



北京信息科技大学

BEIJING INFORMATION SCIENCE & TECHNOLOGY UNIVERSITY

State-of-the-Art Optical Chip for Digital Earth: Towards Implementation

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2026.03

CONTENT



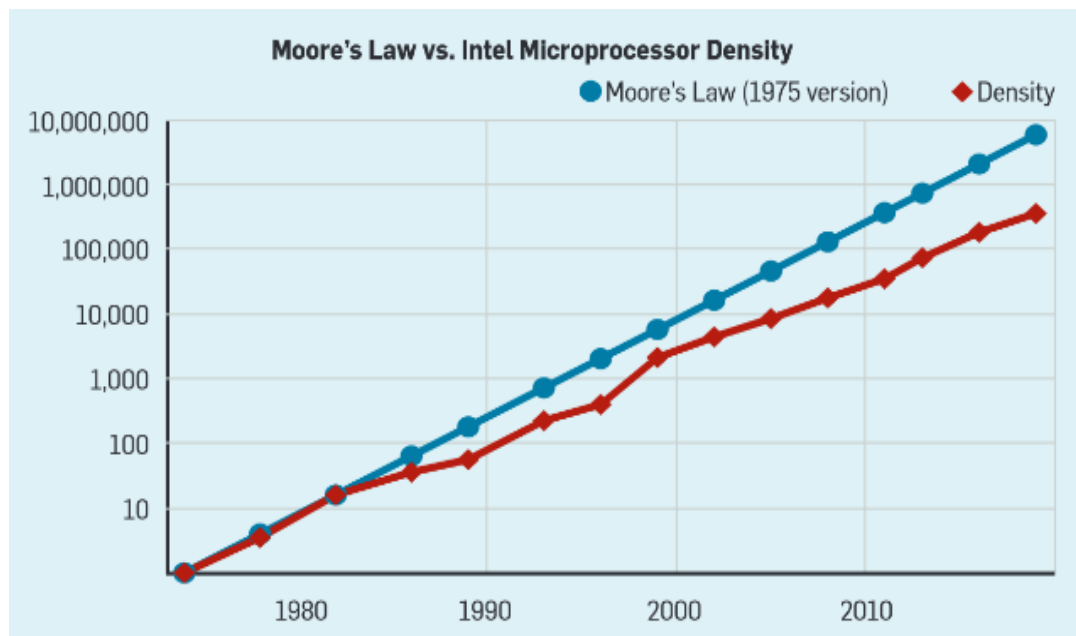
- **1 Background**
- **2 ONN chips architectures**
- **3 Experiment**



1 Background



The Need for Photonic Computing



Extended Data Table 2. Estimated energy consumption of the photonic-assisted image edge detector

| Component | Equation | Energy consumption |
|---------------------|--|--------------------|
| Laser | $E_{laser} = [(P_{laser} + P_{TEC}) / \eta] \cdot t$ | 1.87 nJ |
| Modulator (on-chip) | $E_{mod} = (V_p^2 / 2R) \cdot t$ | 0.61 nJ |
| PD | $E_{PD} = \frac{\Re Y_{bias} P_{rec}}{B} \cdot M$ | 0.44 nJ |
| EDFA | $E_{EDFA} = \frac{\lambda_s}{\lambda_p} [(P_{out}^s - P_{in}^s) / \eta] \cdot t$ | 0.84 nJ |
| Total | $E_{laser} + E_{mod} + E_{PD} + E_{EDFA}$ | 3.76 nJ |

1. Moore's Law

- As transistors shrink to near-atomic levels, the pace of progress has decelerated

2. Rising Demand for Computational Power

- Real-world applications like AI, big data analysis, and simulations require ever-increasing computing performance.

Examples: Autonomous Vehicles, Smart Cities, Scientific Research

3. Photonic Computing as a Solution

- Addresses the limitations of electronic chips by using light for faster, more energy-efficient data processing

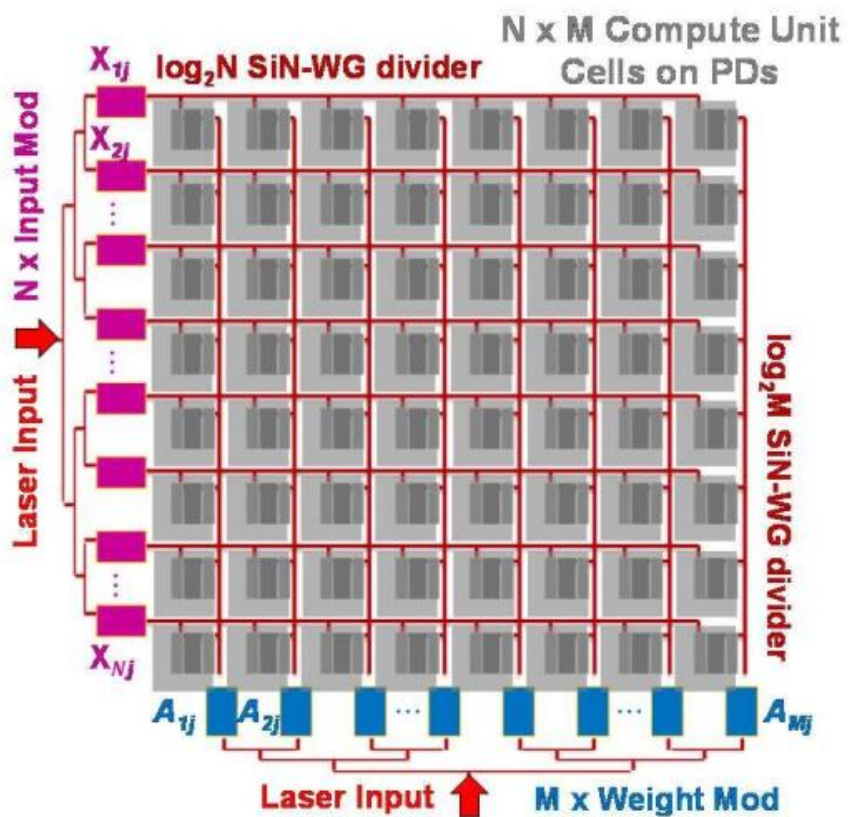
1 Background



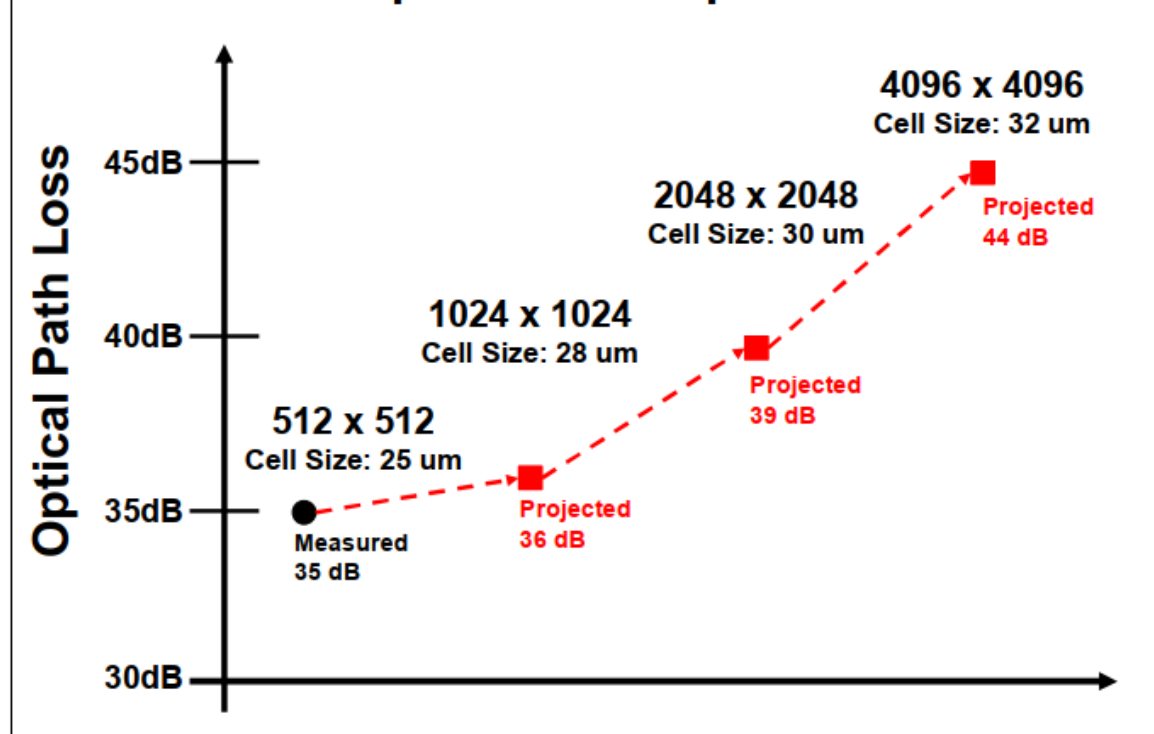
The Need for Photonic Computing

TSMC&NVIDIA

Optical Fan-Out for NxM Compute Matrix



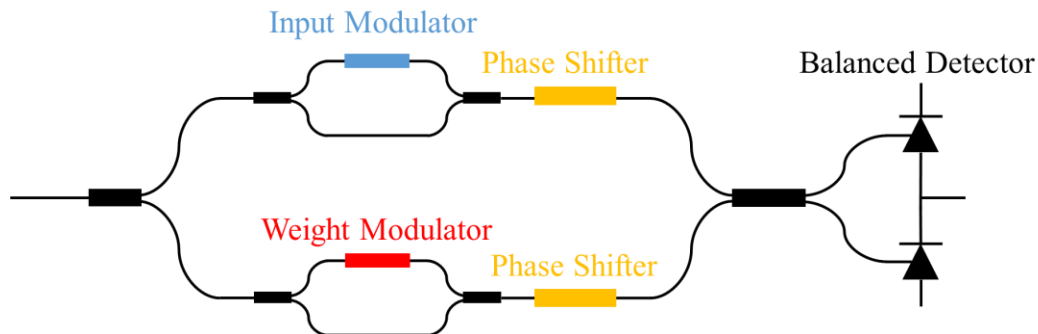
Projected 4-Layer Si_3N_4 NxN Compute Matrix Optical Path Loss



2 ONN chips architectures



Computing unit



encode

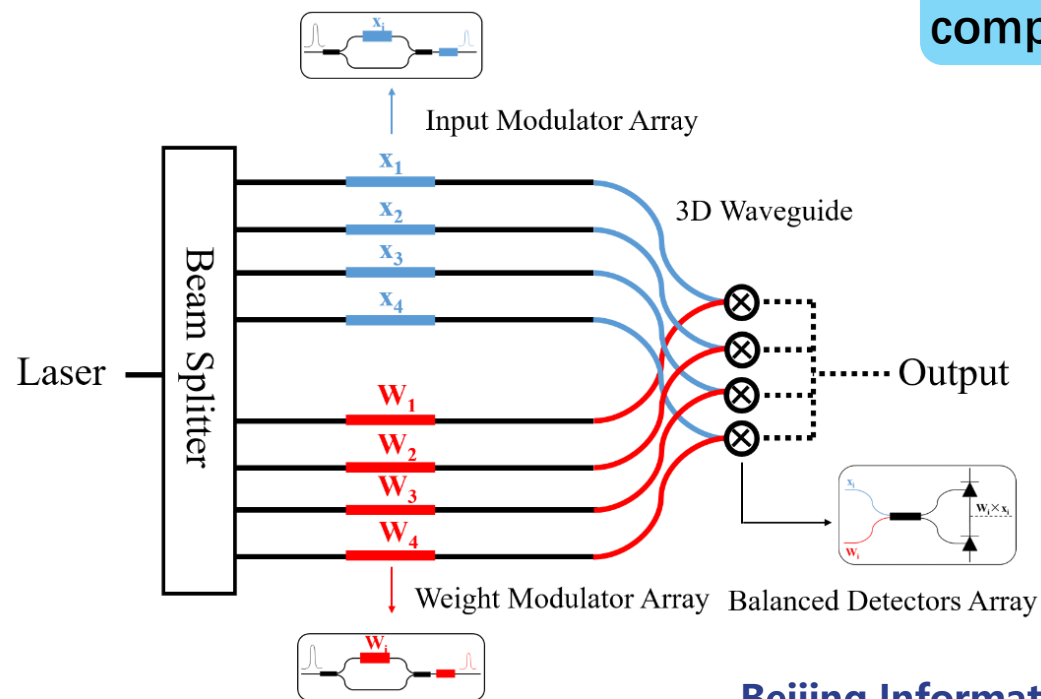
Input: $E_x(t) = A_x e^{i(\omega t + \phi_x)}$

Weight: $E_w(t) = A_w e^{i(\omega t + \phi_w)}$

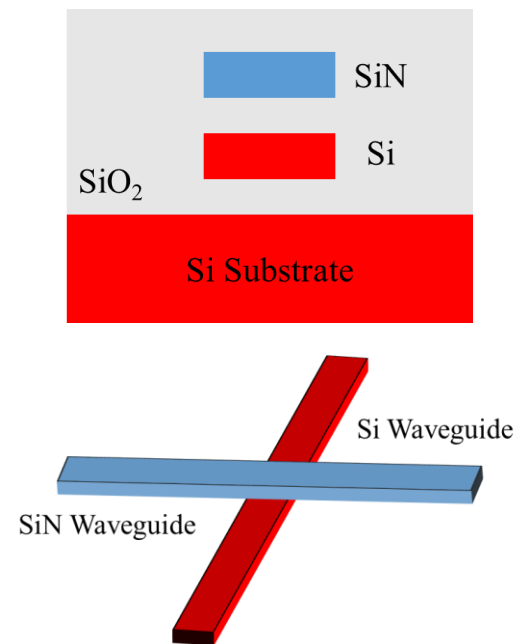
Output: $I = I_1 - I_2 \propto A_x A_w \cos(\Delta\phi)$

Architecture based on balanced detection

Parallel computation



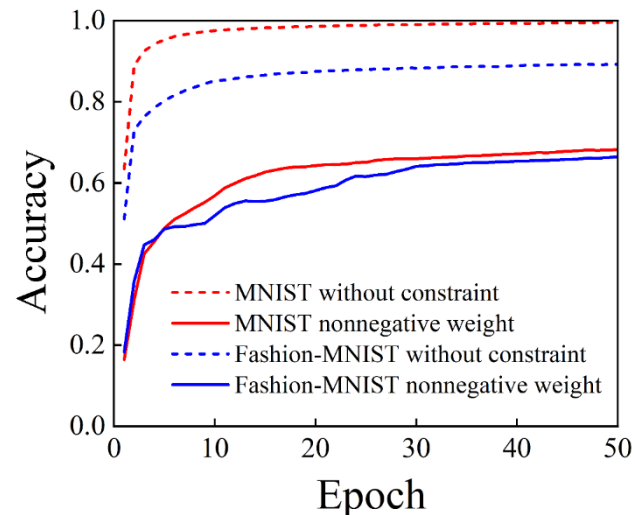
SiN-Si architecture



2.1 Quantization



MNIST and Fashion-MNSIT datasets

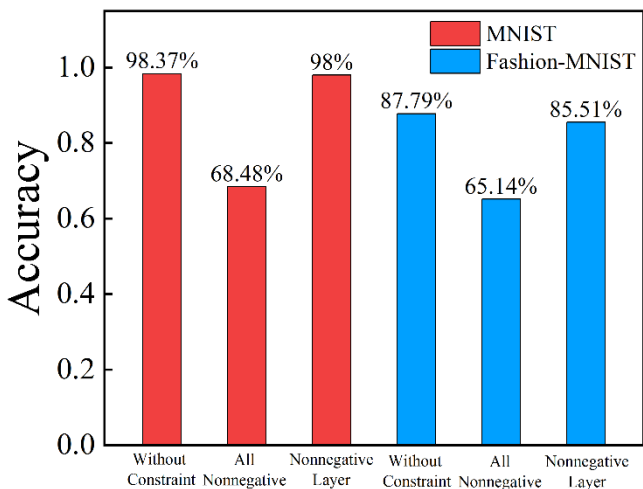


architecture

| Neural network | parameter |
|----------------|-----------|
| CON1 | 75 |
| CON2 | 375 |
| FCNN1 | 5120 |
| FCNN2 | 2048 |
| FCNN3 | 320 |



partial nonnegative



Parameter comparison

| Neural network | | parameter |
|---------------------|----------|-----------|
| Normal weight | positive | 3908 |
| | negative | 4030 |
| | zero | 0 |
| partial nonnegative | positive | 6689 |
| | negative | 416 |
| | zero | 833 |

Power consumption:

MNIST:

89.68%

Fashion-MNIST:

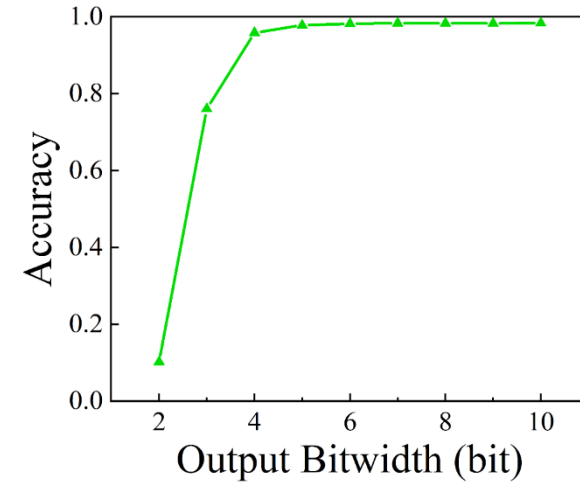
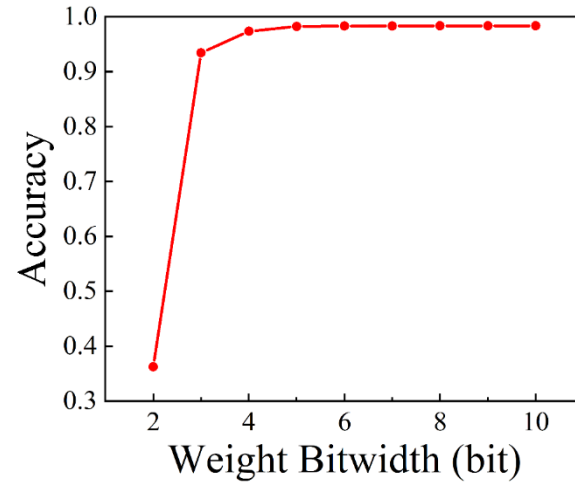
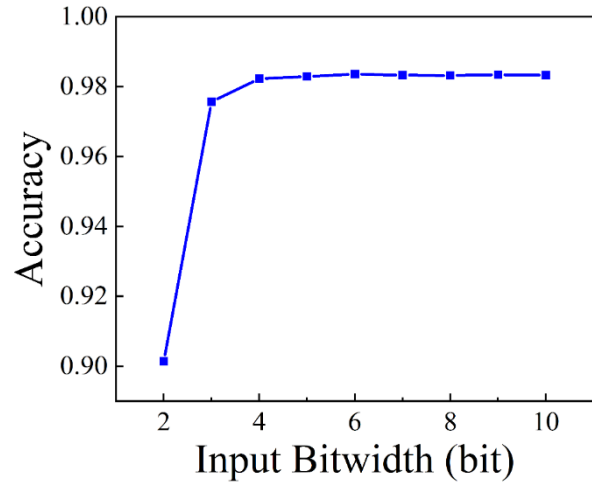
88.89%

Neural Network Type

2.1 Quantization



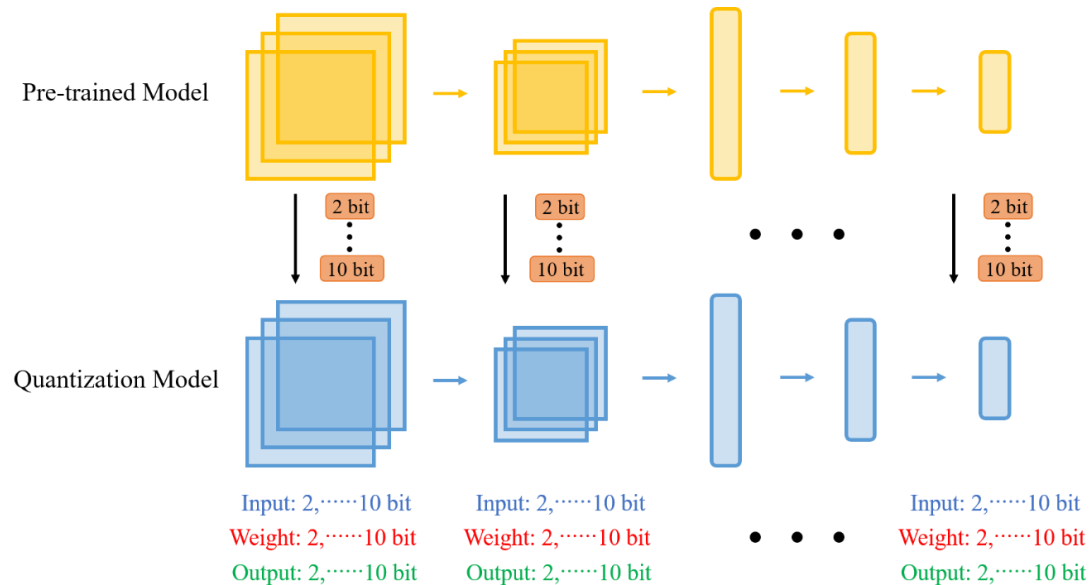
Accuracy at different input、weight、output



Quantizaion widths
between different
layers

Inside layer
Input weight output
Quantizaion bits

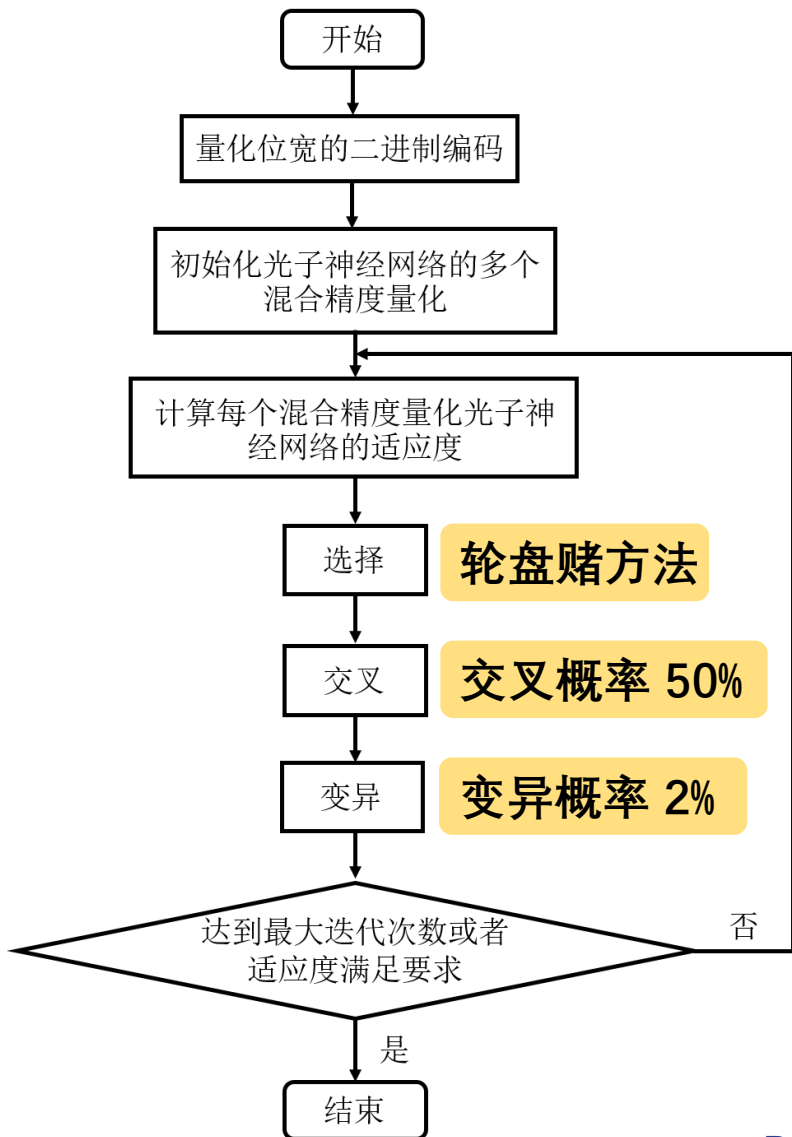
Mixed precision quantizaion



2.1 Quantization



Genetic algorithm

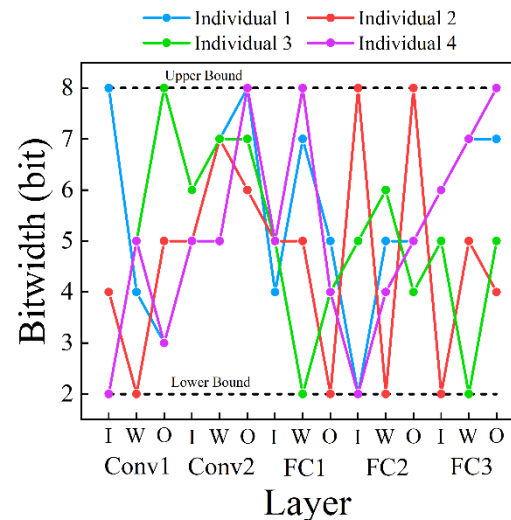


1. Binary encoding:

2---8 bit

$$x = \left(\sum_{i=0}^2 b_i \cdot 2^i \right)_{10} = (b_2 b_1 b_0)_2 \quad x_{bit} = \text{round} \left(2 + x \frac{8-2}{2^3-1} \right)$$

2. initialization:



3. Fitness calculation:

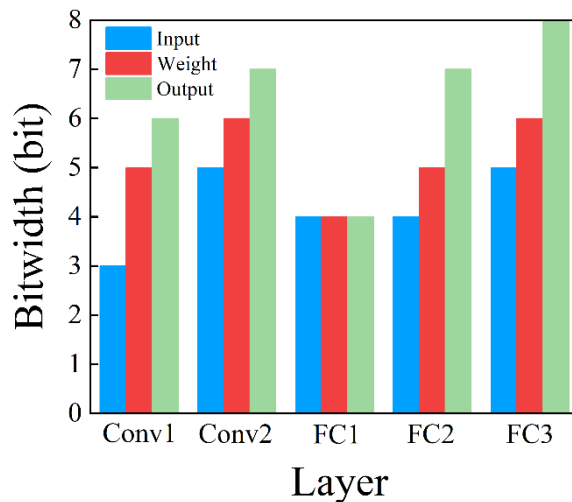
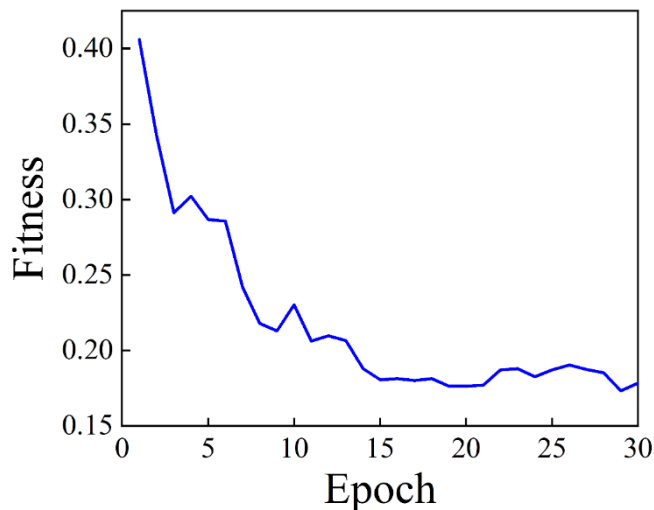
$$f = \alpha \cdot (acc_{org} - acc_{quan}) + \beta \cdot \frac{\sum_{i=1}^{15} P \cdot x_{bit}}{\sum_{i=1}^{15} P \cdot 32}$$

$\alpha = 1$
 $\beta = 5$

2.1 Quantization



MNIST dataset



Input : 4.12 bit

weight: 4.45 bit

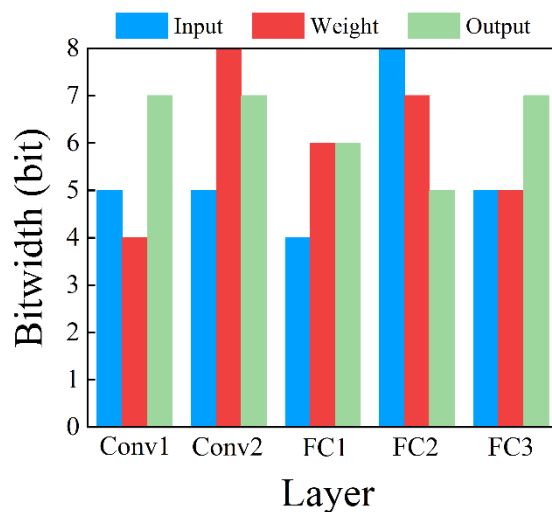
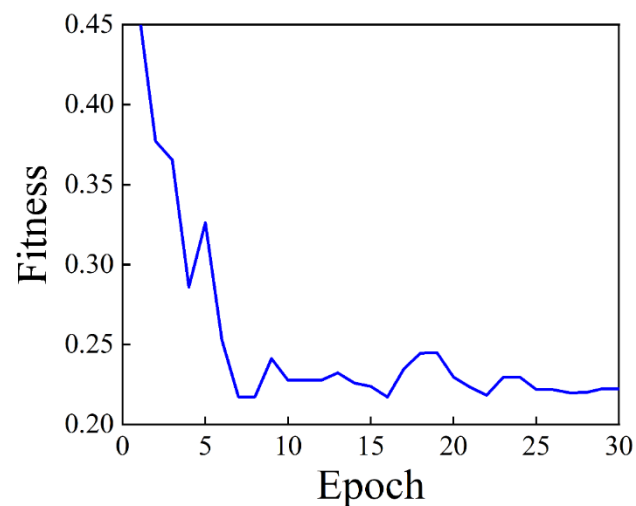
output: 4.94 bit

Compared with **32 bit**

0.65% accuracy decrease

85.94% parameter compression

Fashion-MNIST dataset



Input : 4.72 bit

weight: 6.26 bit

output: 6.03 bit

Compared with **32 bit**

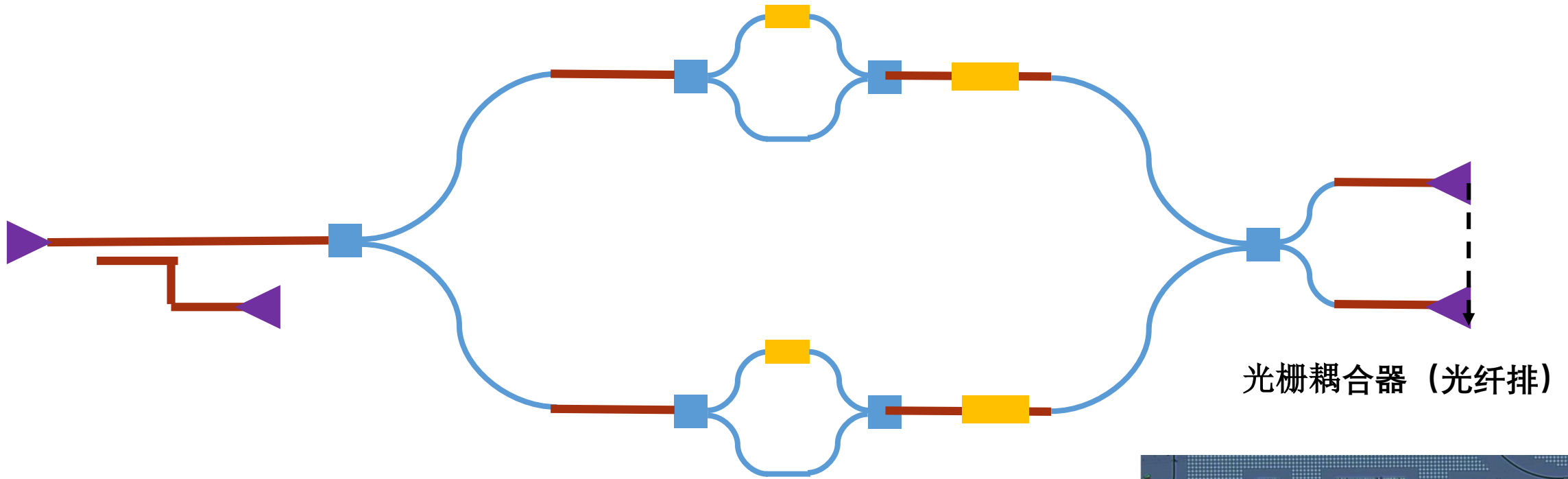
0.80% accuracy decrease

82.28% parameter compression

3 Experiment



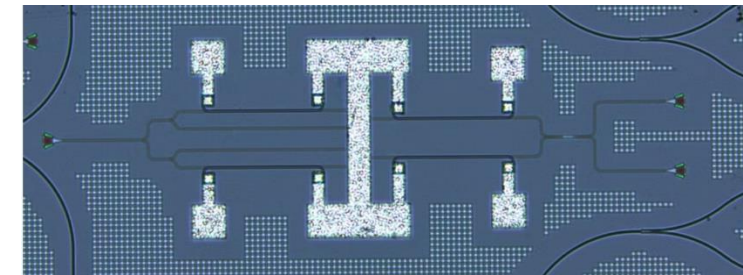
Architecture ①: Balanced detection (MZI-based)



上下对称等长

Input parameter: x
Weight parameter: W

The output current $I_{out} \propto W * x$

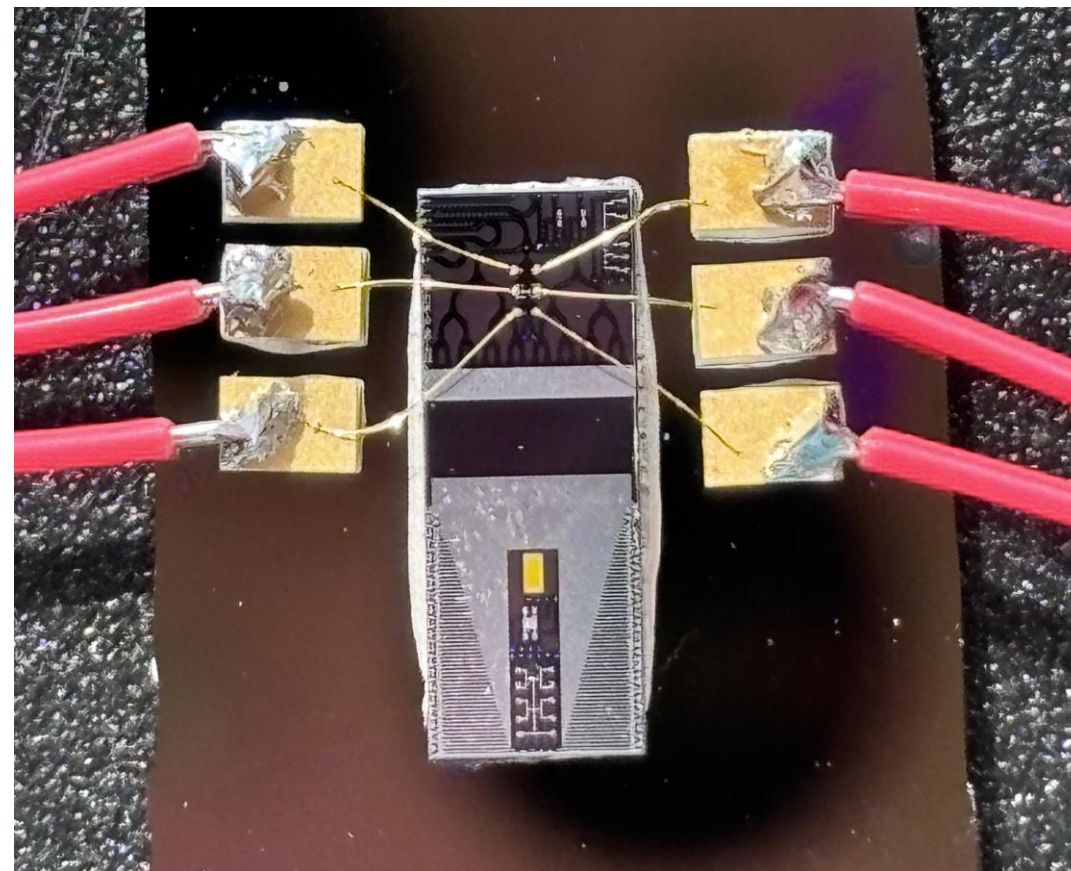
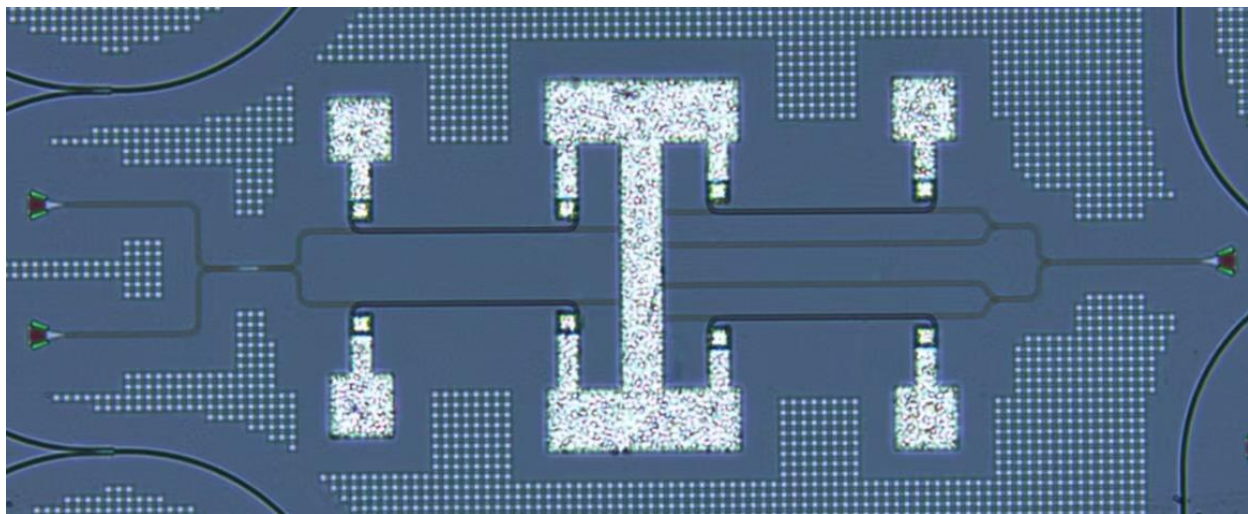


Experiment:



Architecture ①: Balanced detection

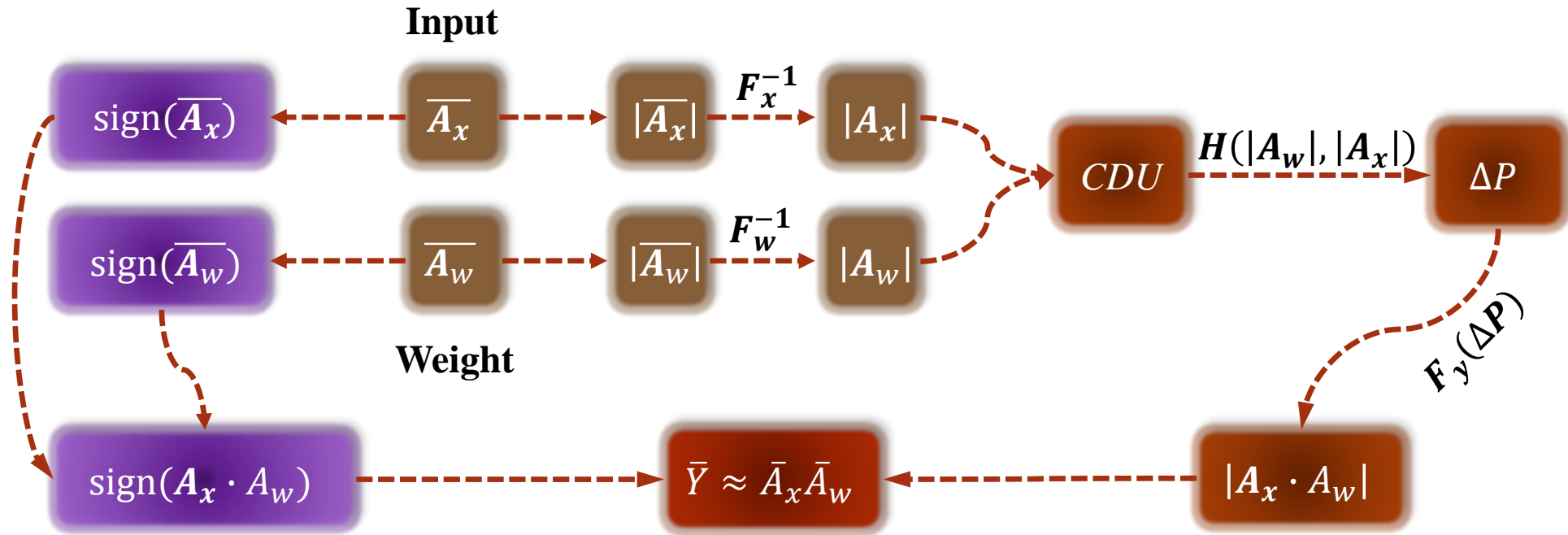
Chips are fabricated in AMF(Advanced Micro Foundry), Singapore



Experiment: Architecture ①



- ONN realize multiplication



where

$$\begin{cases} \bar{A}_1 = F_1(A_1) = a_1 A_1 + b_1 \\ \bar{A}_2 = F_2(A_2) = a_2 A_2 + b_2 \\ \bar{P}_0 = F_0(P_0) = a_0 P_0 + b_0 \end{cases}$$

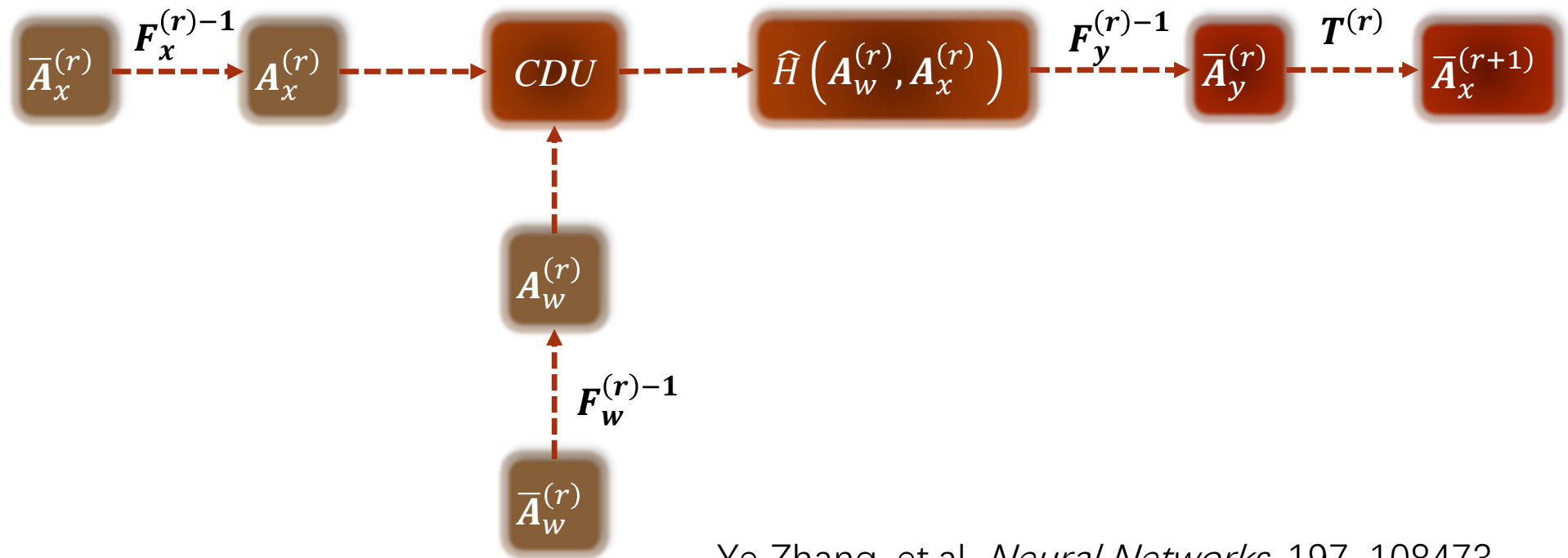
- The experimental realization of A_1 or A_2 is achieved by applying the voltage on the MZI obtained through
- $u = M^{-1}(A_i)$.

Experiment: Architecture ①



Application: Image classification

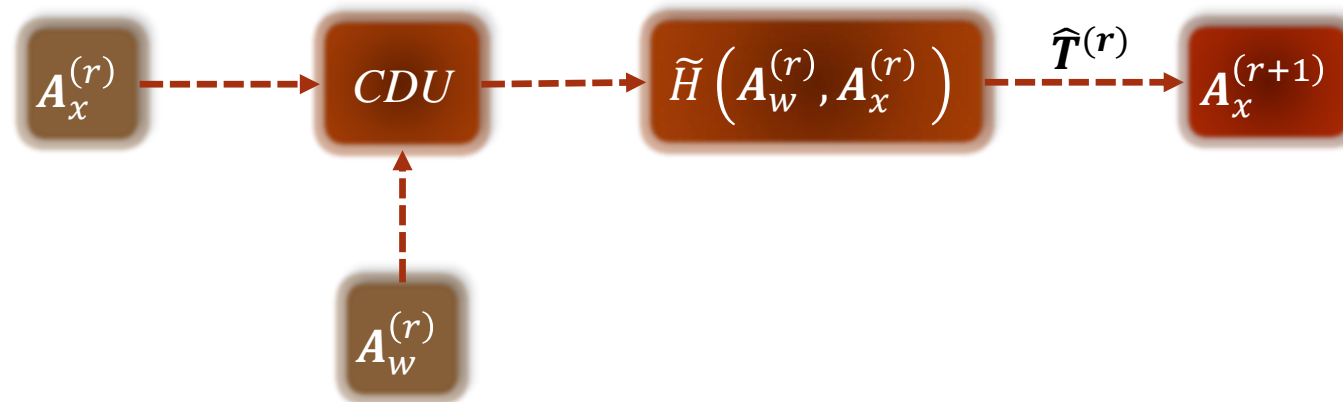
- Improve the process
 - For fully-connected neural networks



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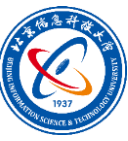
Application: Image classification

- Improve the process
 - To decrease the linear transformation

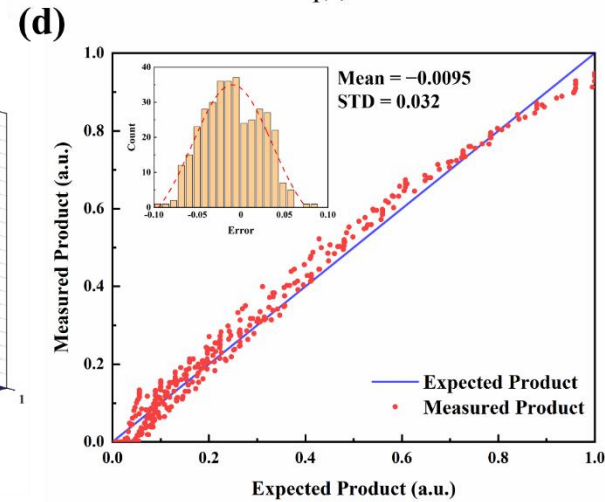
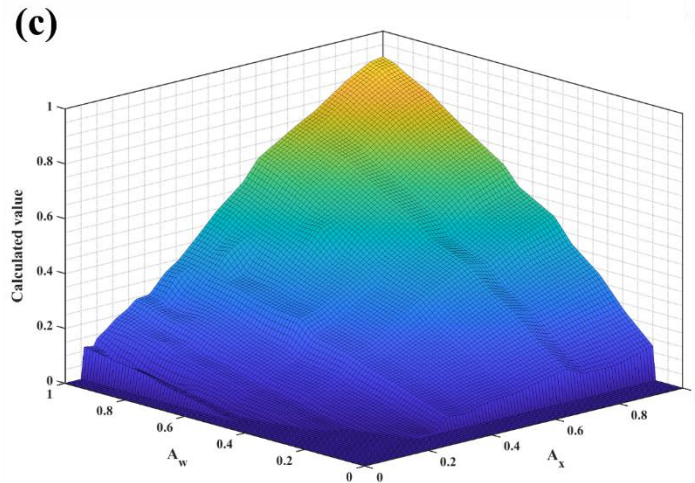
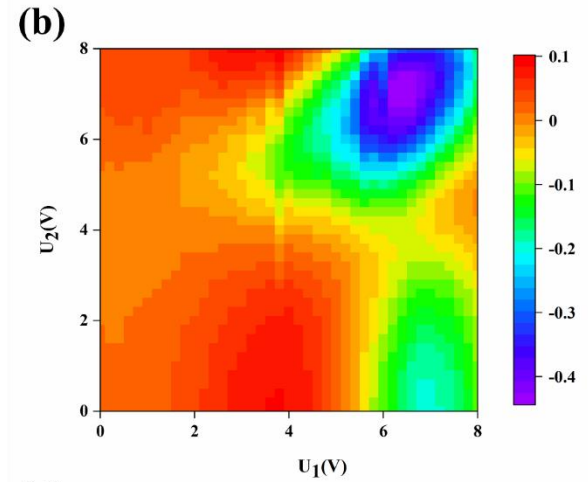
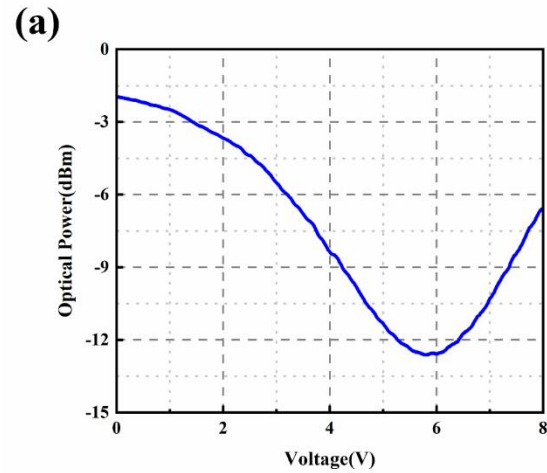


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Experiment: Architecture ①



Test result



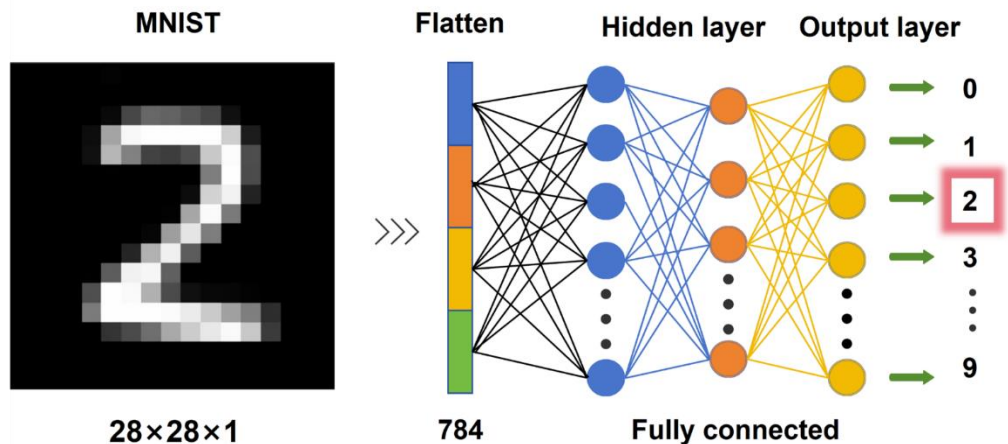
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Experiment: Architecture ①

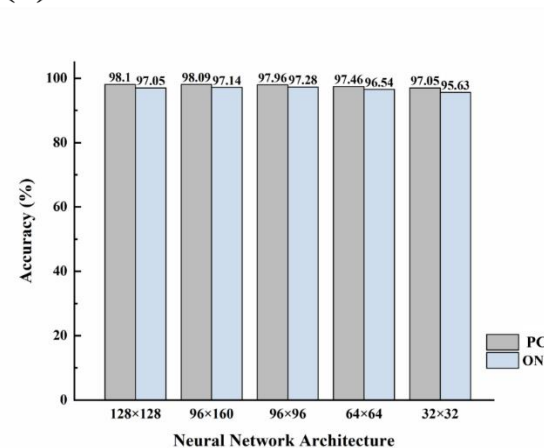


Experimental results

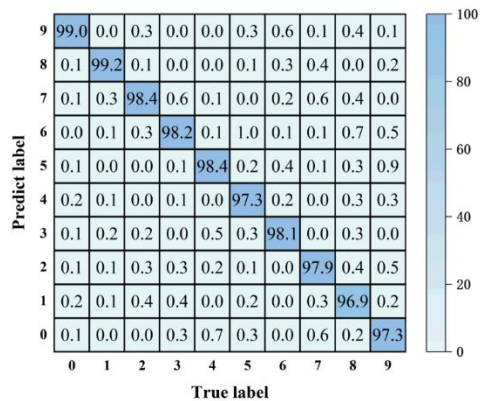
(a)



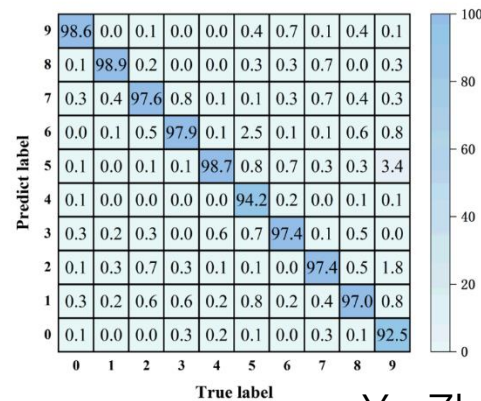
(b)



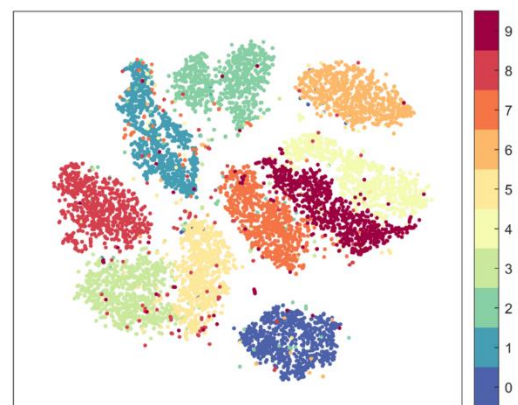
(c)



(d)



(e)



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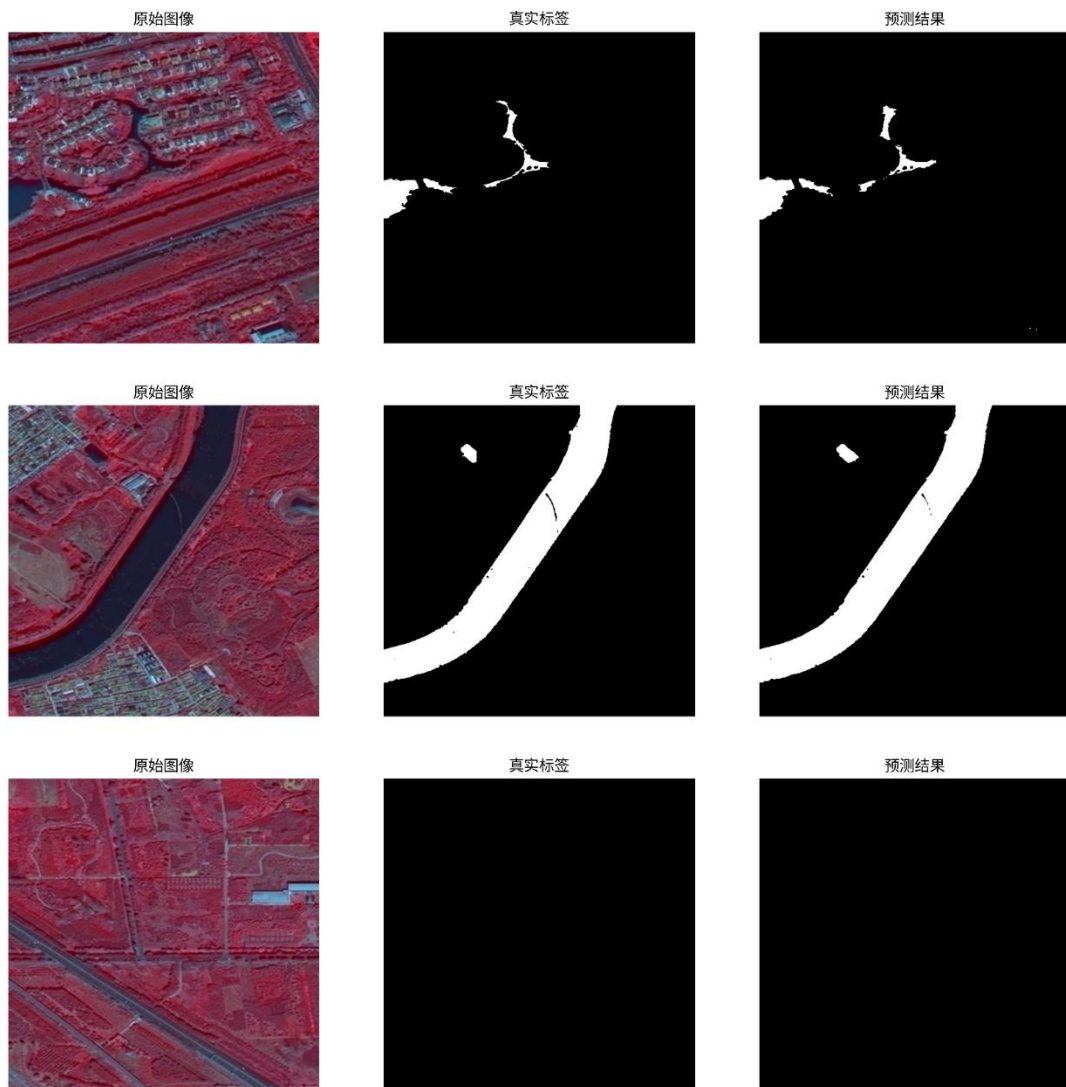
Experimental results

| architectures | Ideal training accuracy | Ideal testing accuracy | ONN accuracy |
|-----------------------|-------------------------|------------------------|--------------|
| 1 hidden layer: 8 | 96.7% | 100% | 97.3% |
| 2 hidden layers:4,3 | 95.8% | 100% | 96% |
| 3 hidden layers:4,4,3 | 99.2% | 100% | 97.3% |

Conclusion:

1. In the experiment, although the output power is not perfectly proportional to the product of the inputs A_1A_2 , our ONN is able to replicate the results of the ideal neural network with minimal accuracy loss.
2. The results obtained for different neural network architectures are consistently high, indicating that our method is universal and highly robust.

Digital Earth application



Photonic chip could be of great use in the digital earth application

- **Remote Sensing**
- **Ground Level Street View / Surveillance**
- **Underwater Geophysics / Sonar**
- **Indoor Positioning**



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Thank you !