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# A New Optical Neuron Device for All-Optical Neural Networks

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A new optical neuron device having a capability of both summation and thresholding operations in optical computation has been developed. Using this neuron device combined with a lenslet array and a memory mask, an all-optical neural network has been constructed to provide purely optical parallel calculations. The network performs an associative memory function without any help of electronic computing.

## 1. INTRODUCTION

Great efforts have been made to realize the implementation of the computing system based on the neural networks. To fully exploit the parallel characteristics of neural networks, an optical implementation has been sought. However no system which is implemented with pure optical processing has been realized.

In general, optical devices for neural networks are required to have functions for summation, subtraction, multiplication and thresholding operations in optical computation. To date, several optical neural networks have been reported and demonstrated.[1-4] All of these networks have used electric thresholding processing in operation.

In this work, a new optical neuron device having summation and threshold processing functions in optics has been developed. An all-optical neural network using this optical neuron device has been constructed, combined with a lenslet array and a memory mask, to provide purely optical calculations for an associative memory. The network can recall the alphabet letters without any help of electronic computing.

## 2. DEVICE CONFIGURATION

Figure 1 shows a cross section of the optical neuron device. The optical neuron device is composed of aluminum thin film segments operating as 6×6 neuron electrodes (2.5mm×2.5 mm in size) arranged between a hydrogenerated amorphous silicon (a-Si:H) layer as a photoreceptor and a ferroelectric liquid crystal (FLC) layer in a chiral smectic C phase as a light modulator.

The a-Si:H photoreceptor was designed to a p-i-n diode structure. A boron-doped p-type layer of about 700 A in thickness, an undoped intrinsic layer of 1.7 $\mu$m, and a phosphorus-doped n-type layer of about 5000 A were continuously deposited on an indium-tin-oxide (ITO) transparent conductive glass substrate by plasma-CVD. And a newly developed conductive polymer[5] was used as an alignment layer for the FLC. This polymer

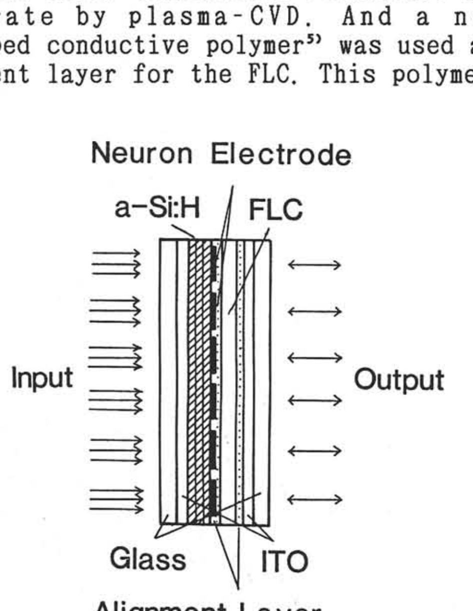


Fig. 1 A cross section of the optical neuron device

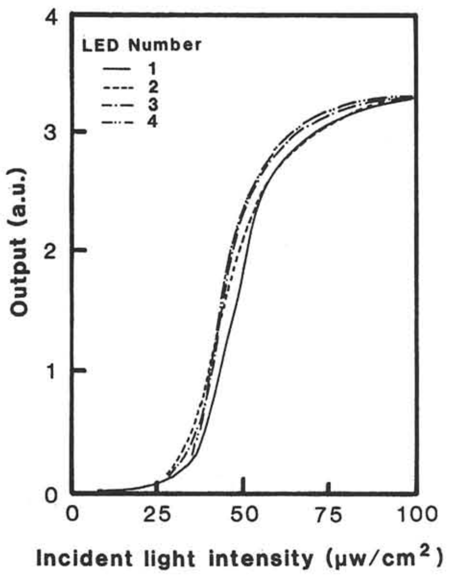


Fig. 2 The thresholding characteristics as a function of the incident light intensity

prevents extra charges from accumulating at a surface of the FLC. The thickness of the FLC cell was kept about 1 μm for getting a high contrast ratio of 300 : 1. The output patterns are obtained as a cross-Nicol read-out by a beam splitter (BS).

## 3. DEVICE CHARACTERISTICS

Figure 2 shows the thresholding characteristics of a neuron in the optical neuron device as a function of the incident light intensity. The output depends only on the sum total input light intensity, regardless of the number of the light source. This characteristics indicates the capability of the precise optical summation. The diode strucutre can produce a good linearity relationship between a photocurrent induced in the a-Si:H and an incident light intensity, that is $\gamma = 1$, which is essential to realize a precise summation in optical computation. The sum total of the incident light intensity to change from OFF to ON state of the FLC is about 45 μW/cm² under the applied pulse voltage of 10 Vp-p.

Electrons induced in the a-Si:H layer by a plurality of incident lights are summed at each neuron electrode. These electrons change the applied voltage across the corresponding FLC cell and modulated its transparency. A series of the summation and thresholding operations can be performed typically in the response time of 100 μsec. The processing speed of the optical neuron device, from writing-in an input pattern to reading-out and erasing an output pattern, is typically 300 μsec.

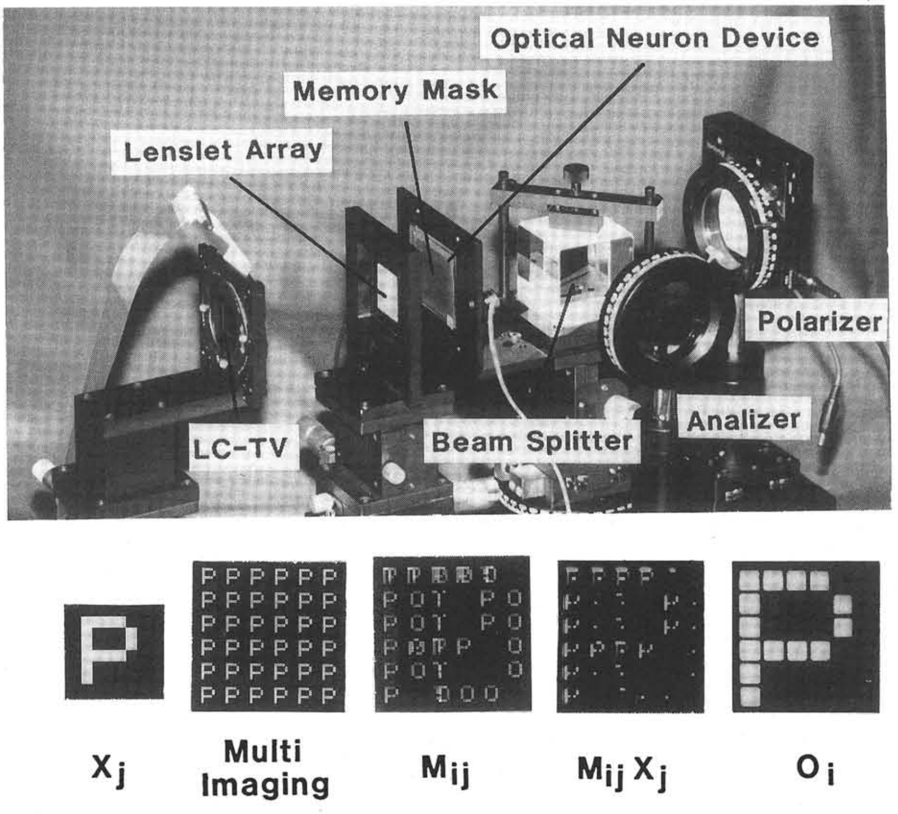


Fig. 3 Setup of the all-optical neural network and the schematic diagram of the experimental recalling process of "P".

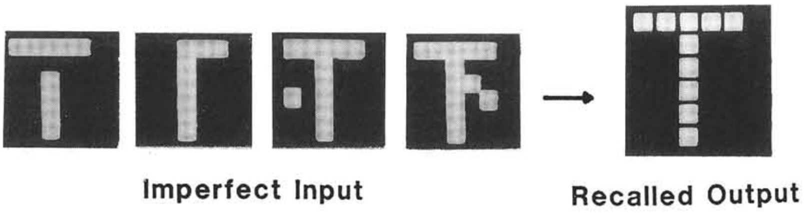

Fig. 4 Recalled output pattern against the imperfect input patterns of "T" with defects or noises.

## 4. ALL-OPTICAL NEURAL NETWORK

The all-optical neural network for an associative memory has been constructed as shown in Figure 3. The network has 36 (6×6) neurons in the input layer and the equal number of neurons in the output layer. The schematic diagram of the experimental recalling process of alphabet letter (P) has been also shown in Figure 3. A liquid crystal television (LC-TV) is used as an input device for the generation of the input patterns, Xj, consisting of 6×6 = 36 pixels. A 6×6 lenslet array (f=20mm, $\phi$ =3mm) makes the same 36 images of an input pattern at a surface of the memory mask which is a transparent film with 16 gray levels representating the weight of a synaptic connection, Mij, for 36×36 synaptic matrix. Each Mij storing 3 alphabet letters (O, P, T) was determined by using an orthogonal recollection model through a computer simulation. The transmitted light through the memory mask, which represents the product of the input signal Xj and the synaptic weight Mij, is focused on the surface of the neuron device. Each neuron electrode summs the multiplex signals MijXj (j=1, · · , 36), and then the thresholding operation has been performed to show the output pattern Oi in the FLC layer.

Figure 4 shows that the perfect pattern of "T" can be recalled against the several imperfect input patterns with noises or defects. It is also confirmed that the perfect output patterns of (O, P, T) can be recalled against some imperfect input patterns with hamming distances within 2. These experimental results are in good agreement with that obtained by the computer simulation.

The processing speed is limited by the speed of the optical neuron device, which operates at a speed of 3000 frames/sec. Thus the operational speed of the proposed network with 6×6 neurons is approximately $3000 \times (6\times6)^2 = 4\times10^6$ interconnection operation per second.

## 5. CONCLUSIONS

We have developed a new optical neuron device using the a-Si:H photoreceptor with a diode structure and the FLC cell with a new conductive polymer. The novel capability of the optical summation and thresholding operations in a parallel processing has been confirmed. Using this optical neuron device in combination with a lenslet array and a memory mask, an all-optical implementation of the associative memory has been shown without any help of electronic computing. Imperfect input patterns have been demonstrated to give perfect output patterns in the recalling operations.

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