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NANO LASERS IN PHOTONIC VLSI

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Abstract: We examine the use of micro and nano lasers to form digital photonic VLSI building blocks. Problems such as isolation and cascading of building blocks are addressed, and the potential of future nano lasers explored.

1. Introduction

Currently complex photonic/optical integrated circuits process information in an analog way. The complexity of photonic integrated circuits (PIC) is now being limited due to the lack of signal regeneration and manufacturing tolerances, similar to the situation of analog electronics in the 1960’s. There is an urgent need to move to digital processing of optical information in order to achieve VLSI complexity. Furthermore, the explosive growth of fibre-optic based telecommunications has focused attention again on all-optical digital processing of information encoded in an optical format.

To implement digital photonic VLSI systems requires a component or set of components that are boolean complete and can be cascaded to make any digital function. The component(s) must be of microscopic size and able to be densely integrated and interconnected using integrated circuit technology (which also implies that the components have low power requirements).

A good review of the requirements for a digital logic device to be used as a building block for larger systems is given in [1]. Some important requirements relevant to optical systems are that device inputs are isolated from the device outputs and visa versa. Furthermore there should be no reflection of energy form the gate output back into the gate. Or if there is reflection then it shouldn’t affect the gate operation.

Most recent work on making digital building blocks has concentrated on passive bistable systems in micro or nano resonators [2,3]. However these attempts have been remarkably unsuccessful in obtaining high speed low power digital elements. A number of issues have frustrated progress in this direction: 1) High power optical fields are required inside the resonator, and the field levels change dramatically for different states. Absorption leads to heating of the resonator, and slow thermal effects dominate the device response. 2) It is difficult to build high quality factor (Q) resonators and furthermore there is a tradeoff between Q and device speed, leading to fast devices requiring high optical power.

2. Micro and Nano Lasers in digital systems

Lasers have a non-linear optical characteristic suitable for digital operations. Recently we have shown how arbitrarily small micro ring lasers can switch each other and function as digital elements [4], fig. 1. Micro and nano lasers have advantages over passive systems for logic elements: They can operate at very low powers, and have extremely small size [5]. A high Q cavity is not required to build up a large optical field, thus permitting high speed operation. Only a small amount of input light may be needed to switch the laser light from one mode to another via injection locking [4]. The optical intensity inside the laser remains approximately constant avoiding thermal effects. Finally, the recovery time of the laser can be arbitrarily fast, by simply pumping the laser further above threshold. Thus micro or nano lasers can serve as a basis for digital integrated optics with integration densities and operating speeds comparable to those of present day electronics.

Fig. 1 Interacting Ring lasers integrated in active/passive technology.
To implement a digital building block such as a 2 input NOR which satisfies all cascading requirements, requires a micro or nano laser with at least three orthogonal cavity modes, two for the input and one for the output. Furthermore some filtering is required on the device output to block inputs propagating to the outputs and visa versa. Ring lasers coupled with a passive ring resonator can fulfill these requirements, using clockwise (CW) and counter clockwise (CCW) modes, plus modes one free spectral range of the resonator away from each other. The operation of such a gate which can be implemented in active/passive photonic integrated circuit technology is shown in fig. 2.

Single defect photonic crystal lasers [6] offer the possibility of even smaller laser devices, with possibly lower power consumption and higher speed than micro disk or ring lasers. Furthermore the large variety and behavior of resonant modes in such cavities can provide novel solutions for making cascadable logic elements.

Consider a modified single defect cavity in a triangular air hole photonic crystal [6] fig. 3. Here just the hexapole mode and doubly degenerate quadrapole modes are considered, a total of three modes. These three modes have a high Q and the resonant frequencies can overlap and be tuned independently by modifying the surrounding air-holes. Remarkably, there exists waveguides with a particular direction and end point, which will couple strongly to one cavity mode and only weakly to the other modes. By choosing an output waveguide which only couples to the main lasing mode and not the two input modes, optical isolation of the output from the inputs is achieved. Furthermore, the inputs can be isolated from the output by choosing input waveguides which only couple to the input modes. Fig. 3 shows this selective excitation for one of the modes.

However, reflections of the output signal back into the driving laser is a difficult problem to solve with single defect cavities, although some solutions exist. This lack of reflections is one area where ring lasers excel, as in theory there is no reflection of light injected into a ring laser.

3. Conclusions

In summary, micro and nano lasers along with active/passive integration technology provide a feasible solution to digital photonic VLSI. Further advances in the miniaturization of lasers, will only enhance their advantages of high speed and low power in this field of integrated optics.

Fig. 2. Ring laser and resonator 2 input NOR gate, a) inputs are low, b) at least one input high

Fig. 3. Finite difference time domain simulation showing selective coupling of even quadrapole cavity mode to just one particular waveguide. The vertical H field is shown in color.

References