系統性能。 (This research focuses on the core physics of high-power microwave sources. Using an A6 magnetron as the primary platform, we employ particle-based simulations (e.g., Particle-in-Cell methods) to resolve the interactions among electron dynamics, space-charge effects, and cavity electromagnetic fields, thereby investigating the formation mechanisms of microwave oscillation modes, output power, and operating-point stability. Beyond the electromagnetic–particle coupling at the source level, we develop capabilities to study and evaluate cold-cathode field emission characteristics, clarifying how cathode materials and local electric-field distributions influence emission current and startup behavior. In parallel, we design and fabricate electromagnets, with engineering emphasis on magnetic-circuit configuration and field uniformity, to provide the required magnetic-field conditions for magnetron operation and to link hardware implementation to overall system performance.)



π mode characteristics of A6 magnetron



Electromagnet design and fabrication