Design of NAND Gate using Nanowire: Application of photonic VLSI

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ABSTRACT

There is an rising need for high speed digital like processing of signals in optics. The use of recent nanowire and nano lasers to address this issue is examined. Further developments in nano laser technology will get better their use in digital systems. more directions of these further developments in nano lasers are also examined. There is an insistent need to move to digital processing of optical information in order to achieve VLSI complexity. Furthermore, the volatile growth of fiber-optic based telecommunications has focused attention again on all-optical digital processing of information encoded into an optical format.

Keywords : Nanowire, Nanowire switches, Nanowire NAND gates , CdS.

I. Introduction

Now a day's complex photonic/optical integrated circuits process information in an analog way. The intricacy of photonic integrated circuits (PIC) is now being limited due to the lack of signal regeneration and manufacturing tolerances, same as the situation of analog electronics. There is an insistent need to move to digital processing of optical information in order to achieve VLSI complexity. Furthermore, the volatile growth of fiber-optic based telecommunications has paying attention on all-optical digital processing of information encoded in an optical design. To apply digital photonic VLSI systems requires a component or set of components they are arrange in Boolean complete and can be cascaded to make any digital function.[8] The component(s) must be of microscopic size or more small and able to be tightly integrated and interconnected using integrated circuit design(which also implies that the components have low power requirements).[1]

A good review of the necessities for digital logic devices to be used as a building block for larger system. Some important necessities relevant to optical systems are that inputs device are isolated from the outputs device. Furthermore there should be no reflection of energy from gate output back into gate input. Or if there is reflection then it shouldn't affect the gate action(operation). Most recent work on making digital building blocks has concentrated on passive bistable systems in nano resonators. However they attempts have been extremely ineffective in obtaining high speed and low power in digital network system.so the number of issues have frustrated progress in this direction: [2]

1) High power optical fields are necessary inside in the resonator, and the field levels change radically for different states. Absorption leads to heating of the resonator, and slow thermal effects dominate the device reaction.

2) It is not easy to build high quality factor (Q) resonators and there is a tradeoff between Q and device speed, leading to fast devices requiring very high optical power.

II. Nano Lasers in photonic VLSI

Lasers have a non-linear optical characteristic suitable for digital design operations, and also they required a light source for the optical signals. However, these large conventional laser devices extreme considerable power, had limited speed, and finally the passive waveguide technology to interconnect such active devices has only recently been widely availablity. Employing nano lasers for digital elements can address some of the disadvantages of larger conventional lasers and also passive bistable systems. Nano lasers have been shown to operate at very low powers, this is because there is only a little quantity of gain material in the cavity. Even when the laser gain material is pumped hard or above threshold, power level is still manageable. Furthermore as the laser size decreases, the ratio of surface area to volume increases, allowing improved heat dissipation. When light is injected into the laser at a resonant frequency of the laser cavity, only a small amount of input light may be needed to switch the laser light from one mode to another. Thus the amount of light in the laser cavity does not change greatly. Hence, laser based logic gates will not suffer from slow thermal effects caused by the input signals, as occurs in passive systems.

III. Nanowire implementation in photonic VLSI

Nanowire can act as a nanolaser because it simultaneously Semiconductor nanowires are 1D structure with high length-diameter aspect ratios, with provides both a gain medium and a waveguide. As optical waveguides, nanowires have two unique features:

1) Their diameter is comparable to the wavelength.

2) The refractive-index contrast (between semiconductor and air) is large.

Our research shows that this results in many unique nanowire-laser properties, including a confinement factor diameters of tens to hundreds of nanometers and lengths of tens to hundreds of microns. A single (the ratio of modal to material gain) greater than unity, strongly frequency- and diameter-dependent facet reflectivity's, and a very nontrivial far-field emission pattern. In addition to,nanoscale optical waveguide, cavity, and laser are vital for the realization of highlyintegrated photonic circuits. Importantly, free-standing semiconductor NWs can function as stand-aloneoptical waveguides, cavities and gain medium to support lasing emission. In general, a NW can function as a single-mode optical waveguide much like a conventional optical fiber when$1 \sim (\pi D/\lambda)\{(n_1)^2-(n_0)2\}^{0.5} < 2.4$, where D is the NW diameter, $\lambda$is the wavelength, and n_1 and n_0 are the refractive indexes of the NW and surrounding medium(fig.a).If the ends of the NW are cleaved(fig.b), they can function as two reflecting mirrors that provide opticalfeedback and define a Fabry–Perot optical cavity with modes $m(\lambda/2n_1) = L$, where m is an integerand L is the length of the cavity.[3]

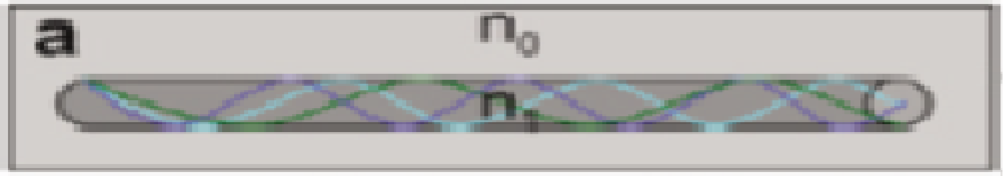


Fig (1): Nanowire surrounding the medium.

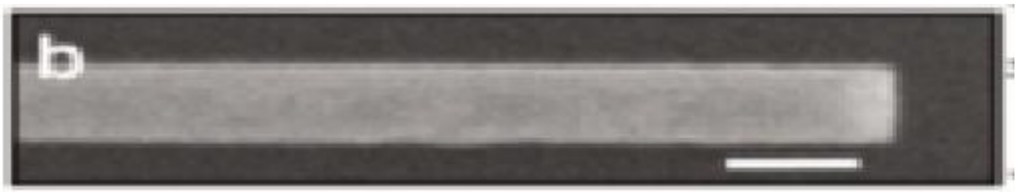
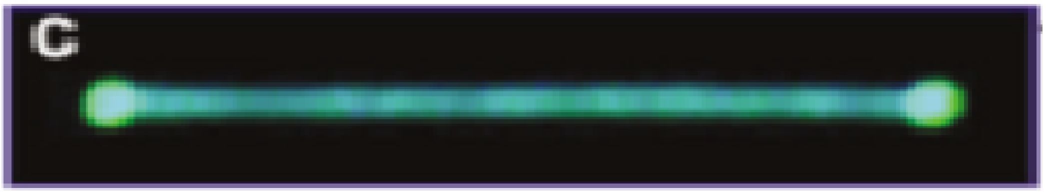


Fig (2): The ends of the NW are cleaved.



Fig(3): Pronouncedemission from both ends of nanowire.

Photoluminescence image of CdS NWs of proper diameter shows pronouncedemission from both ends(fig.3), clearly demonstrating waveguide effect along the NW axis.Furthermore, spectra of the emissions from NW ends show prominent periodic modulation in intensity, which can be attributed to the longitudinal modes of a Fabry–Perot cavity . For a cavity oflength L, the mode spacing,$\Delta\lambda$,is given by $(\lambda^2/2L)[n_1-\lambda(dn_1/d\lambda)]^{-1}$, where $dn_1/d\lambda$is the dispersion relationfor the refractive index. This expression provides a good description of the observed spacingwhen the measured nanowire length. Moreover, analysis of similar data from NWs of varying lengthdemonstrates that the mode spacing is inversely proportional to the wire length as expected. Together,these results demonstrate that the individual NW can function as nanoscaleoptical waveguide. The observation of sharp modes in the uniform CdSNW gain medium suggests asingle NW can support laser emission. Indeed, optical excitation at higher powers leads to preferentialgain in a single mode and the onset of lasing. The observation of laser emission with optical excitation further prompts us to investigate electricallypumped nanolasers.[5]

IV. Designing digital logic gates using nanowire

However more is required than the system presented in for a digital building block (such as a 2 input NAND gate), that can be used to make arbitrarily large and complex digital systems. In particular the basic requirements of isolating inputs from outputs in the device and avoiding reflections need to be satisfied. To achieve input/output isolation requires at least three orthogonal cavity modes in the nano laser, two for the inputs and one for the output. Furthermore some filtering is required on the device output to block inputs propagating to the outputs and visaversa. Systems using differences in wavelength to obtain orthogonality have been demonstration integrated systems, although with large lasers. Ring lasers coupled with a passive ring resonator can have orthogonal modes and provide isolation between inputs and outputs by using 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 examined. Additionally the problem of reflections is solved, as in theory no reflections occur in such ring systems. Single defect photonic crystal lasers offer the possibility of even smaller laser devices, with possibly lower power consumption. Furthermore very high speed operation has been demonstrated in these devices [7]. Photonic crystal cavities also posses a large variety of resonant modes. In such cavities spatial orthogonality can be used to separate the input and output modes. Consider a modified single defect cavity in a triangular air hole photonic crystal fig. 1. Here just the hexapole mode and doubly degenerate quadrapolemodes 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.4 shows this selective excitation for two of the modes. However, reflections of the output signal back into the driving laser is a difficult problem to solve with single defect cavities. 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.

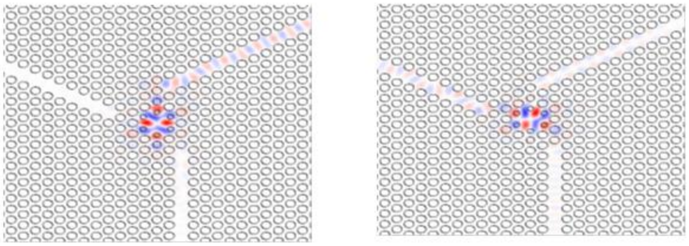
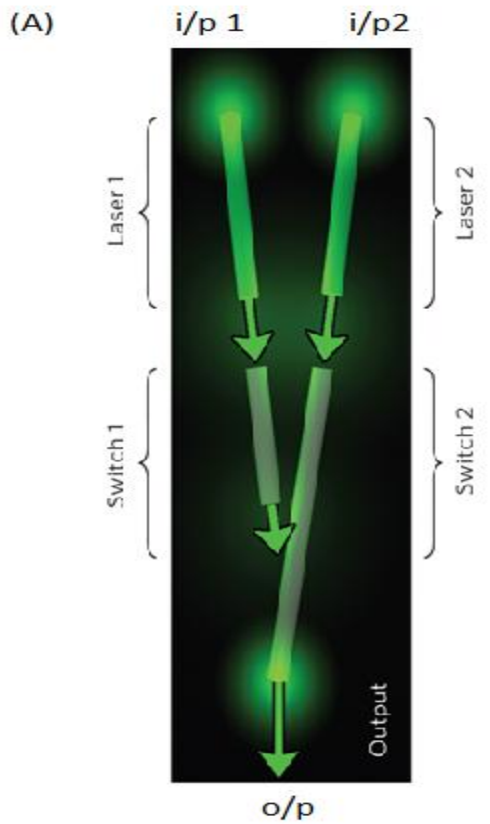
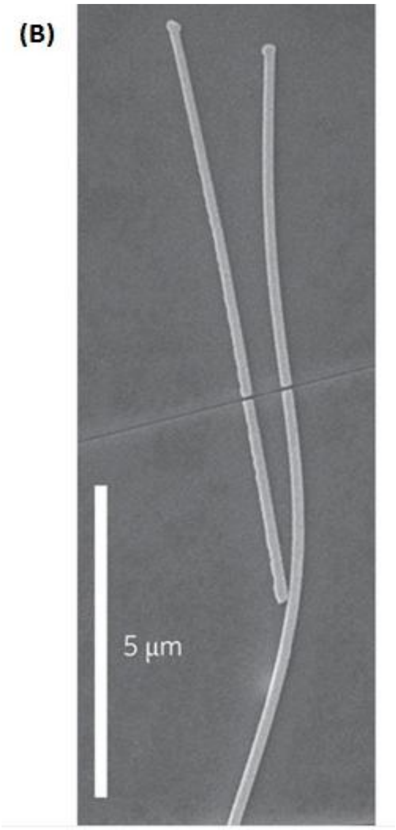


Fig (4): Finite difference time domain simulation showing selective coupling of cavity modes to just one particular waveguide. The vertical H field is shown in color. Left: even quadrapole mode of single defect cavity. Right: odd quadrapole mode.

V. Designing NAND gates using nanowire

We designing and explaining a NAND gate using nanowire. **(A**)Schematic of an all-optical nanowire NAND gate. The design requires two on-chip laser sources and two nanowire switches (3.31 and 7.25 µm long) with their outputs combined through evanescent coupling in a waveguide. With no applied Ar^+ pump, this illustration corresponds to the (0 0 1) logic condition. The first digit corresponds to the left switch, and the second digit corresponds to the right switch. Each switch is considered 'on' (1) when the argon ion laser is on and 'off' (0) when the argon ion laser is off. The third digit represents the state of the gate output being on (1) or off (0). (**B)**, Image of all-optical nanowire NAND gate device. Spectra collected from the output, illustrating the (0 0 1) (black) and (0 1 1) (red) (**C**) and (0 0 1) (black) and (1 0 1) (red) (**D**) , logic conditions with application of 1 mWAr^+ power to each switch. Minor differences between the three initial (0 0 1) logic spectra are due to sample drift over the course of multiple experiments.





Fig(5): Schematic of an all-optical NAND gate device.

Fig (6):SEM image of all-optical nanowire nanowire NAND gate.

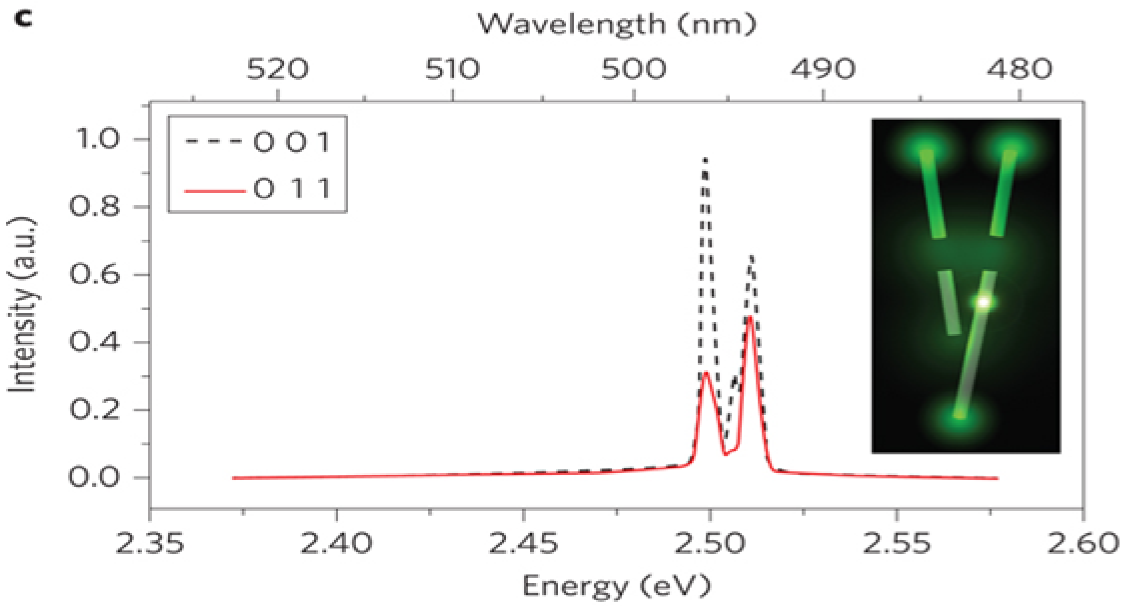


Fig.7: Spectra collected from the output, illustrating the (0 0 1) (black) and (0 1 1) (red)

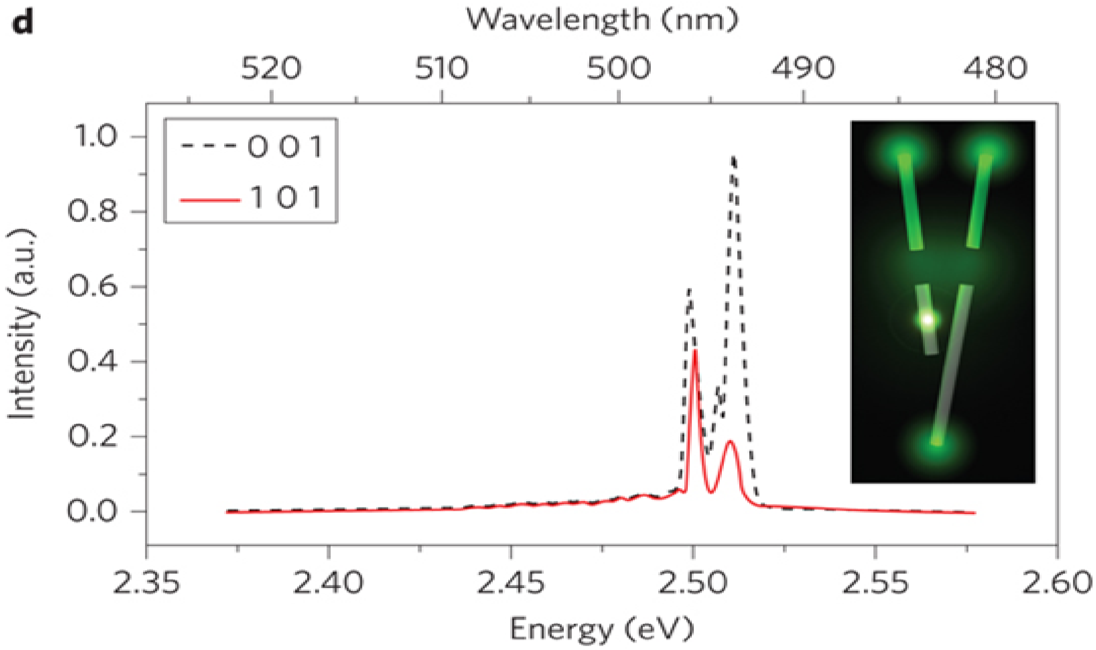


Fig.8: Spectra collected from the output,(0 0 1) (black) and (1 1 0) (red)

VI. Conclusion

The rapid progress in integrated optics and laser technology in recent years means that nanolasers are a potential solution for VLSI photonics. In theory it is possible to satisfy all the requirements for a digital system using nanolasers and active integrated optics components. Thus providing medium scale integration digital systems with moderate performance. However to truly exploit the high bandwidth potential of optics, and also achieve high integration levels will require further progress in the miniturization of lasers. A method that this can in theory be achieved is via nanowires.

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