A Photonic-Crystal Logic Circuit Based on the Binary Decision Diagram

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One of the challenges in optoelectronics is the development of novel photonic devices that can be used for constructing large-scale digital computing systems (LSIs). The authors propose one such promising device, which is a *photonic-crystal logic circuit based on the binary decision diagram.*

In developing photonic crystal LSIs, we must first consider the architecture suitable for constructing logic circuits with photonic crystals. The nature of photonic crystal devices is quite different from that of CMOS, therefore we cannot make use of the existing circuit architecture (an architecture based on the Boolean equation) conceived and developed for CMOS devices. In this paper the authors propose that, for constructing LSIs with photonic crystals, we should develop a circuit architecture that is based on the *binary decision diagram* instead of on the Boolean equation.

The binary decision diagram (BDD) is a way of representing digital functions by using a directed graph. It provides a complete and concise representation for most digital functions encountered in logic design application. A BDD is a graph consisting of many nodes and two leaves, with each node labeled by a variable (Fig. 1). In determining the logic value of the function for a given set of the variables, we start from the root and proceed downward to a leaf. At each node, we follow the branch corresponding to the value of the variable; i.e., we follow the 1 branch if $Xi = 1$ and the 0 branch if $Xi = 0$. The logic value of the function is equal to the value of the leaf we reach; the logic value is 1 if we reach the 1 leaf and 0 for the 0 leaf.

The function of the node in BDD is a two-way switching controlled by an input variable. In a photonic crystal circuit, this switch function can be easily implemented by using an optical directional-coupler switch in which the coupling coefficient for two waveguides can be modulated by an input voltage (Fig. 2). In materializing a BDD on a photonic crystal, we combine identical directional-coupler switches into a cascade to construct the BDD graph, using an optical waveguide as a branch for connecting two nodes.

The authors designed a photonic-crystal logic circuit for the sample BDD given in Fig. 1. The configuration of the circuit is illustrated in Fig. 3. An optical pulse is injected into the circuit at the root, and is transferred to a leaf along the BDD-graph path specified by the input voltages applied to the switch elements. The logic output is determined by observing which leaf the optical pulse reaches. Several elementary subsystems such as adders and comparators were also designed. In our rough estimation, a photonic crystal 32-bit adder is expected to operate at very high speed with a time delay of only 5-10 ps. (An up-to-date 32-bit CMOS adder operates with a delay of 1-2 ns.)

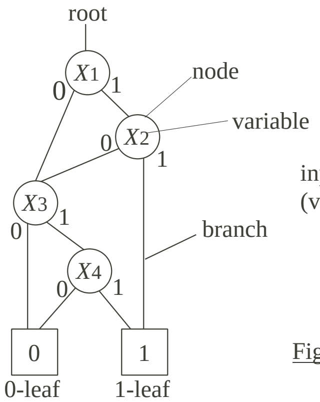

Fig. 1 Binary decision diagram. An example representing digital function $X_1X_2 \vee X_3X_4$.

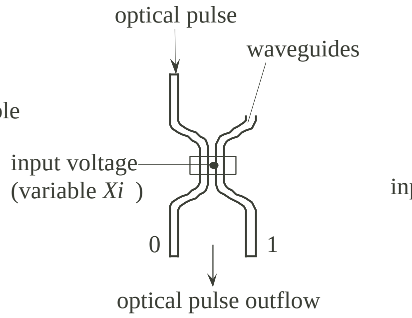

Fig. 2 Optical directional-coupler switch for implementing the function of the node.

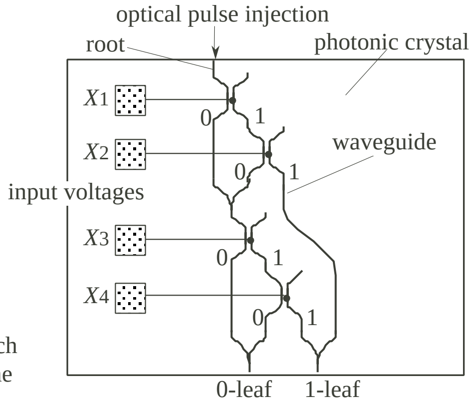

Fig. 3 Photonic-crystal logic circuit that materializes the BDD given in Fig. 1.