Guided-wave multiwavelength Content-Addressable Memory (CAM) processing module for database and networking applications

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Abstract

The proposed multiwavelength guided-wave CAM processing module provides parallel constant-time perfect-match search for database and networking/routing applications, with the capability of achieving an aggregate processing speed of 10^{12} bits/s.

1. Introduction

Any application requiring fast searches of databases, lists or lookup tables can be extensively improved by the use of content addressable memory (CAM). CAM provides faster performance over RAM by comparing the desired information against the entire data simultaneously [1]. CAM is not only suitable for database applications, it is also highly applicable to several networking applications. That include Ethernet address lookup, data compression, pattern-recognition, cache tags, high-bandwidth address filtering, and fast lookup of routing. Hence, CAM is used in applications where search time is critical and must be very short. For example, a CAM might store an Ethernet address (or IP address) and switch port numbers. The CAM compares the received data packets against the table that has been stored within, and if the comparison yields a match, the port identification is given, and routing control forwards the packet to the correct port or address (see Figure 1).

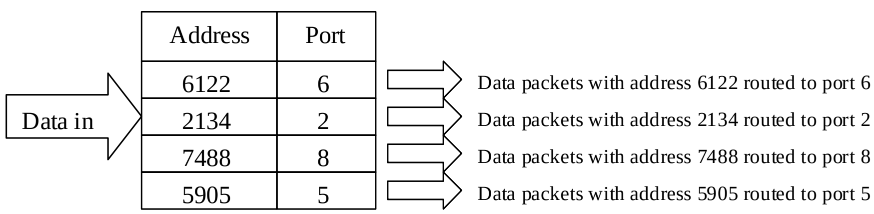

Figure 1. routing application

Hence the purpose of this paper is to present a module that realizes these equality search functionality. We name this proposed module Multiwavelength Equality Search Intensity-based (polarization-insensitive) Guided-wave Unit (MESIGU). MESIGU uses intensity-based dual-rail logic, therefore MESIGU can be realized with a wide range of existing intensity-based guided-wave components and techniques that are well developed under WDM technology (phase, intensity, polarization-insensitive and electro-absorption).

2. Equality Operation

The equality search is one of the most basic operations for database processing. This search is basically a matching process based on XOR (exclusive-OR) operation. If two comparing words are a match, the XOR operation will produce a resultant word containing only logical '0' bits. If two words do not match, the resultant XOR word will be a mixture of '0' and '1' bits. Equivalency results can be determined by simply logical 'OR'ing all of the individual bits in this intermediate word. The two words are mismatched if the result is a '1', and likewise the words are equivalent if the result is a '0'. Therefore MESIGU requires two inputs and produces an output. The inputs are comparand array (CA), representing the search words and relational array (RA), representing the database words. The output is the equality register (ER) which is the result of the comparison between CA and RA.

3. Dual-rail Logic

MESIGU uses dual-rail logic to encode binary logic on an optical signal [2]. Two pixels are required to represent a binary state. Figure 1 illustrates the schemes of dual-rail logic. Logical '0' is encoded using two pixels as an opaque pixel on the left, followed by a transmissive pixel on the right in CA. Whereas logical '1' in CA, is represented by a transmissive pixel on the left, then an opaque pixel on the right. However, the RA data are encoded in the exact complement of CA. Individual words on CA are differentiated from one another by encoding each with a unique wavelength. Due to color limitation in figure illustration, there is a difference between the white pixels in active elements and the white pixels in optical signals. In figure 1b, gray level pixels in dashed boxes symbolize illuminated optical signals with a designated wavelength. The "white" pixel, on the other hand depicts a non-illuminated optical signal. In the CA and RA, which is in effect a spatial light modulator, white pixels (with solid line) are "transparent state" (that passes all light) and black pixels denote an opaque state (that block any light).

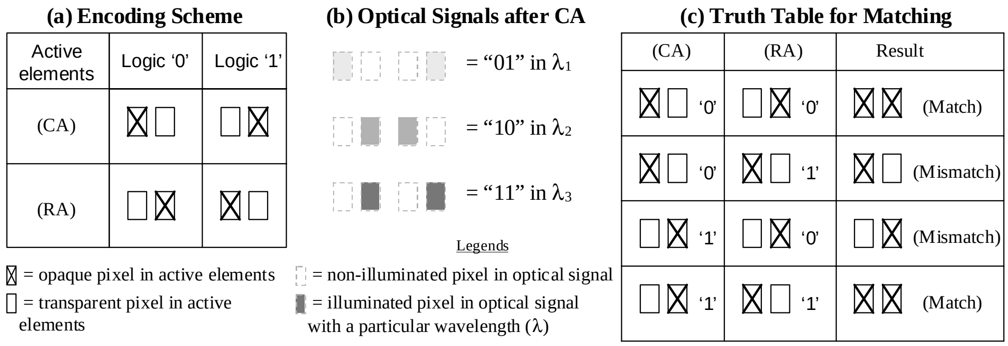

Figure 2. Dual rail logic

4. MESIGU Layout

There are five types of components required in MESIGU. The key building blocks include laser array, modulators for CA, multiplexers, modulators for RA, demultiplexers and detectors. If there are *m* words in the CA, *q* words in the RA, and *n* bits in both CA and RA, then there must be $2*m*n$ sources with *m* wavelengths, $2*m*n$ CA modulators, $2*n$ sets of multiplexers, $2*q*n$ RA modulators, *q* demultiplexers and $m*q$ detectors. Since each bit is comprised of left pixel and right pixel, MESIGU is designed to group all the left (or right) pixels of an arbitrary order bit (eg: 2^{nd} bit) of all CA words (from CA_0 to CA_m) into proximity. The multiplexers perform a fan-out function of the combined wavelengths from CA to the RA modulators. Subsequently, the branch of the same RA word from each group (irregardless of left and right) will be channeled to the same demultiplexer, performing the logical OR'ing process. The demultiplexers then separate the wavelengths to the appropriate detectors. In the detector array, the equality result is based on "negative logic". ER_{xy} is not illuminated when a CA word in order *x*, is equal to a RA word in order *y*, where $x < m$ and $y < q$. Depend on the design, the CA array can be optionally combined with the directly modulated lasers to simplify the hardware used.

Figure 3 depicts the guided-wave implementation layout of MESIGU. The unit is designed with 4 CA words, 4 RA words and 2 bits. The 4 CA words in figure 3 are CA_0="00", CA_1="01", CA_2="10" and CA_3="11". Whereas 4 RA words contain RA_0="01", RA_1="11" RA_2="00" and RA_3="10". In figure 3, modulator CA2 of "B1 left" (transparent) and modulator CA2 of "B1 right" (opaque) in figure 3 make up the logical '1' of CA_2. The remaining logical '0' of CA_2 is made of modulator CA2 of "B0 left" (opaque) and modulator CA2 of "B0 right" (transparent). Notice that the encoding of pixels for RA data is the opposite of the CA, as depicted in figure 1. RA3 of B0 left (opaque) and RA3 in B0 right (transparent) of figure 3 make up of the '1' of RA_3. The '0' is encoded into RA3 of "B1 left" (transparent) and RA3 of "B1 right" (opaque). The λ in figure 3 indicates the presence of the wavelengths in the particular branch of the waveguides. The CA or RA modulators with crosses are in fact opaque pixels that block all wavelengths. Exiting the waveguides, the wavelengths are de-multiplexed by the Rowland-circle grating demultiplexers [3] and channeled into corresponding photodetectors. Each group (Q0-Q3) of photodetectors in figure 3 corresponds to detectors associated with a "Demux" group (Demux 1 to Demux *q*) in figure 2. For example, in group Q3 of figure 3, photodetector 2 is not illuminated. This corresponds to a non-illuminated pixel in ER_{23}, which mean a match between CA_2 and RA_3. Similar interpretation applied to non-illuminated photodetectors of E_{02}, E_{31}, E_{10}. The MESIGU layout can be adapted to both fiber-based systems and integrated optics systems.

A preliminary performance analysis of the proposed system with 4 CA words, 2 RA words, of 2 bits each, running at a modulation speed of 9.7 GHz was conducted. MESIGU is able to provide a peak bit comparison rate of 310.4 Gigabits/sec. This represents significant performance improvement compared to any of its optical and even electronic counterparts. The current electronic CAM (such as NL877313 by NetLogic Microsystems) can perform 83 million data comparison per second with a data width of 288 bits. That translates to a processing rate of about 23.9 gigabits per second. This means the proposed 2-bits system is able to process 13 times faster than the current high performance CAM. MESIGU is also a scalable architecture. The number of words (in CA and RA) and the number of bits can be easily extended to provide a processing rate in the range of Terabits/second (as in EP^{3}IC, 82 Terabits/sec). The I/O bandwidth requirement for the proposed 2-bits system is about 155 gigabits/sec for both input and output.

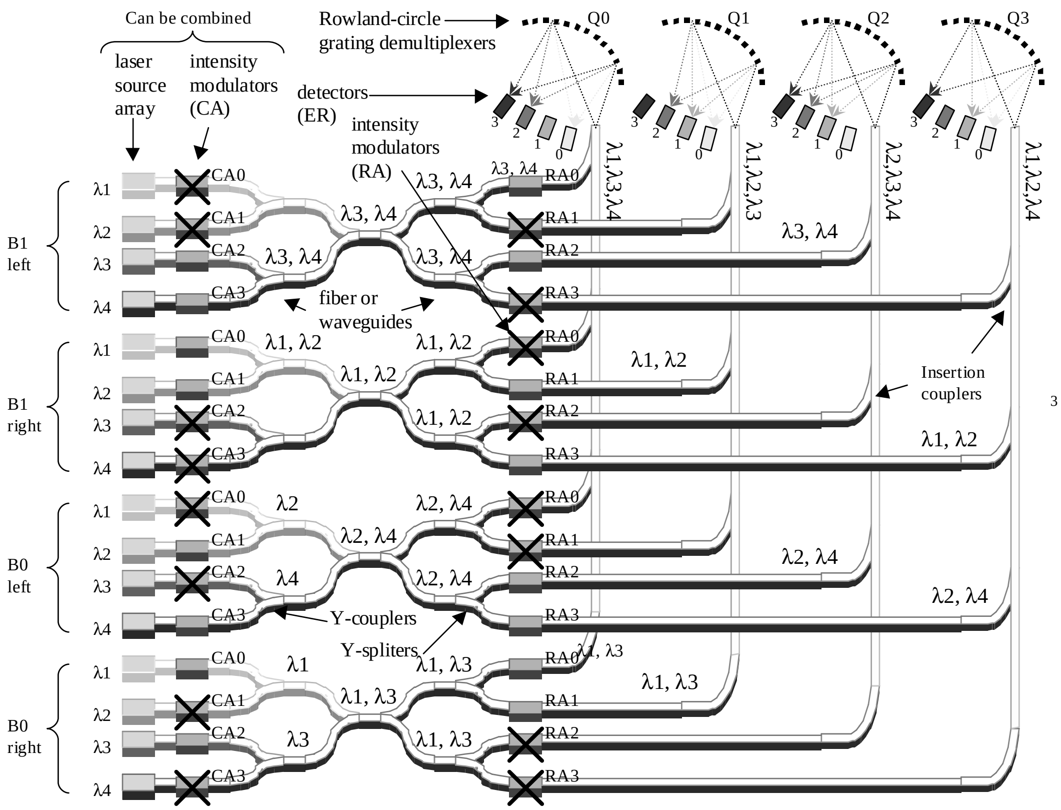

Figure 3. MESIGU implementation layout

The scalability of MESIGU is limited by the optical power of the laser source, the sensitivity of the detector, the fan out factor and the inherent power loss by the non-ideal components. Further improvements can also be done by utilizing more efficient y-couplers in MESIGU, since the y-coupler junctions in the multiplexing process impose heavy power loss (typically –3dB per junction). There is also an issue on the scalability of the wavelengths and it is mainly determined by the modulators (broadband modulation) and the sensitivity of the demultiplexers (diffraction to individual wavelengths). The t-crossings (crossovers in waveguides) in the architecture may not be a problem in fiber-based systems since such crossovers can be overlapped. However, these crossings will pose a challenge in the planar integrated-optics waveguide systems due to fabrication difficulties and penalties. In conclusion, an optical guided-wave polarization-insensitive module for high speed database processing system called MESIGU is presented. It harnesses a unique combination of guided-wave technology and multiwavelength architecture to achieve a high level of performance. MESIGU brings the optical high performance CAM processing schemes closer to where they might actually be built and compete with its electronic counterparts in terms of size and performance.

References

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