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Thermal Crosstalk Limits for Silicon Photonic DWDM Interconnects

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Abstract: We present theoretical modeling and experimental results of the thermal crosstalk and time constants of micro-disk modulators as a function of the spacing between nearby devices, taking into consideration the effects of dense metallic interconnects.

1. Introduction

Silicon nanophotonics is a growing area of research and development for optical interconnects. Microresonator devices offer the promise of the lowest energy consumption due to their small size and the highest bandwidth density using dense wavelength division multiplexing (DWDM) [1]. However, their resonant frequencies vary as a function of manufacturing process, temperature, and optical power level. Therefore, one needs to align their resonant wavelength to the wavelength of the incoming laser to make the devices usable in these DWDM interconnect systems.

While some tuning range is possible with forward bias [2] and even reverse bias tuning of the device [3], both of these have limited range and require a more complex interface to the drive circuit when integrated on chip. An integral micro-heater has been proposed by several groups to allow both filters and modulators to be tuned to the frequency of the incoming laser [4-7]. These micro-heaters are relatively efficient and allow a large tuning range. In fact, tuning over 30 nm has been demonstrated in [4].

Moving from single device demonstrations to the design of systems using these devices a critical issue to be considered is the thermal crosstalk between adjacent elements. To date, we know of no systematic investigation of the thermal crosstalk between ring or disk modulators or filters. Here, we present theoretical and experimental results of the measured crosstalk for disk modulators as a function of the spacing between the devices.

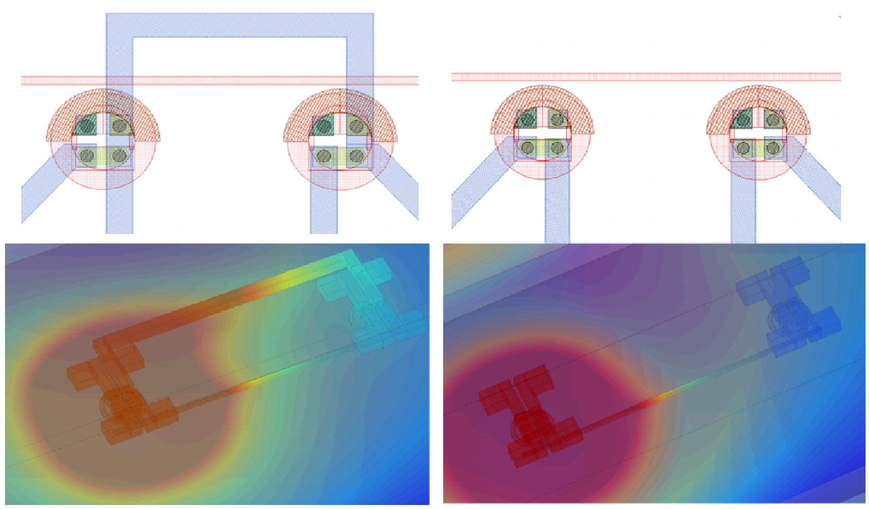

Fig. 1 A gds mask layout schematic of two connected micro-disk heater-modulators (top left), gds mask schematic of fabricated isolated micro-disk heater-modulators (top right), steady state thermal simulation of connected micro-disk heater-modulators (bottom left), steady state thermal simulation of isolated micro-disk heater-modulators.

2. Simulation

Using the heat transfer model in a commercially available FEM package, COMSOL Multiphysics, we simulated the thermal crosstalk and tine constants of two adjacent micro-disk resonator heater-modulators, taking into account the layer structure of the device in our standard silicon photonics process. The metallic interconnects of nearby control electronics creates an additional path for thermal crosstalk between nearby microresonators. We considered two cases to determine the upper and lower bounds of thermal crosstalk between nearby micro-disk heater-modulators.

The lower bound case considered is two isolated micro-disks, where thermal crosstalk occurs only through the oxide cladding and silicon handle wafer (Fig.1 right). The upper bound case considered two micro-disk heater-modulators directly connected with a metal-one line (Fig. 1 left). A resonator flip chip bonded to a CMOS control circuit will be somewhere in the middle, because the ring connections will be longer than the directly connected disks.

Simulations were performed with the spacing between adjacent micro-disks varying from 3-20 μm with 5 mW of electrical power applied to an Ohmic heater integrated in the device as described in [6], while the second micro-disk is left in a passive state. Simulation results concluded that the maximum temperature rise in the connected disk was 63.2 °C while in the isolated case was 70.4 °C. This indicates that a reduction in efficiency of up to 14 % is possible due to thermal loading. We can define the thermal cross talk as the increase in temperature in the passive device divided by the increase in temperature of the driven device. Results of the simulated thermal cross talk are presented in Fig. 2, middle. From the simulated results we can conclude that the crosstalk decays in an exponentially and is increased by up to a factor of two at large separations by the presence of the metal-one connection furthermore, for separations above 15 μm the temperature rise in the passive micro-disk is only a few percent of the rise in the thermally driven micro-disk in both cases.

Control of individual micro-disk modulators in feedback loops is a powerful method to mitigate thermal fluctuations in the operating environment. It the response time of such a control loop matches the thermal time constant for heat transfer undesirable oscillations may result. Thermal time constants were simulated using the full time-dependent heat equation for varying gaps with results presented in Fig. 2, left.

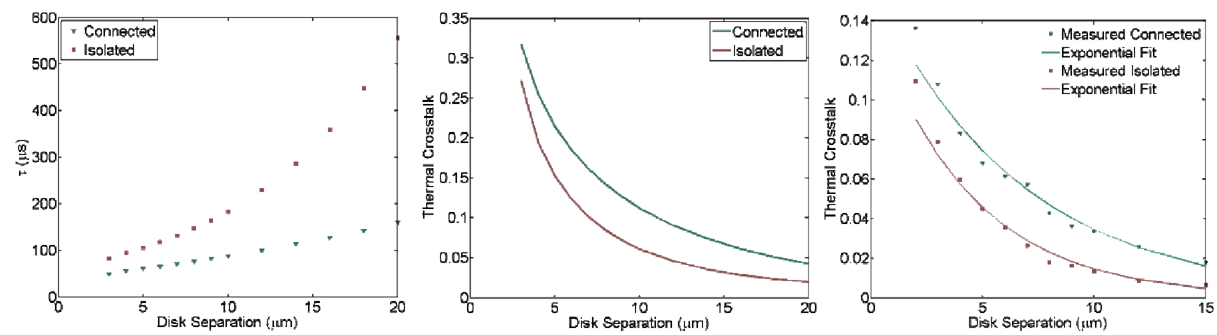

Fig. 2 The simulated thermal time constants for isolated and connected micro-disks (left), simulated thermal crosstalk for isolated and connected micro-disks (middle), measured thermal crosstalk for isolated and connected micro-disks (right).

3. Experimental Results

Devices were fabricated in Sandia's MESA facility using standard CMOS processing techniques. A DC voltage was applied to one microresonator using a source-meter and the resultant shift in the resonant wavelength of that resonator as well as the adjacent resonator were measured using a scanning laser and power meter. The crosstalk is merely the ratio of the adjacent resonator wavelength shift divided by the wavelength shift of the device with the applied electrical power, a plot of the measured results is shown in Fig. 2, right. Good linearity was observed in the shifts as a function of applied electrical power over more than a factor of 10 in applied electrical power. The devices were similar to those in reference [6]. While the general trend of the experimental data is in good agreement with simulation, the crosstalk values between measured and simulated devices differ by a about a factor of 3. Further investigation is required to resolve this discrepancy.

4. Conclusions

We presented a theoretical framework and experimental results of crosstalk between nearby micro-disk resonator heater-modulators, considering the effects dense metal electrical interconnect lines will have on performance. We observed good linearity with applied heating power, and have shown experimentally that for modest distances of about 10 μm, the resultant shift in the adjacent device is a few percent of that of the device being driven.

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5. References

[1] Q. Xu, *et al.*, "Cascaded silicon microring modulators for WDM optical interconnection", *Opt. Express* (2006).
[2] K. Padmaraju, *et al.*, "Thermal stabilization of a microring modulator", *Opt. Express,*(2012).
[3] E. Timerdogan, *et al.*, " A one femtojoule athermal modulator", arXiv: 1312.2683 (2014)
[4] M. R. Watts, *et al.*, "Adiabatic Resonant Microrings (ARMs) with Directly Integrated Thermal Microphotonics", *CLEO* (2009).
[5] J. E. Cunningham, *et al.*, "Highly-efficient thermally-tuned resonant optical filters", *Opt Express* (2010).
[6] W. A. Zortman, *et al.*, "Integrated CMOS Comaptible Low Power 10Gbps Silicon Photonic Heater Modulator", *OFC* (2012).
[7] G. Li, *et al.*, "25Gb/s 1V-driving CMOS ring modulator with integrated thermal tuning", *Opt. Express* (2011).