Optimization of Pinfin Heat Sink for SiC Power Module based on LBM-LES

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Introduction-Motor drive is one of the three key components of electric vehicles. High power density is an important direction for the development of next-generation motor drive systems. integration and efficiency. Improving the heat dissipation path and its performance plays a crucial role in the overall performance of the motor drive. In terms of heat dissipation, more and more power modules use Pinfin baseplate with water cooling in EV application. Fig.1 shows typical Pinfin baseplates. This paper aims to conduct fluid simulation on the power module Pinfin heat sink using the lattice Boltzmann method and turbulence model.

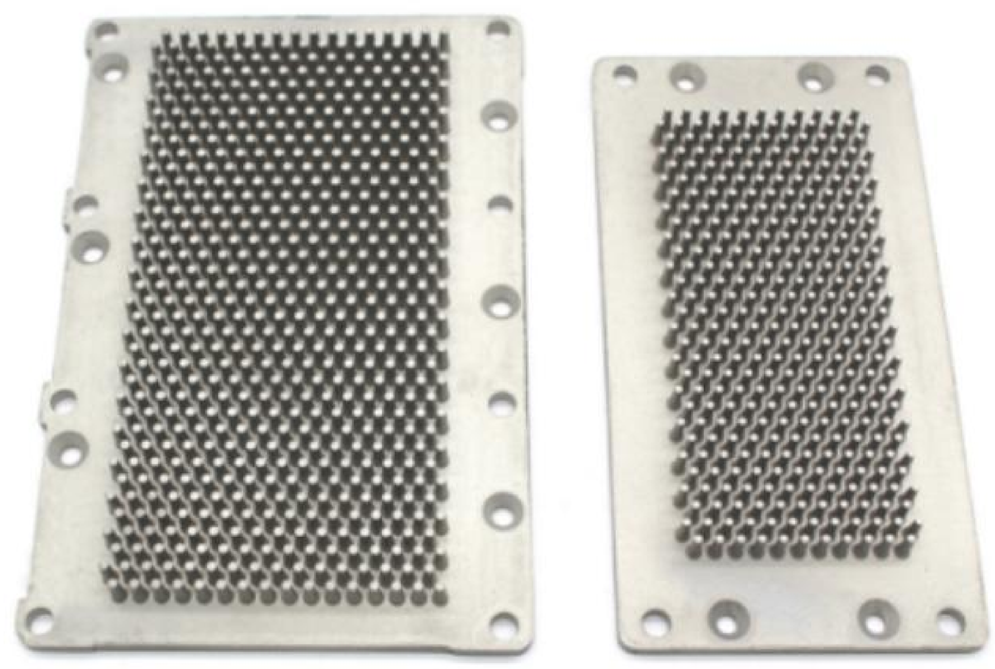

Fig. 1. Typical Pinfin cooling baseplates

In Fig. 2 uses computational fluid dynamics (CFD) to evaluate the overall thermal performance after manual design.

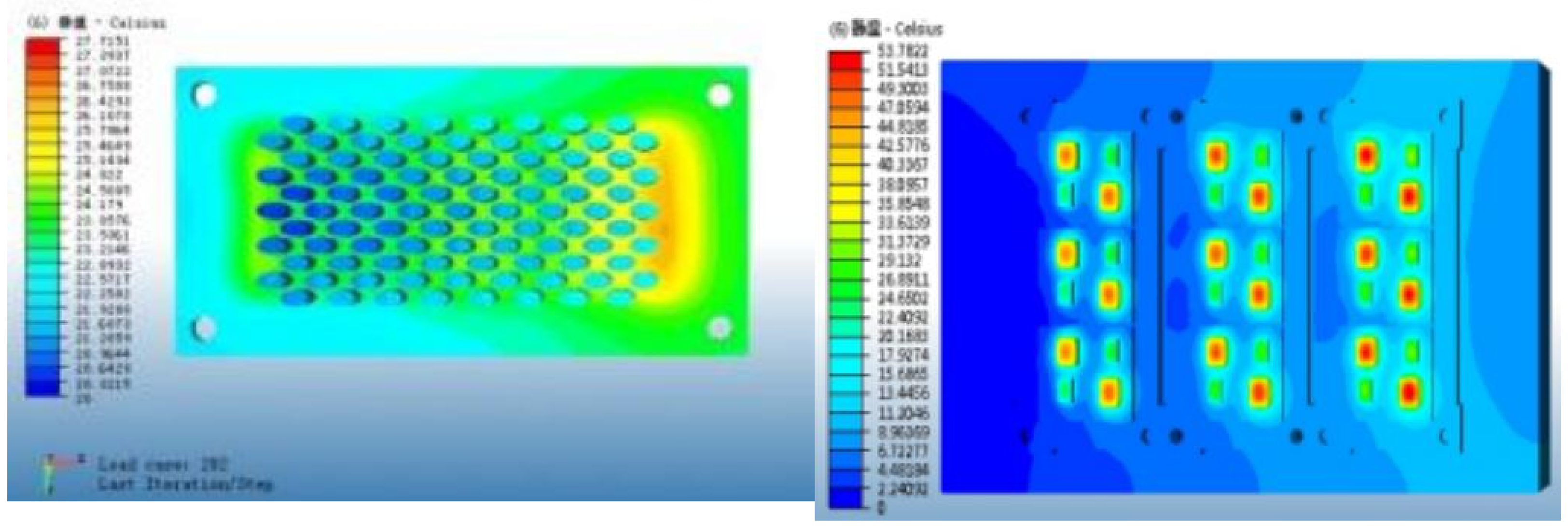

Fig. 2 Evaluation and optimization of heat dissipation of Pinfin and water cooling tank

Simulation Model

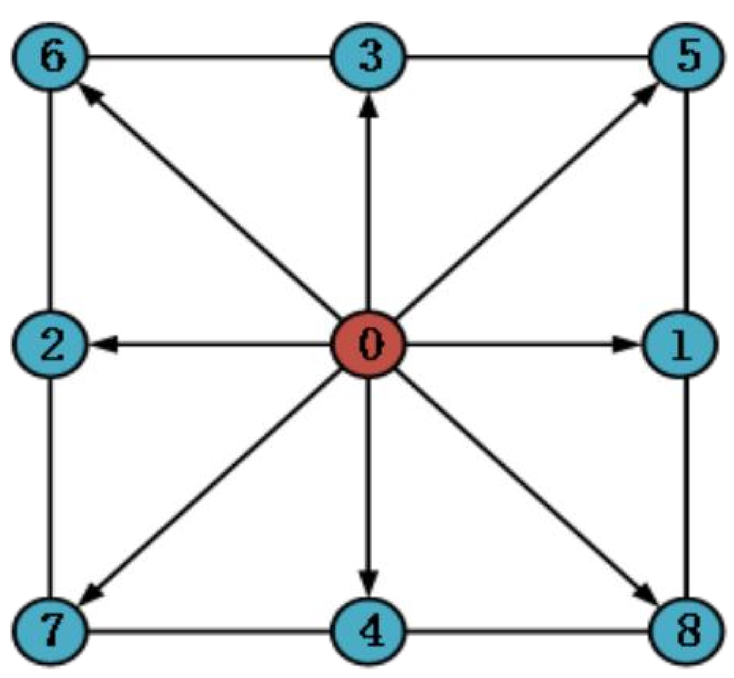

Fig. 3. D2Q9 migration direction

The distribution function for the incompressible D2Q9 LBGK model is as follows,

$$f_k^{eq} = \begin{cases} -4\sigma \dfrac{p}{c^2} + s_0(u) & k = 0 \\ \lambda \dfrac{p}{c^2} + s_k(u) & k = 1,2,3,4 \\ \gamma \dfrac{p}{c^2} + s_k(u) & k = 5,6,7,8 \end{cases}$$

$$s_k(u) = w_k \left[\frac{c_k \cdot \boldsymbol{u}}{c_s^2} + \frac{1}{2}\frac{(c_k \cdot \boldsymbol{u})^2}{c_s^4} - \frac{1}{2}\frac{\boldsymbol{u}^2}{c_s^2} \right]$$

The final distribution function can be expressed as

$$u = \sum_{k=1}^{8} c_k f_k \qquad p = \frac{c^2}{4\sigma}\left[\sum_{k=1}^{8} f_k + s_0(u) \right]$$

Curved boundary alternative method

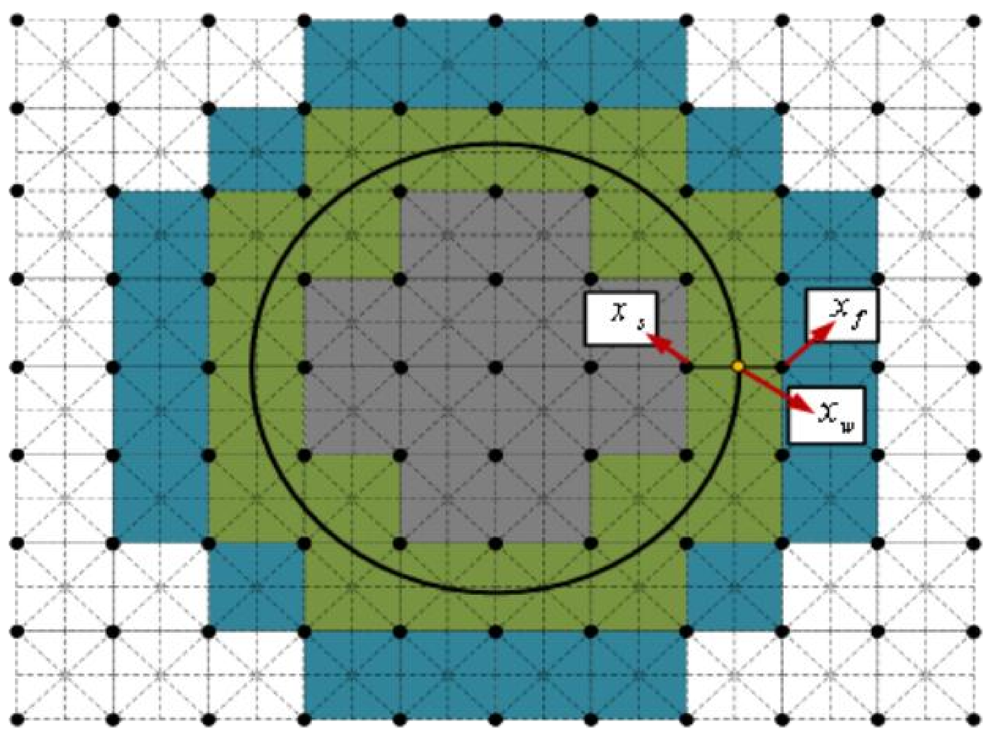

Fig.4. Curved boundary alternative method

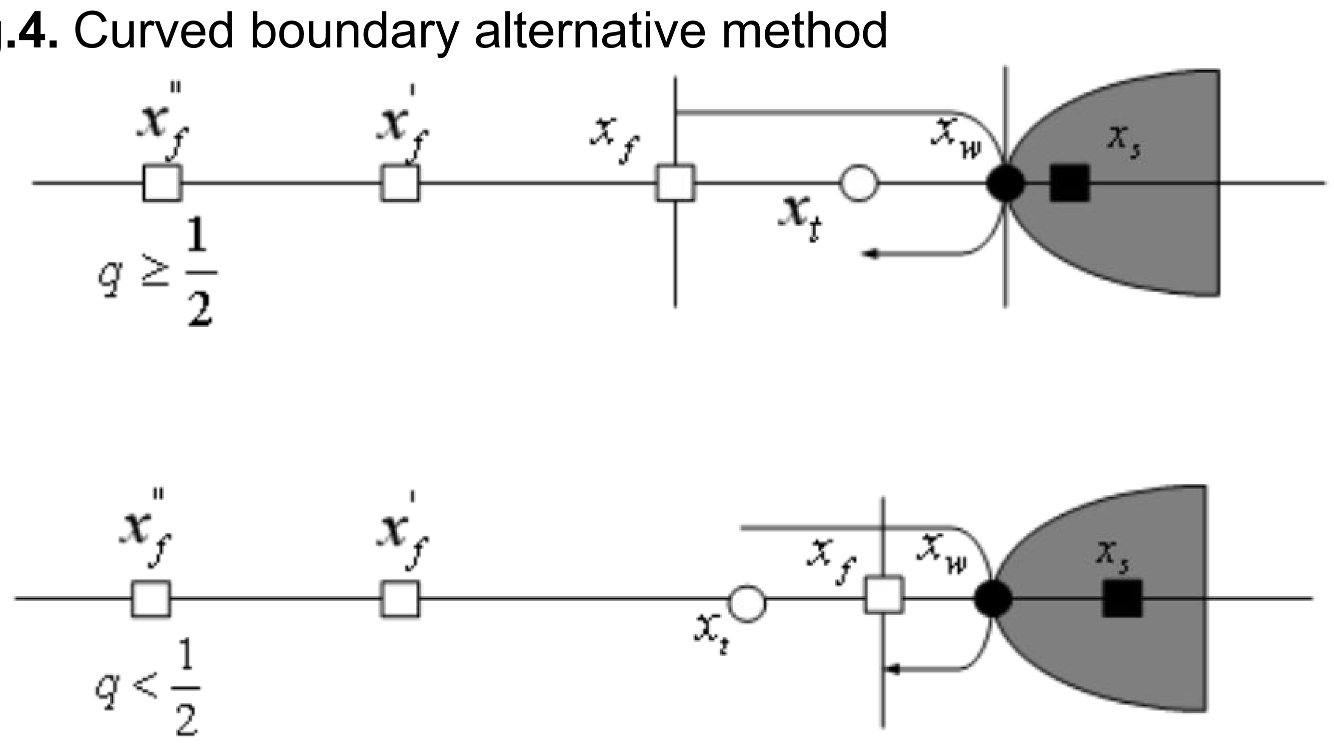

Fig.5. Curved boundary calculation method in two cases

When q ⩾ 1/2,

$$f_k(x_f, t+\Delta t) = \frac{1}{2q} f_k(x_t, t+\Delta t) + \frac{2q-1}{2q} f_k(x_f', t+\Delta t)$$

When q < 1/2

$$f_k'(x_t, t+\Delta t) = f_k'(x_t, t) = 2q f_k'(x_f, t) + (1-2q) f_k'(x_f', t)$$

Large eddy simulation turbulence model

Used in high Reynolds numbers

Introduce subgrid subscale models

$$\nu_{total} = \nu_0 + C\Delta^2 \left| \bar{S} \right|$$

The strain rate tensor is calculated as .

$$\bar{S}_{ij} = \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) \frac{\partial u_i}{\partial x_j} - \frac{2}{3}\left(\frac{\partial u_k}{\partial x_k} \right)^2$$

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The d2q9 model can evolve as follows:

$$f_k(x+\Delta x, t+\Delta t) = f_k(x,t)\left[1-\frac{1}{\tau_{total}}\right] + \omega f_k^{eq}(x,t)$$

Pinfin Optimization Method

A typical characteristic curves of centrifugal pumps are shown in the Fig.6.

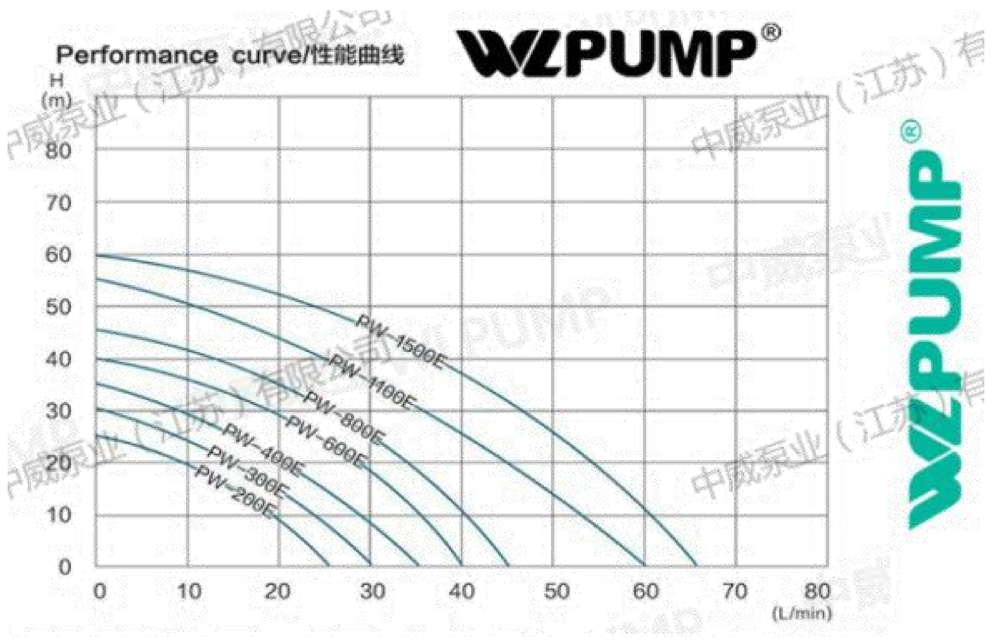


Fig.6. A typical characteristic curves of centrifugal pumps

In Figure 7, the characteristic curve of the pipe can be changed by designing the pin-fin layout.

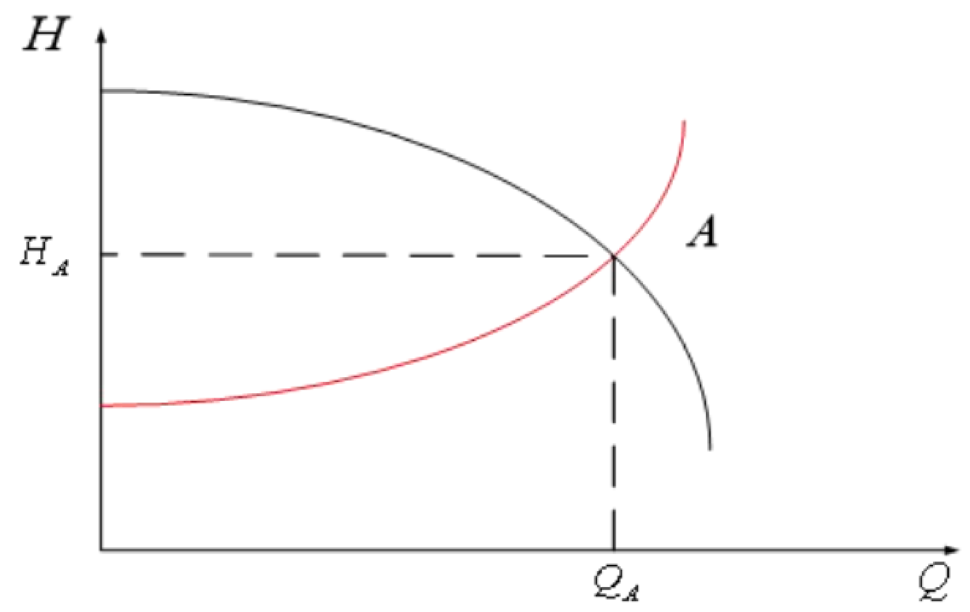


Fig.7. A typical characteristic curves of centrifugal pumps

Pinfin structure optimization based on operating point

Select the diameter and horizontal and vertical spacing as variables (as shown in Figure 8).The sum of the flow velocities around the cylinder was used as the criterion for fitness evaluation.

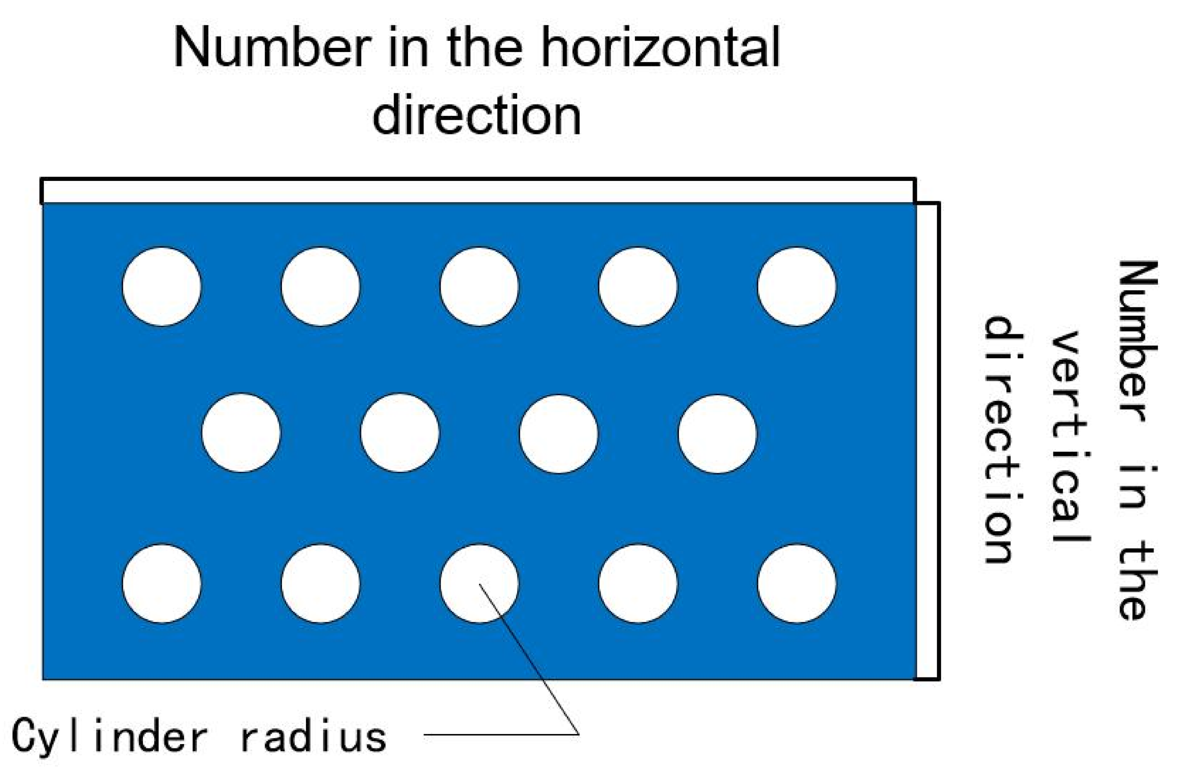


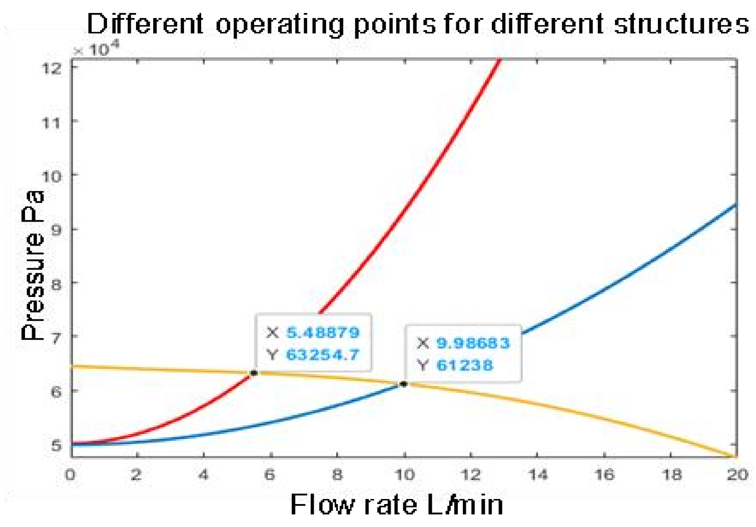
Fig. 8. Optimization variable settings

Table. 1. Optimization variable set range

Variable set range	Cylinder radius(Grid count)	Horizontal grid cell count	Vertical grid cell count
Interleaved arrangement	8-15	6-14	5-10

Table. 2. Optimization result

Variable set	Cylinder radius(Grid count)	Horizontal grid cell count	Vertical grid cell count
Optimum layout	11	12	8
One midway layout	10	10	6



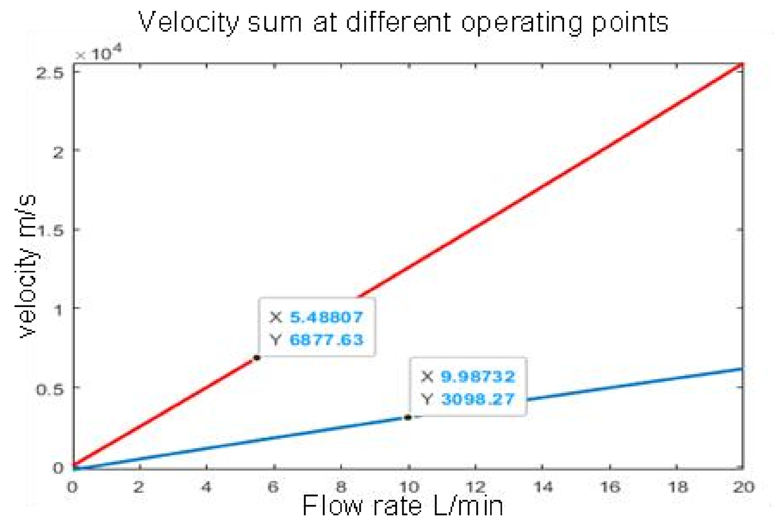


Fig. 9. Operating characteristic curve **Fig. 10.** Velocity summation curve

Simulation validation

The simulation results of this paper are shown in Fig.11. Fig.12 and Fig.13 are COMSOL simulation results

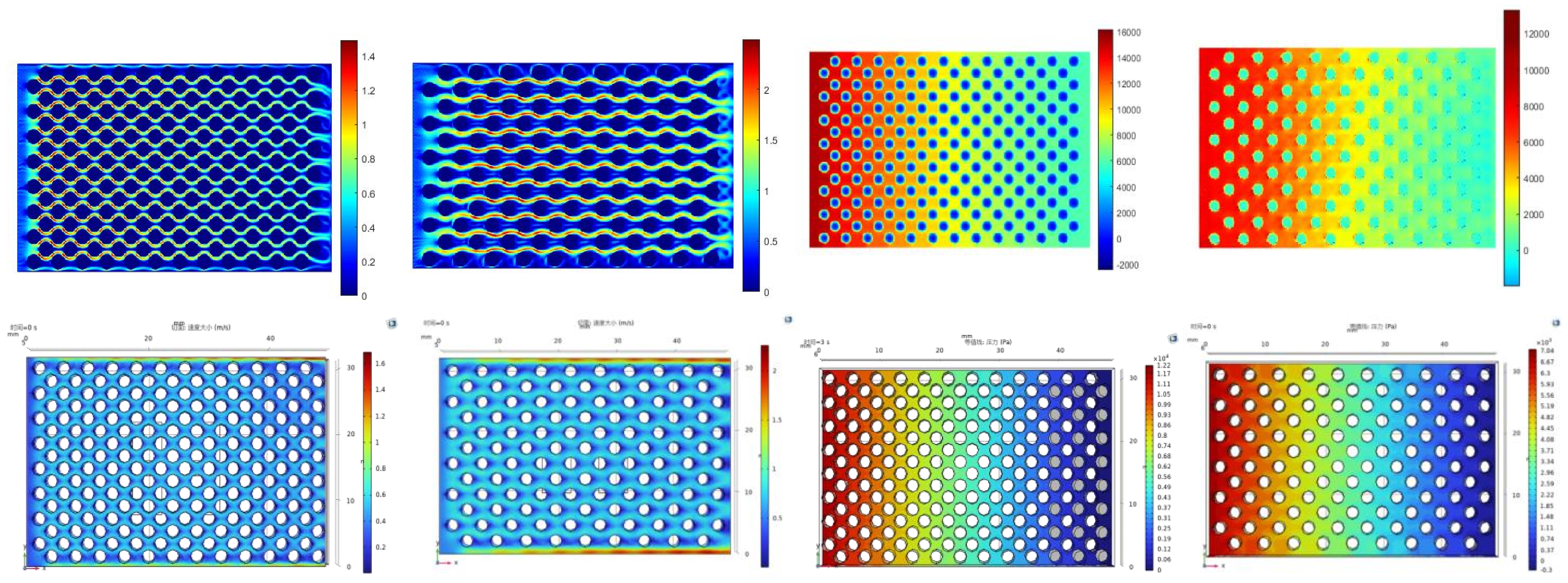


Fig. 11. LBM simulation velocity contour **Fig. 12.** COMSOL simulation result contour

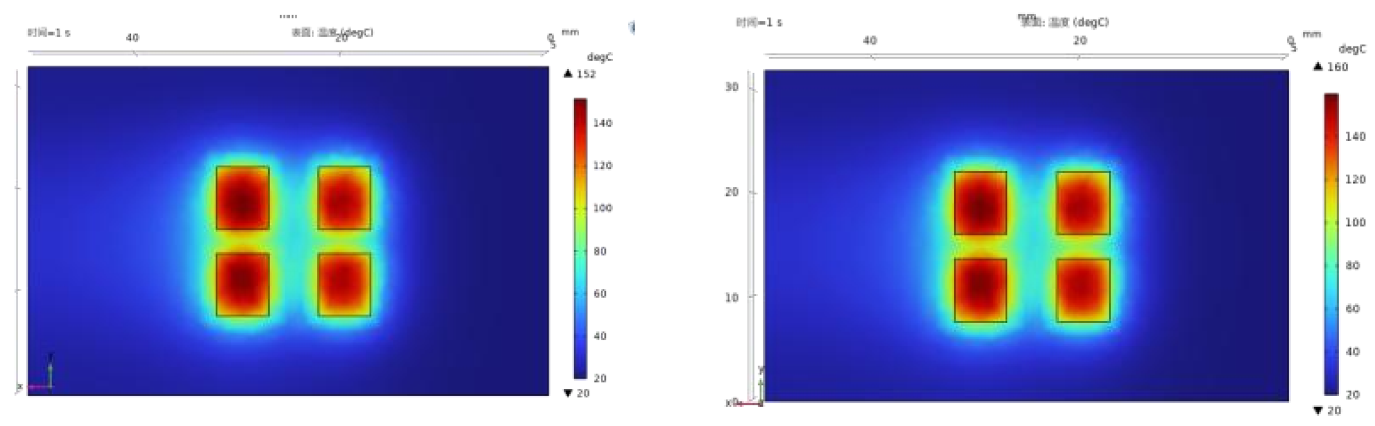
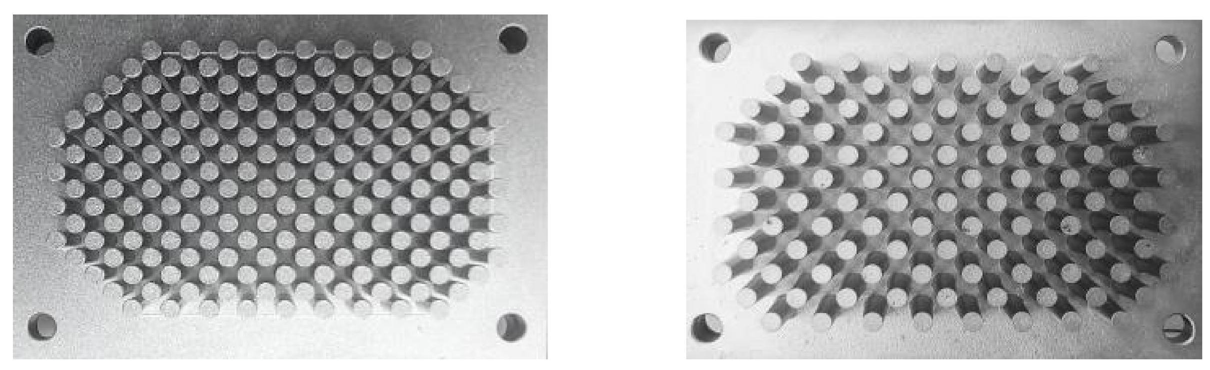


Fig. 13. Cooling situation of the chip

Experimental validation



Optimum layout Midway layout

Fig. 14. Photo of the Pinfin structure to be validated

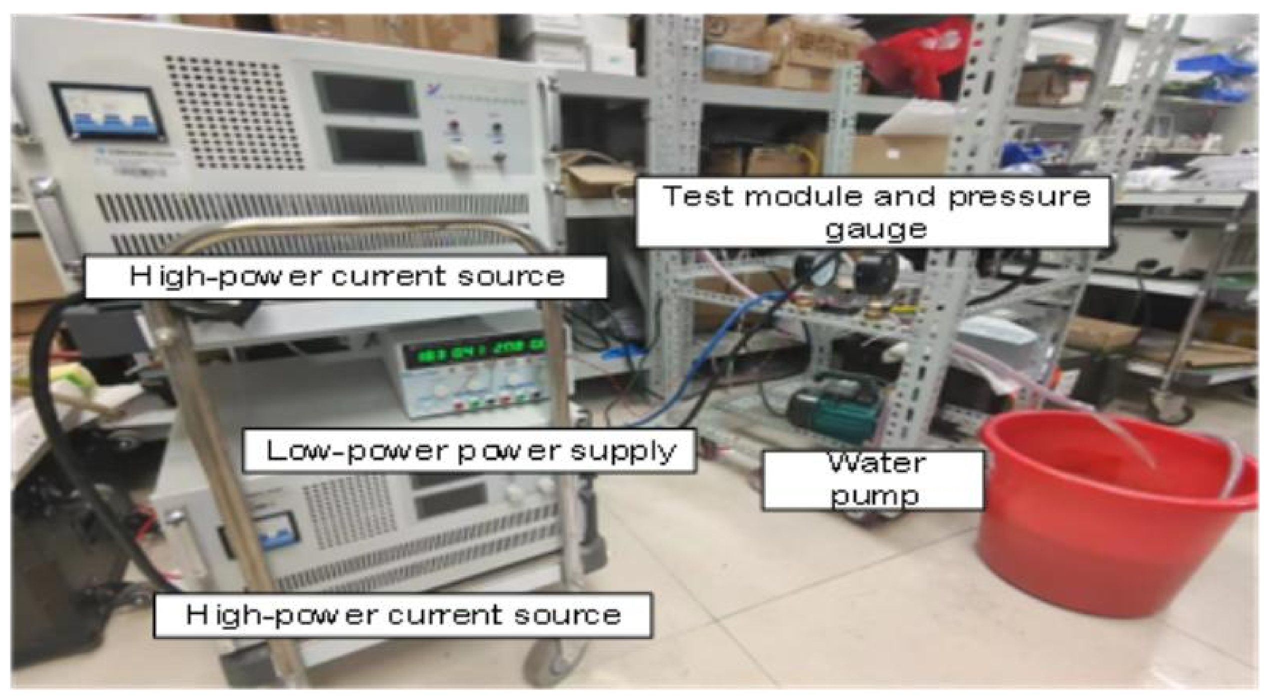
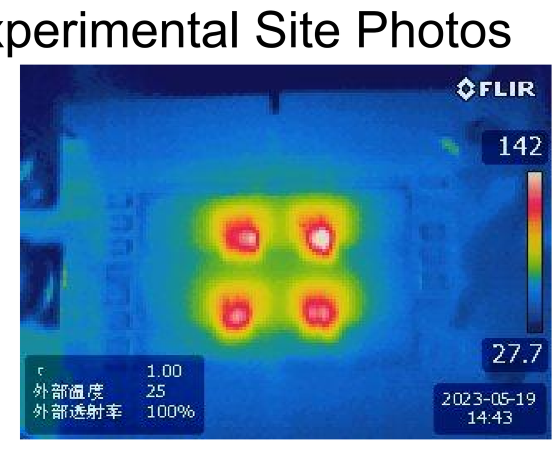
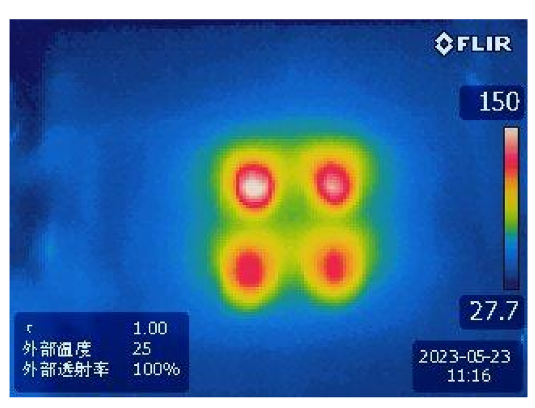


Fig. 15. Experimental Site Photos





Optimum layout Midway layout

Fig. 16. Temperature measurement