ALL OPTICAL READ ONLY MEMORY HAVING 2-BIT ADDRESS

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Abstract: The all-optical read only memory (ROM) having 2-bit address has been successfully demonstrated with a numerical assessment employing an all-optical 2-to-4 line decoder based on cross gain modulation (XGM) in semiconductor optical amplifiers (SOA). Experimental demonstration also has been carried out for the operation of decoder. We have shown that four characters can be stored at each address as an American standard code for information interchange (ASCII).

1. INTRODUCTION
Every intellectual system requires non-volatile memory to save the initial program that runs when the system is turned on or otherwise begins execution. The memory used for this purpose is not necessarily rewrites, so read-only memory (ROM) can be used for saving the initial program. Usually it is cost effective to use ROM rather than random access memory (RAM), so many computers employ ROM to store the initial program. Meanwhile, much effort has been made to develop all-optical digital logic circuits which can be a candidate for future replacement of low speed electrical circuits. All of the all-optical Boolean logic gates had been demonstrated [1-5] by means of XGM. Here, based on these logic operations we have demonstrated all-optical ROM which has not been demonstrated yet. We stored four characters at each addresses in the American standard code for information interchange (ASCII) format utilizing an all-optical 2-to-4 line decoder. First, experimental demonstrations of the Boolean operations that are required to construct an all-optical 2-to-4 line decoder are carried out, and then an all-optical ROM employing this decoder is demonstrated using a numerical assessment.

2. THEORY
The ROM we would like to demonstrate has two address bits. Thus, four different data can be stored at each memory address. So we stored the word, as an example, ‘KIST’ in the ROM as shown in Figure 1. (The word ‘KIST’ is just an example for the demonstration of this system, so this word can be changed by using other characters that can be formed by changing some of the connections and this will be illustrated later.) The ASCII code table for each of the characters in ‘KIST’ is shown in Table 1. When the inputs of the 2-bit address are applied to this ROM, the corresponding outputs of the 7-bit ASCII character come out. In order to implement this function, we utilize the 2-to-4 line decoder that is used widely in digital electronics [6]. The function of the 2-to-4 line decoder is illustrated in Figure 2 with the truth table that shows its Boolean operations. If we let the input be a binary number where $I_1$ is the most significant bit (MSB) and $I_0$ is the least significant bit (LSB), only the output port number that corresponds to the binary number indicates level-1 while the others indicate level-0.
summation of the decoder outputs. If we designate the MSB as Bit6 and the LSB as Bit0, each bit of the outputs can be written as shown in Equation (1). It is worth noting that Bit6 can be implemented by nothing but a Clock signal, but we obtain it as Equation (1-a) to observe the signal degradation. Simple logical calculations show that these output bits from the ASCII word ‘KIST’ in response to the four binary numbers at the inputs to the decoder.

\[ Bit6 = O_0 + O_1 + O_2 + O_3 \]  \hspace{1cm} (1-a)

\[ Bit5 = O_2 + O_1 \] \hspace{1cm} (1-b)

\[ Bit4 = O_3 + O_3 \] \hspace{1cm} (1-c)

\[ Bit3 = O_4 + O_4 \] \hspace{1cm} (1-d)

\[ Bit2 = O_5 \] \hspace{1cm} (1-e)

\[ Bit1 = O_6 + O_2 \] \hspace{1cm} (1-f)

\[ Bit0 = O_6 + O_1 + O_3 \] \hspace{1cm} (1-g)

To construct this function all-optically, we utilized the XGM process in SOAs. Boolean expressions of the outputs for the 2-to-4 line decoder can be written as Equation (2) and its all-optical implementations are shown in the Figure 4. From Figure 4, the logical operation principles can be understood by figuring out the roles of the pump and probe signals [1-5]. The RZ signal was assumed for our implementation because the XGM process for the RZ signal is generally faster than the NRZ signal according to [5].

\[ O_6 = I_1 I_0 \] \hspace{1cm} (2-a)

\[ O_1 = I_1 I_0 \] \hspace{1cm} (2-b)

\[ O_2 = I_1 I_1 \] \hspace{1cm} (2-c)

\[ O_3 = I_1 I_0 \] \hspace{1cm} (2-d)

3. RESULTS

The demonstration of the 2-to-4 line decoder was carried out with experiments for the specific input patterns making all of the possible one-zero combinations. In order to optimize the XGM process, attenuators and erbium doped fiber amplifiers (EDFAs) were used to adjust the pump and probe power levels. 10Gbps RZ input patterns were applied to the 2-to-4 line decoder and the exact output patterns were obtained as shown in Figure 5.

As it is difficult to make independent random input patterns of \( I_1 \) and \( I_2 \) and experimental demonstration for the entire system is somewhat bulky, the operation of the all-optical ROM and the signal quality evaluations were carried out using a numerical assessment. In our numerical assessment, the propagation equation and the rate equation were adopted from reference [7] to create Equations (3) and (4). To make faster calculations, the integral equation approach [8] was used for the static simulation by modifying Equation (3), so the equation takes the integral form as shown in Equation (5). The SOA simulation parameters that correspond to Equations (3)-(5) are shown in Table 2 with the parameter names. For the time domain dynamic simulations, Equation...
(3) was expanded as a full propagation equation including the time dependence as shown in Equation (6), and the transfer matrix method [9] was utilized with Equation (6).

\[
\frac{dN}{dt} = \frac{J}{qd} - \frac{N}{\tau_s} \frac{g(N)}{\hbar \omega_0} [\epsilon], \quad \tau_s = \frac{1}{A + BN + CN^2}
\]

\[
a_z(z) = a_z(0) + \frac{1}{2} g(N) \left\{ \frac{1}{\tau_s} \sum_{n} \frac{(1 - j\beta_n)\epsilon_n}{1 + j\Delta \omega_n \tau_n} \right\} \frac{\gamma_s a_i}{2}
\]

\[
\frac{\partial a_i}{\partial z} + \frac{\partial a_i}{\partial \tau} = \frac{1}{2} g(N) \left\{ \frac{1}{\tau_s} \sum_{n} \frac{(1 - j\beta_n)\epsilon_n}{1 + j\Delta \omega_n \tau_n} \right\} \frac{\gamma_s a_i}{2}
\]

<table>
<thead>
<tr>
<th>(a_z(z))</th>
<th>complex amplitudes of the signal fields</th>
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<tbody>
<tr>
<td>(z)</td>
<td>propagation axis</td>
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<td>(N)</td>
<td>carrier density</td>
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<tr>
<td>(g(N))</td>
<td>modal gain</td>
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<tr>
<td>(\alpha)</td>
<td>linewidth enhancement factor</td>
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<td>(\gamma_s)</td>
<td>scattering loss per unit length</td>
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<td>(\Delta \omega)</td>
<td>frequency difference ((\omega_i - \omega_j))</td>
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<td>(\epsilon_m)</td>
<td>inverse saturation powers from the nonlinearity</td>
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<td>(\beta_m)</td>
<td>contributions of line-width enhancement factor</td>
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<td>(\tau_m)</td>
<td>relaxation times</td>
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<tr>
<td>(\iota, j, k, l)</td>
<td>index of different wavelengths</td>
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<tr>
<td>(\Delta \omega_{ik})</td>
<td>frequency difference ((\omega_i - \omega_k))</td>
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<td>(J)</td>
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<td>(q)</td>
<td>electron charge</td>
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<td>(d)</td>
<td>active layer density</td>
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<tr>
<td>(A, B, C)</td>
<td>Recombination coefficient</td>
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Table 2. Names and values of SOA simulation parameters

Taking SOAs that have lengths of 300μm and driving currents of 300mA, the XGM processes were optimized by adjusting the pump and probe power levels with the help of the static simulation. Pump power levels of 0dBm to 10dBm and probe power levels of -20dBm to -10dBm were assumed for the 0-level to 1-level in the analysis. Amplified spontaneous emission (ASE) noise was added to both the input signals and the clock signal, so all of the input signals have an OSNR of around 17dB.

Figure 6 shows the simulation results of the all-optical ROM. Decoder output signals from \(O_0\) to \(O_1\) agreed well with our previous experiment shown in Figure 5. For each input address from \(0 (I_1=0, I_0=0)\) to \(3 (I_1=1, I_0=1)\), the corresponding output ASCII code characters were achieved exactly from 'K' to 'T' as expected. As can be seen in Figure 6, the zero level of the output bit was more floated as many decoder outputs were added.
The signal quality was evaluated by calculating the eye diagram with a 2^7-bit pseudo random bit sequence (PRBS) input pattern that takes different seed values. Eye diagrams from Bit0 (LSB) to Bit4 are shown in Figure 7. (It was not necessary to evaluate the qualities of Bit5 and Bit6 (MSB) because these bits do not contain any information in the case of the word ‘KIST’.) Q factors of above 7 could be achieved for all of the output values.

4. CONCLUSION

We have demonstrated an all-optical ROM employing an all-optical 2-to-4 line decoder based on XGM in SOAs. Experimental demonstrations of the decoder output have been carried out and a numerical study for storing the four characters on the ROM has been done. Q factors of above 7 could be achieved with input signals having a 17dB OSNR while running at 10Gbps.

REFERENCES