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Automated Optimization of Irregular Elliptical PinFin Heatsinks for SiC Power Module

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Motivation

Silicon Carbide (SiC) devices, with their low losses, high-temperature tolerance, and high-frequency operation capabilities, are advantageous technologies that facilitate the doubling of power density in electric drive systems. **Thermal management** plays a critical role in the performance of motor drives, as heat generated from power module losses is a primary concern. Therefore, **optimizing power module heatsinks** is crucial to enhancing the overall performance of the motor drive system.

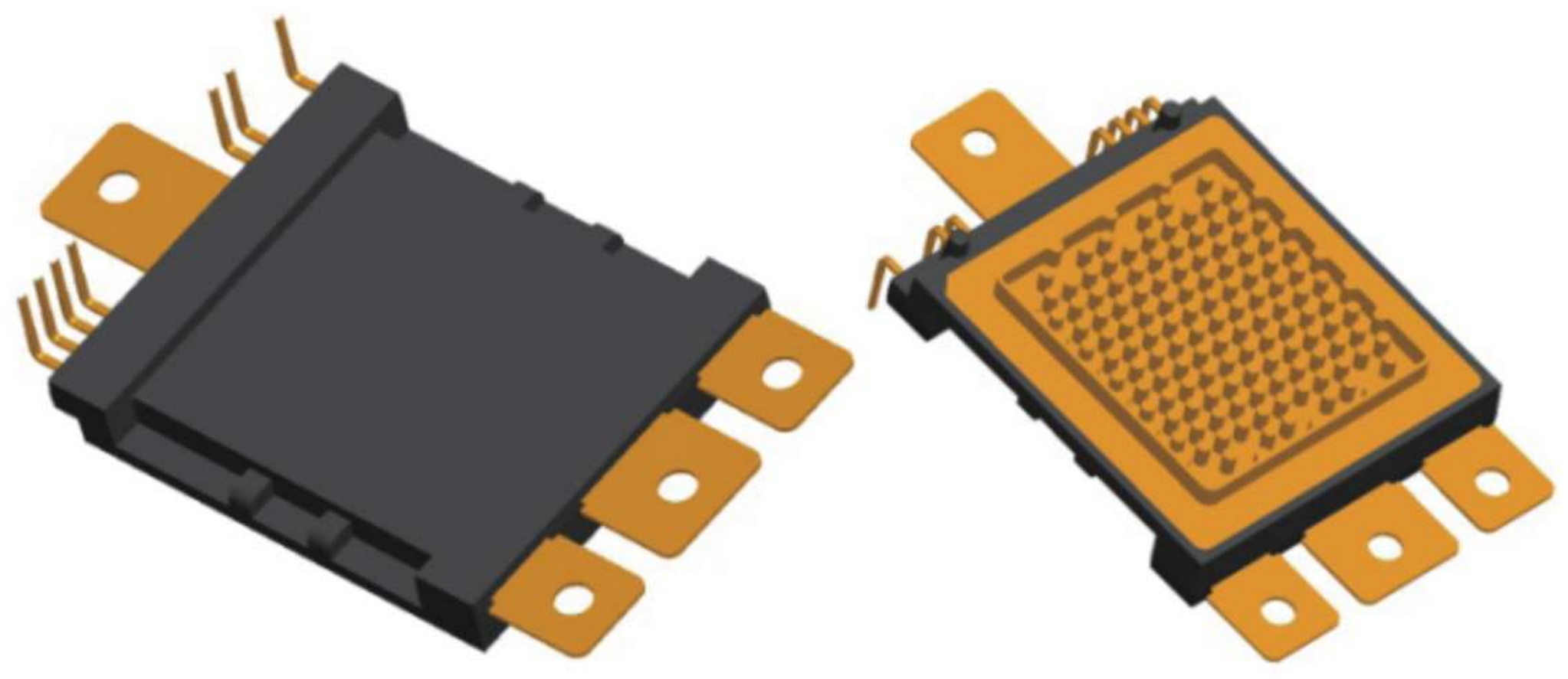

Fig.1 SiC power module with PinFin heatsink

Automated Optimization Methodology

Encoding Initialization

To automatically **generate candidate solutions** for irregular PinFins with different rotation angles, sizes, and random positions, an encoding method is proposed. Genetic operations ensure that the offspring maintains effective layout characteristics inherited from the parent.

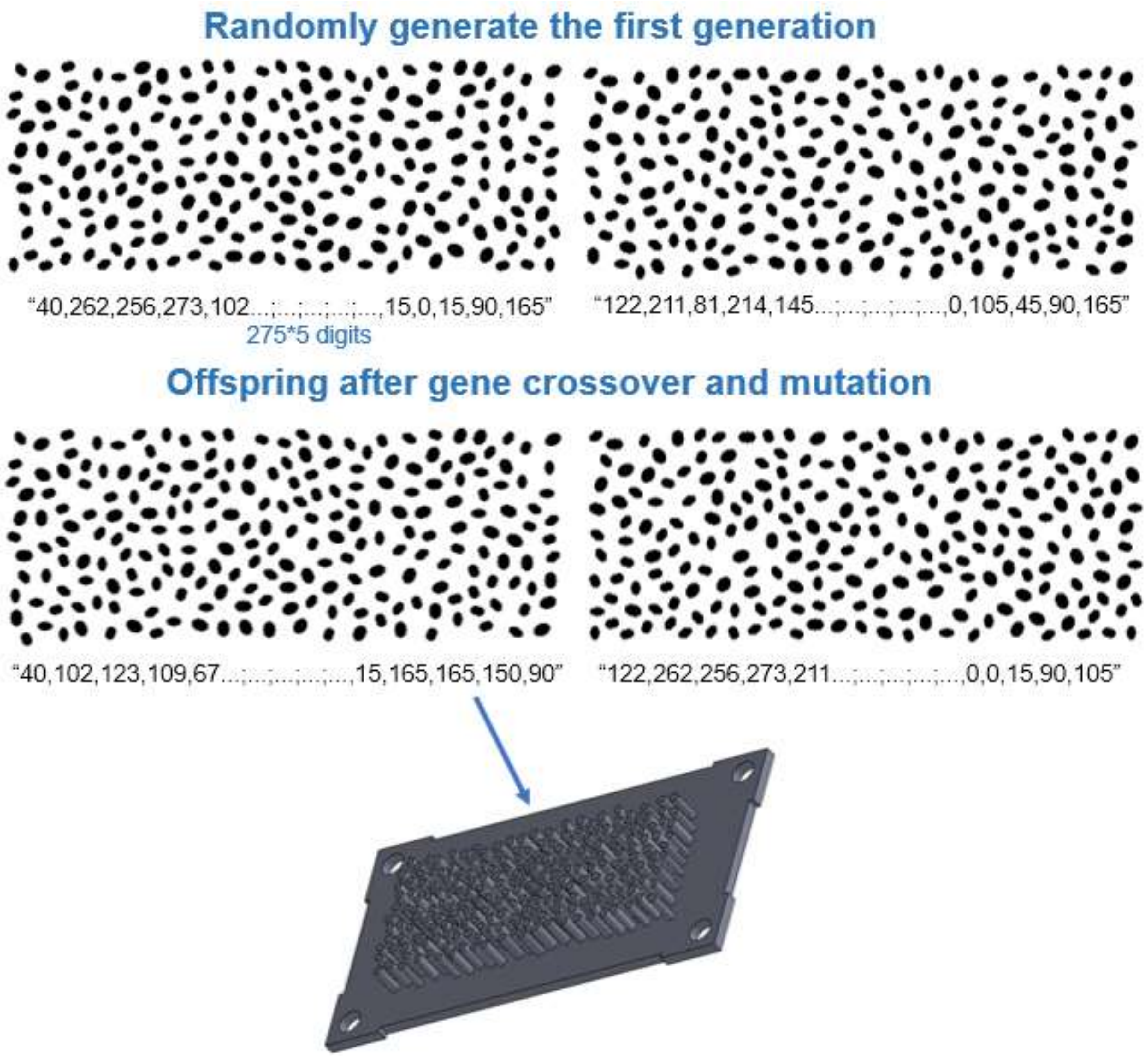

Fig.2 Genetic operations for irregular elliptical PinFin

Sequential weight	(1,2,3,4,5,6,7,8)	(7,2,1,4,8,6,3,5)
X-displacement	(0,0,0,0,0,0,0,0)	(3,-1,1,0,-2,0,0,-1)
Y-displacement	(0,0,0,0,0,0,0,0)	(1,-1,-1,0,1,2,2,0)
Major axis length	(6,6,6,6,6,6,6,6)	(7,8,8,6,6,8,6,6)
Rotation angle	(0,0,0,0,0,0,0,0)	(150,0,135,90,30,0,45,150)

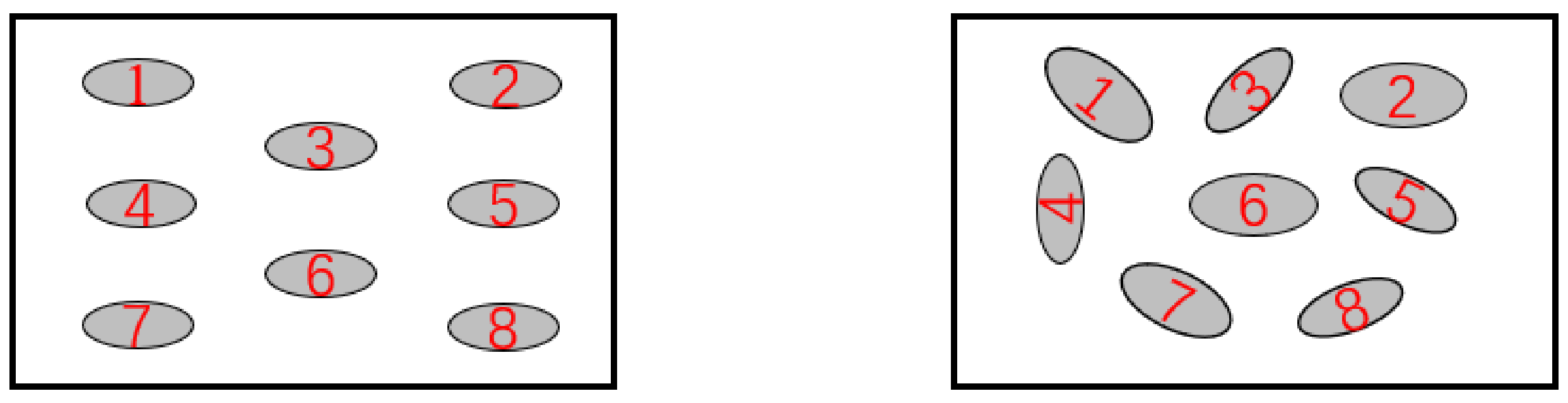

Fig. 3. Encoding of Irregular PinFins

Evaluation Method

The combination of **LBM-LES (Lattice Boltzmann Method - Large Eddy Simulation)** with incompressible LBGK can be used to solve the flow velocity field of PinFin.

$$\underbrace{f_k\left(x+\Delta x, t+\Delta t\right)-f_k\left(x,t\right)}_{\text{Streaming}}=\underbrace{-\frac{f_k\left(x,t\right)-f_k^{eq}\left(x,t\right)}{\tau}}_{\text{Collision}}$$

- f : distribution function at time t at location x
- feq : equilibrium distribution function
- τ : the relaxation time

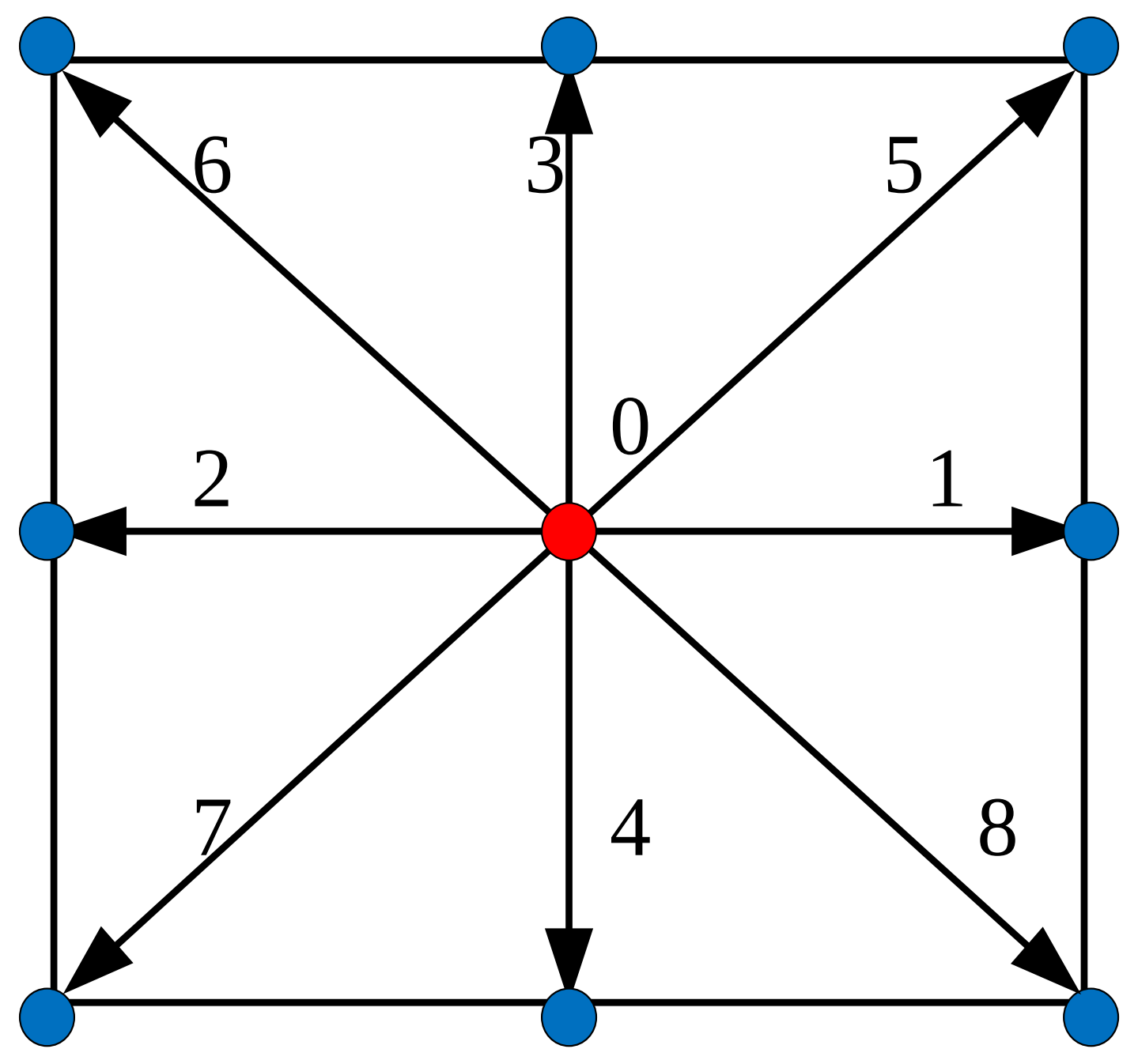

Fig. 4. D2Q9 model in LBM

When caculating the distribution functions at curved surfaces, the bounce-back method will be utilized, considering all lattice points along the ellipse as the surface. Each directional distribution function can be obtained from the opposite direction distribution function.

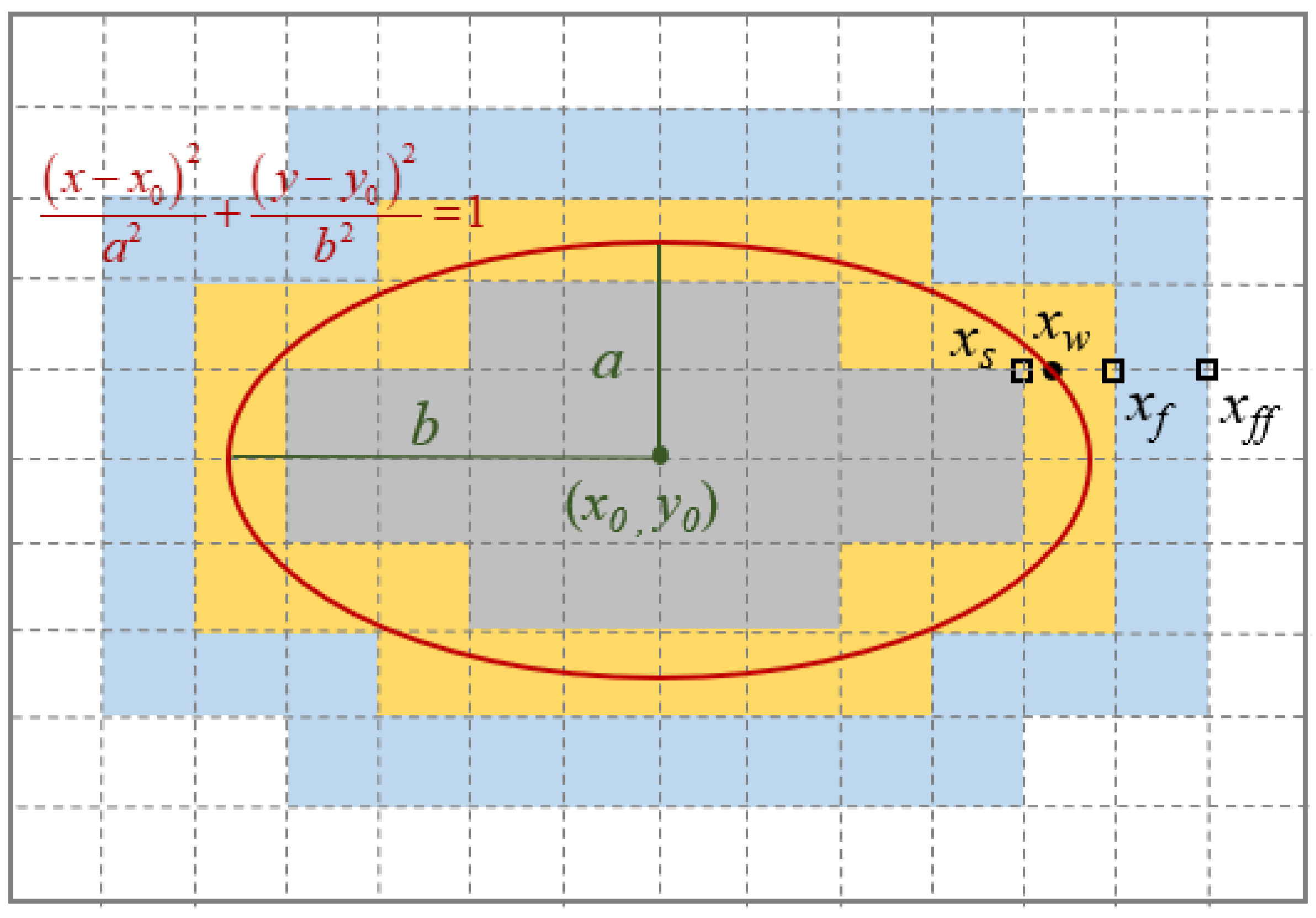

Fig. 5. Elliptical boundary handling method

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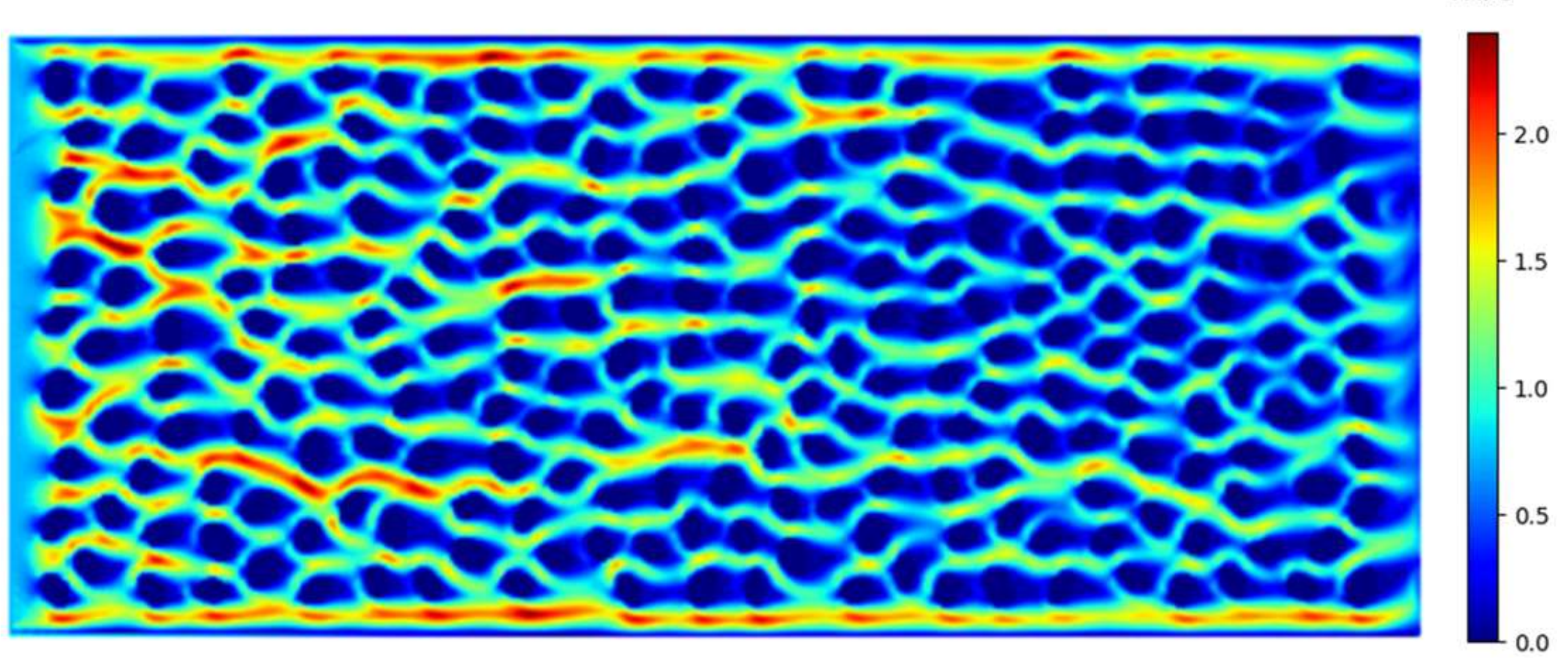
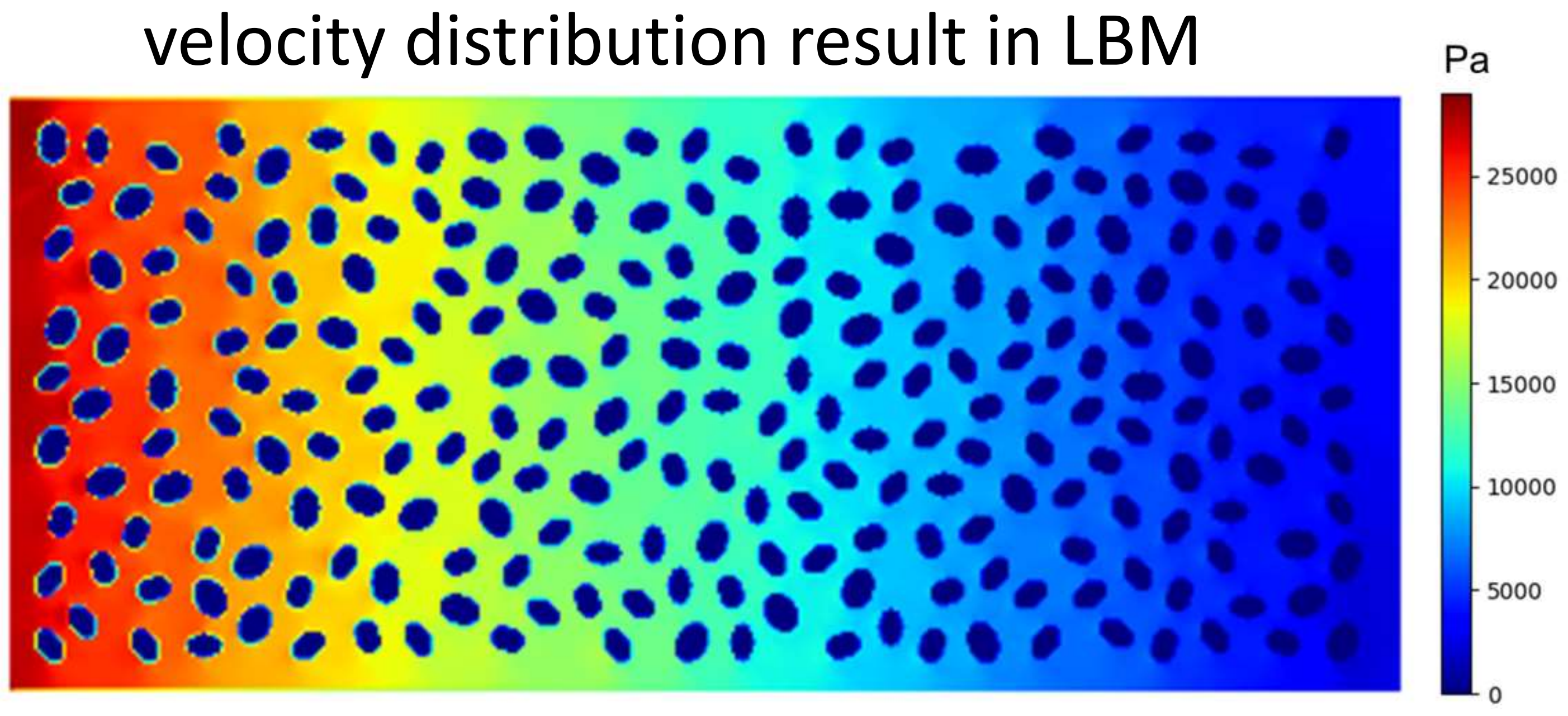
Optimization Procedure and Result

Different heatsink structures have different operating points. In the optimization process, it is necessary first to determine the flow rate and pressure differential characteristic curve for each candidate structure.



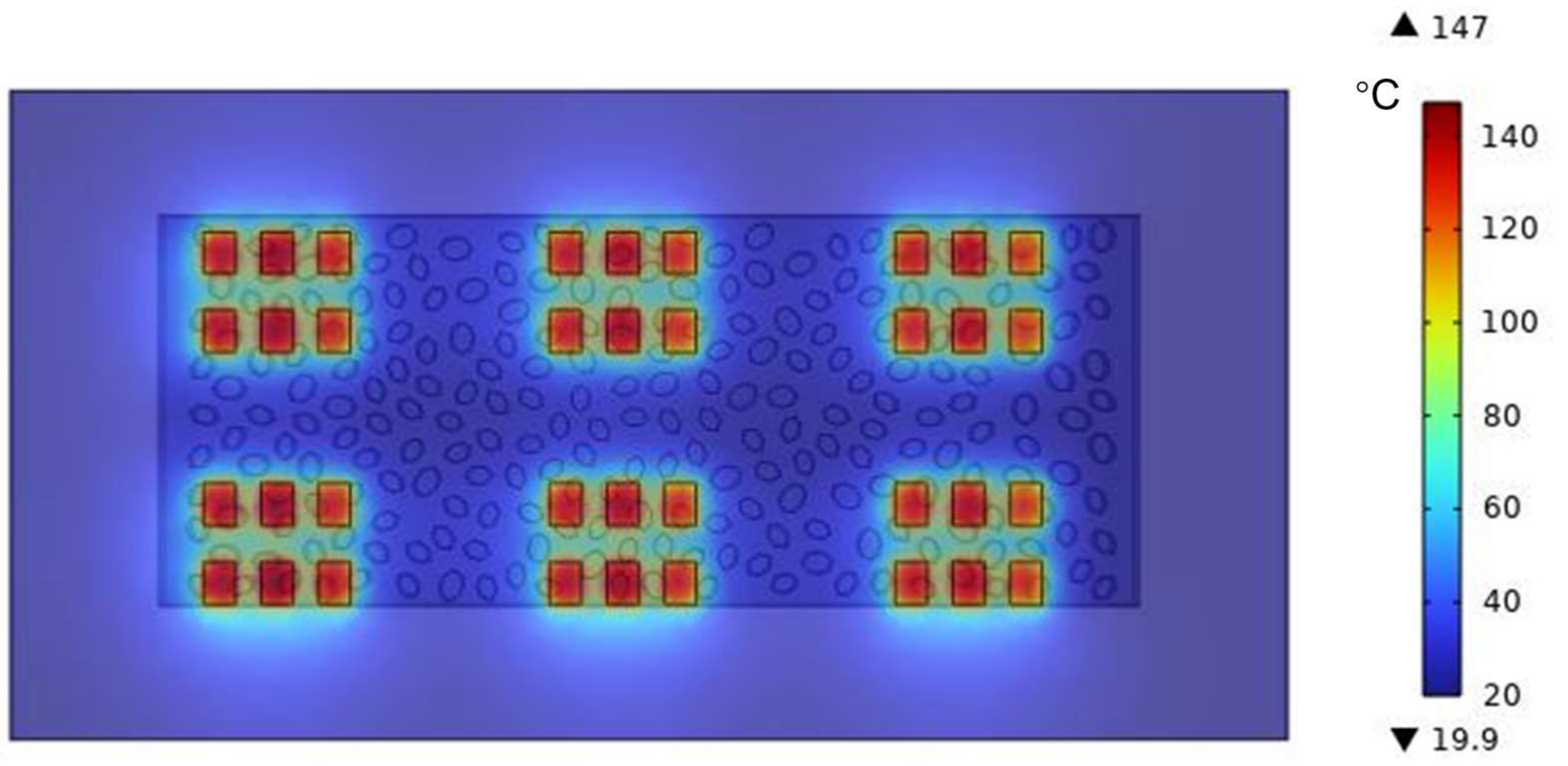
velocity distribution result in LBM



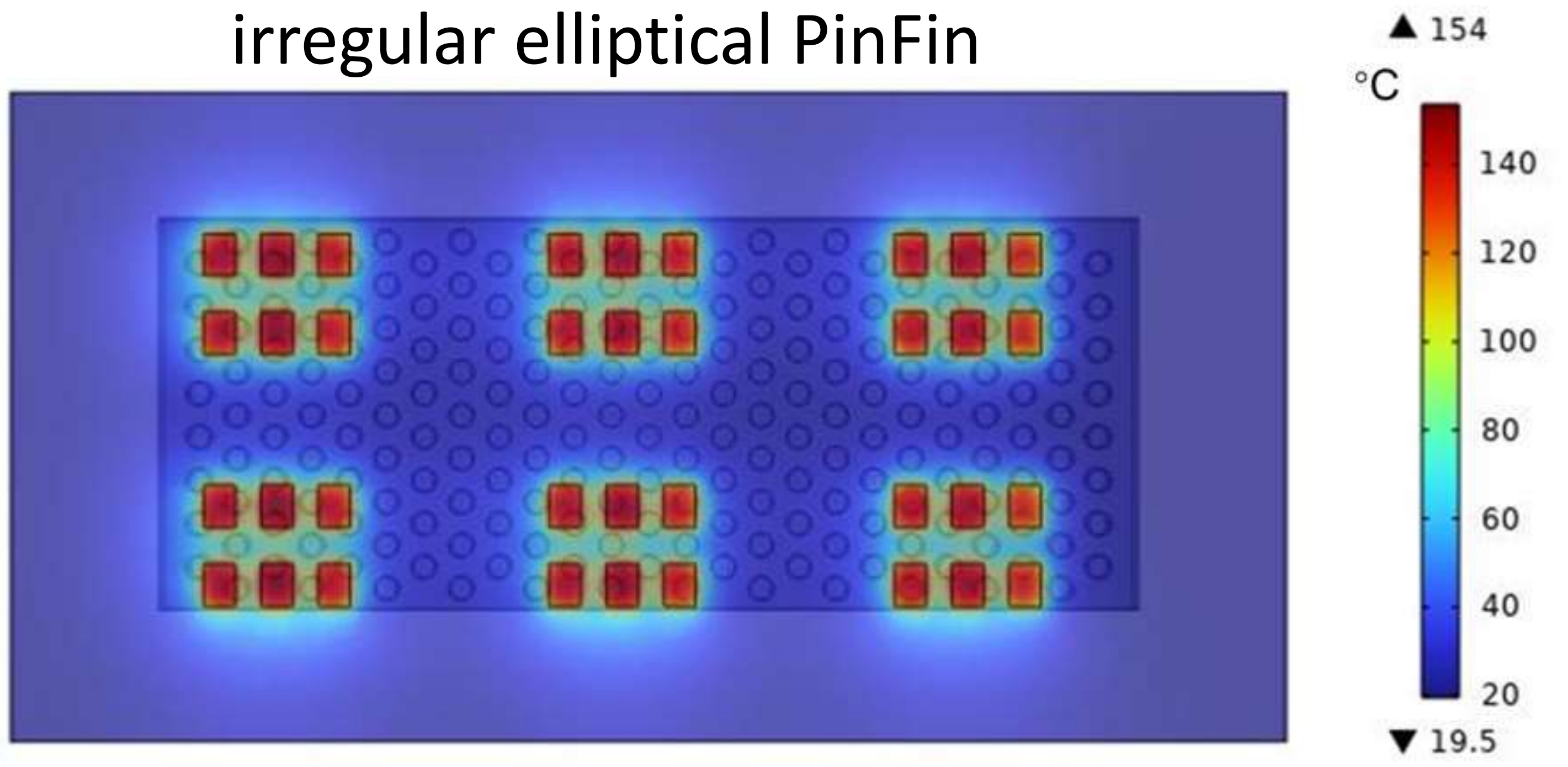
pressure distribution result in LBM

Fig. 6. Optimal result in LBM

A comparison with the optimization results of regular cylindrical PinFin of the same size. It can be observed that the proposed method achieves an improvement of approximately 7° C.



irregular elliptical PinFin



regular cylindrical PinFin

Fig. 7. Optimization result comparison

Experimental Verification

Based on the optimized results, an irregular elliptical PinFin heat sink was machined. Subsequently, a high power density three-phase SiC power module based on stacked DBC was fabricated to validate the thermal performance.

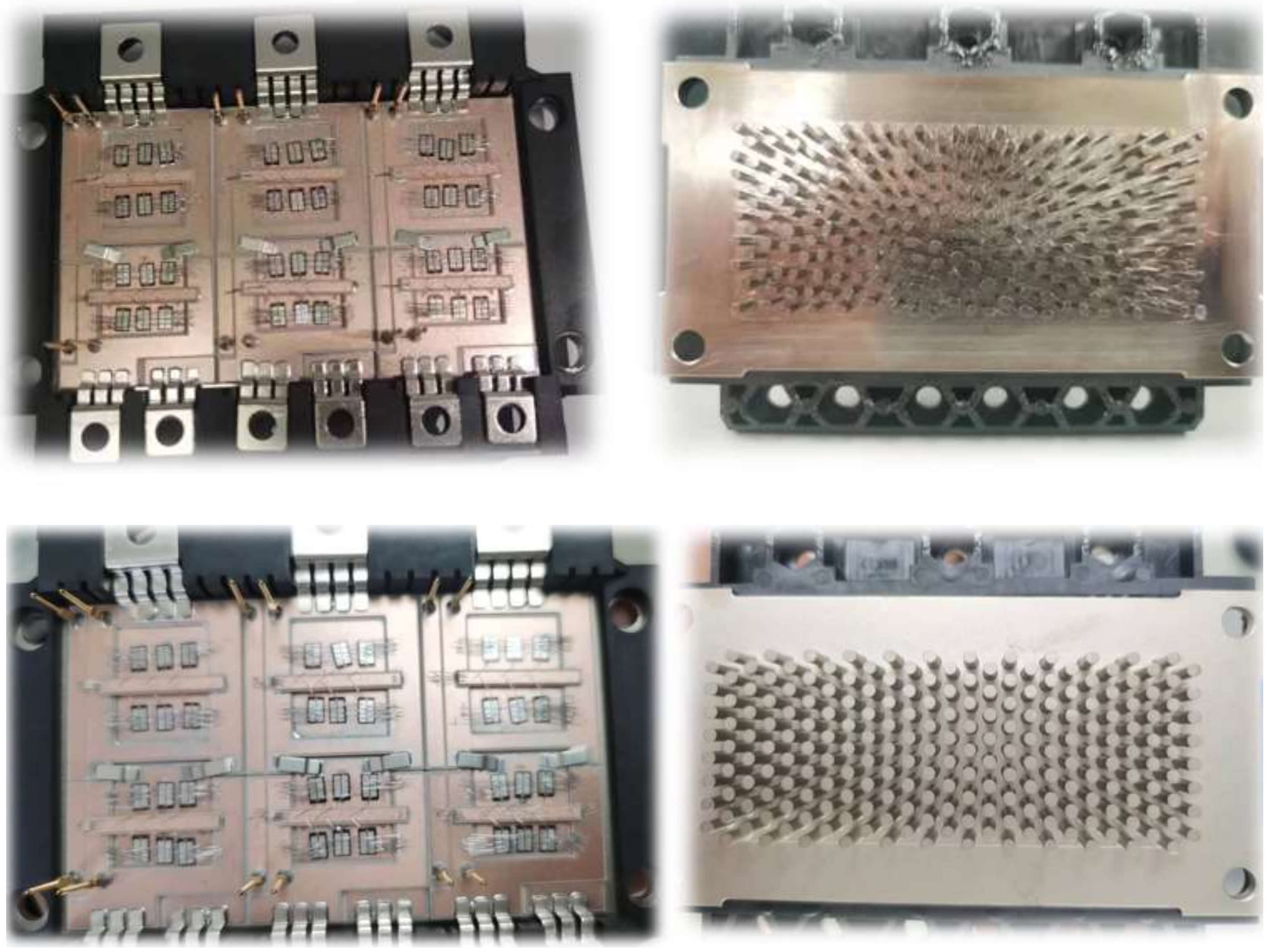


Fig. 8. Manufactured power module

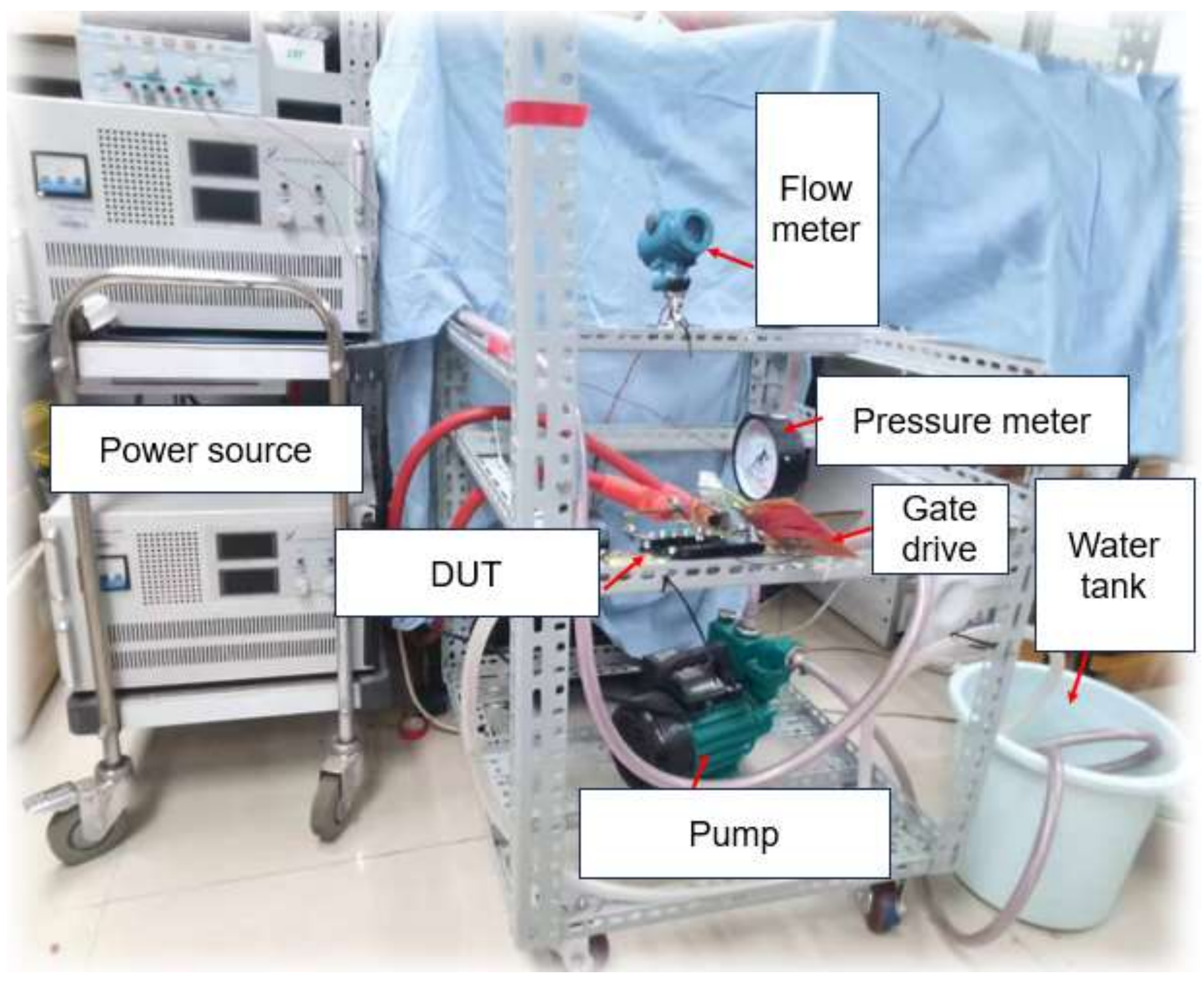
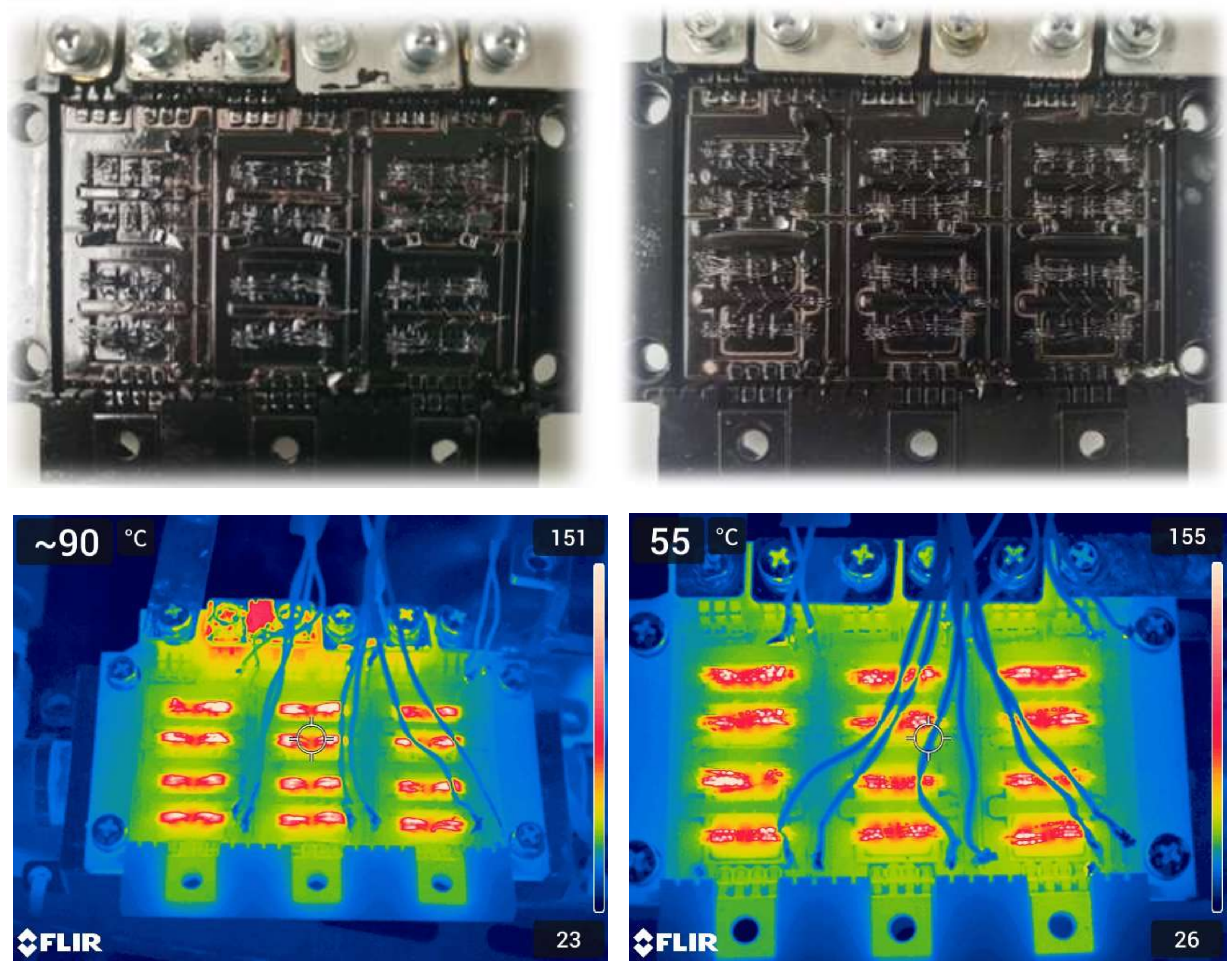


Fig. 9. Experimental environment

The experimental results still indicate that the optimized irregular elliptical PinFin heat sink results in a junction temperature that is 4° C lower for the power module, thereby validating the effectiveness of the design method.



irregular elliptical PinFin regular cylindrical PinFin

Fig. 10. Temperature distribution experimental results.