Dynamic Thermal Control of Silicon Nitride Photonic Integrated Circuits

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Abstract

Multiple heaters in photonic integrated circuits must be controlled accurately to achieve reliable performance of the thermooptic system. In this paper, we show wavelength stabilization using a system with unique design for silicon nitride circuits.

Keywords; Thermooptic, dynamic, control, feedback

I. INTRODUCTION

Photonic Integrated Circuits (PIC) are a key technology for the practical realization of optical processing in applications as diverse as microwave photonics to quantum applications [1-3]. PIC using silicon based materials in a thermooptic system can be fabricated with relatively low cost using Complementary Metal-Oxide Semiconductor (CMOS) technology. However, the use of multiple heaters on a chip is prone to thermal crosstalk and environmental change because of the relatively high thermooptic coefficient of these materials [4][5], creating undesirable wavelength shifts and affecting system performance.

Prior efforts to resolve thermal sensitivity of a thermooptic system have focused on differential control techniques [6], Wheatstone bridge with Proportional-Integral Derivative (PID) feedback [7], active feedback [8], mean power monitoring [9], dithering [10], and balance homodyne locking [11]. These all require external or on-chip photodetectors to monitor the traveling light in the resonators. The robustness, loop interaction and control are also hard to analyze and may not yield the best overall control.

In this paper, we demonstrate wavelength stabilization in compact and low loss silicon nitride multi-heaters PIC based on Mach Zehnder Interferometer (MZI) structure. We demonstrate that a single-board low-cost microcontroller-based design can be used to implement a reconfigurable multi-channel heater controller for silicon nitride PIC.

II. PHOTONIC CHIP CHARACTERIZATION

The measurement setup for the feedback control system is shown in Fig. 1. Amplified Spontaneous Emission (ASE) generates a broadband light source in the telecom C-band. The output is controlled with an attenuator, a fiber Inline Polarizer (IP) and a Polarization Controller (PC). The input power was monitored using a Power Meter (PM) and a 50:50 fiber coupler. The fiber connection (red lines) from the coupler to the chip is via Polarization Maintaining optical Fiber (PMF) pigtailed to the chip. The output was connected to Optical Spectrum Analyzer (OSA) and PM using 99% and 1% coupler for analysis.

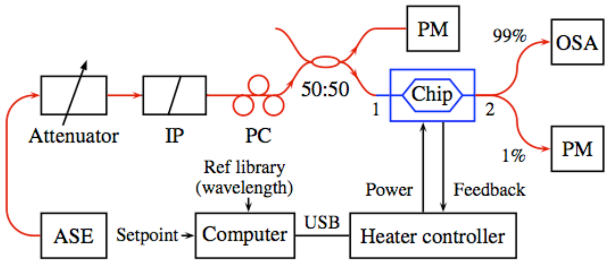
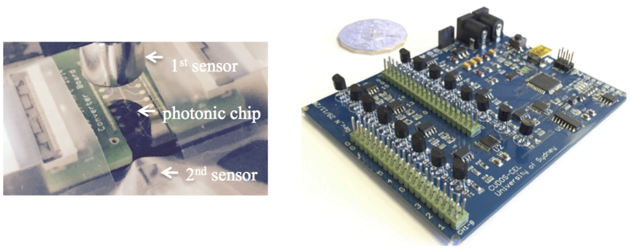


Figure 1. Measurement setup

The silicon nitride circuits were fabricated using double-stripe waveguide technology with LioniX BV [8]. The waveguides comprised of cladding and two strips of Si_3N_4 layers stacked on top of each other with SiO_2 as an intermediate layer. The strips were constructed to be 1.5 μm wide, and the Si_3N_4 layers and the SiO_2 intermediate layer were formed to be 170 and 500 nm thick, respectively. This allowed < 100 μm bending radius with a propagation loss of < 0.2 dB/cm for TE polarization and single mode operation at 1550 nm with high index contrast.

There are 15 heaters inside the chip, each with a nominal resistance of 600 Ω. In this experiment, heaters were connected via electrical wire (black lines) bonded directly to the heater controller as illustrated in Fig. 1. The chip temperature is monitored via an infrared sensor (first sensor), which collects the target chip and ambient temperature. The gap between chip and sensor is around 5 mm. The second sensor is attached on the heatsink plate to monitor overall temperature of the chip. This sensor is using TSIC™306 with T092 package. The photonic chip and sensor setup are shown in Fig. 2(a).



(a) (b)

Figure 2. Photonic chip setup (a) and heater controller (b)

The heater controller, as shown in Fig. 2(b), consists of 16 channels outputs, and 15 of them can be used to provide power to the 15 heaters on the photonic chip. The hardware is designed specifically based on open source Arduino using ATmega32u4 with two 16-bit Octal Digital to Analog Converter (DACs), eight dual amplifier and 16 voltage follower circuits integrated onto one board. These electronic circuits can be scaled for more channel output.

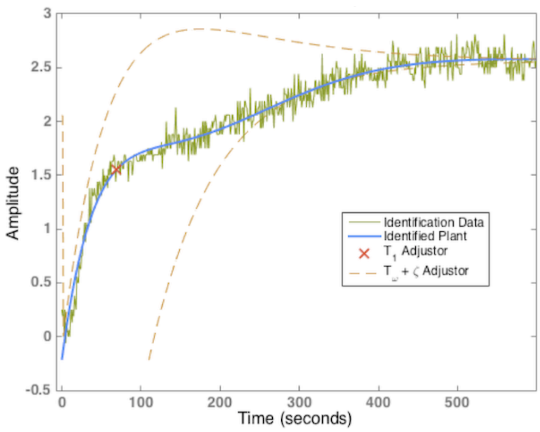


Figure 3. Underdamped pair and real pole plot

III. CONTROL MODEL

The step response model of the plant for Proportional-Integral-Derivative (PID) feedback controller is generated using plant identification system in Matlab and followed by parameterized *H(s)* with underdamped pair and real pole as shown in Fig. 3 which is described by equation 1. In this model, the configurable parameters include the damping coefficient ζ and the gain K. The other parameters are the first time constant T_1 and the time constant associated with the natural frequency Tω. The estimated parameters for identified plant structure are K = 5.3132, T_1 = 67.285, Tω = 76.3 and ζ = 0.714.

$$H(s) = \frac{K}{(T_1 s + 1)(T\omega^2 s^2 + 2\zeta T\omega s + 1)} \quad (1)$$

Using PID tuner with balance setting, the rise time and setting time are 108 seconds and 502 seconds respectively. The overshoot is about 3.87 %, peak 1.04 and phase margin 69 deg@0.014 rad/s with stable closed loop.

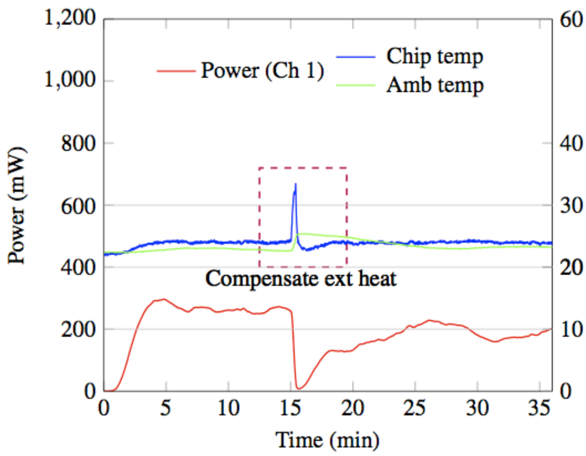


Figure 4. Closed loop experiment with a fan heater disturbance

IV. FEEDBACK CONTROL SYSTEM

For feedback control system, temperature and wavelength data are collected on computer by supplying voltage from 1 to 14 V. The correlation between temperature and wavelength is used as reference for the program. The tuned PID parameters (Kp = 0.3877, Ki = 198.1, Kd = 49.52) are then applied to the feedback control systems. To evaluate the performance of the system, we measure the system stability of closed loop systems.

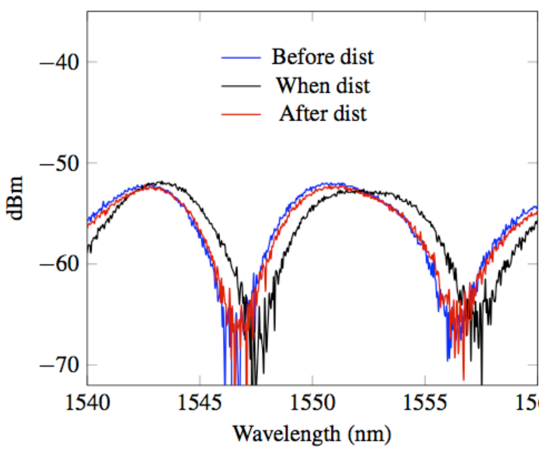


Figure 5. Wavelength stabilization with disturbance

In the closed loop experiment test, channel 2 as the arm of the same MZI on the chip is supplied with 12.9 V. The second step is to set the temperature to 24.2°C. External disturbance is created using a fan heater. The blower increases the photonic chip temperature to around 34°C as shown in Fig. 4.

Fig. 5 demonstrates wavelength stabilization. From this figure, the wavelength after disturbance is stabilized by the closed loop system control which recovers the wavelength shift to the condition before disturbance.

V. CONCLUSION

In conclusion, feedback control system with reconfigurable multiple channels has been demonstrated. The model can be used as a basic control scheme for more complex system.

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