Waveguide temperature in a lasing micro cavity

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We propose a method for measuring the temperature of a waveguide inside a micro ring laser cavity during lasing. The method is developed for biosensing applications. However, it can be applied to many other waveguide lasers applications.

1. Introduction

Sensing with micro ring resonators has been demonstrated in many material platforms, such as SOI [1], SiN [2] and SiON [3]. Recently, Yb^{3+} doped Al_2O_3 micro ring laser biosensors have been demonstrated [4-7]. A lower detection limit is possible with an active lasing sensor due to its much narrower linewidth compared with a passive ring sensor. However, the intense pump light and intracavity lasing power may cause a temperature increase. It can exceed the upper limit of a certain biological process, such as protein binding to the antibody on the waveguide surface during a biosensing measurement. Thus, an measurement of the waveguide temperature in an active sensor during lasing is an important aspect.

Heating the chip and monitoring the resonance shift of a ring laser cavity as a function of temperature is used as calibration for the changes in temperature of the device as a function of increasing pump power. The cavity resonance frequency shift is measured by tuning an external laser cross a non lasing cavity mode. The temperature measurement can be performed both below and above the lasing threshold.

2. Experiment setup

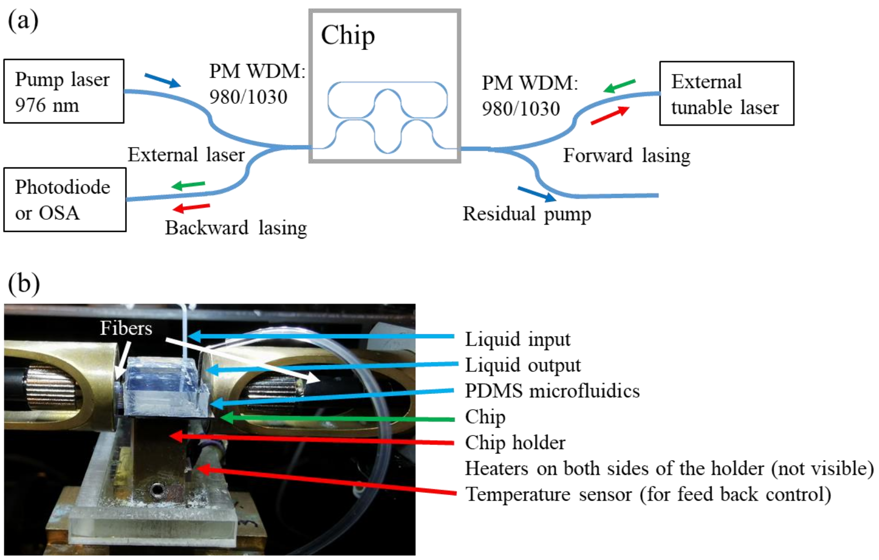

Fig.1 The experiment setup. (a) The setup layout. Pump (976 nm) light is indicated with blue arrows. On-chip lasing is indicated with red arrows. The external tunable laser light is indicated with green arrows. (b) Image of the setup around the optical chip during experiment. The fiber coupling to the chip, the microfluidics on the chip, and the temperature control components are indicated in the image.

The optical path is shown in Fig.1(a). The device on the chip is a Yb^{3+} doped Al_2O_3 micro ring laser with water top cladding. The pump (976 nm) is coupled into the chip, from the left side, through a polarization maintaining fiber wavelength-division multiplexing (PM WDM). The backward lasing light is coupled through the same PM WDM into an optical spectrum analyzer (OSA). Thus, the lasing threshold and lasing spectrum can be measured.

An external tunable laser (Toptica CTL1050) is coupled into the chip from the right side through a second PM WDM. The light pass through the chip can also be measured with the OSA to obtain its spectrum. The resonance frequency of the ring laser cavity can be monitored by replacing the OSA with an photodiode and scanning the Toptica lasing frequency across one of the ring resonances.

The external Toptica laser has internal optical isolator, thus, the forward lasing light from the chip did not shown any noticeable influence to the Toptica laser during our experiment.

The chip temperature is controlled by controlling the chip holder temperature as shown in Fig.1(b). The typical temperature stability is ~1 mK. The flow system delivers DI water to the microfluidic channel on the chip with a constant flow rate of 50 μl/min.

3. Experiment results

A lasing spectrum of a measured on-chip laser is shown in Fig.2(a). Its threshold is 11.3 mW (pump power before the chip). The spectrum shown in Fig.2(a) is measured with 15.9 mW pump before the chip. The spectrum of the Toptica external laser through the chip is measured with pump off. The wavelength of the Toptica laser has been set far enough form the on-chip lasing wavelength. Thus, no significant influence to the lasing spectrum of the on-chip laser. This can be seen by the almost identical on-chip lasing spectrum with and without the Toptica laser on.

The fine tuning of the Toptica laser through one of the ring resonances is performed by piezo scan function of the Toptica laser as shown in Fig.2(b). The Toptica laser power before the chip is 1.5 mW. In order to better determine the resonance peak frequency, a moving average is applied to smooth out a fast oscillation in the raw data.

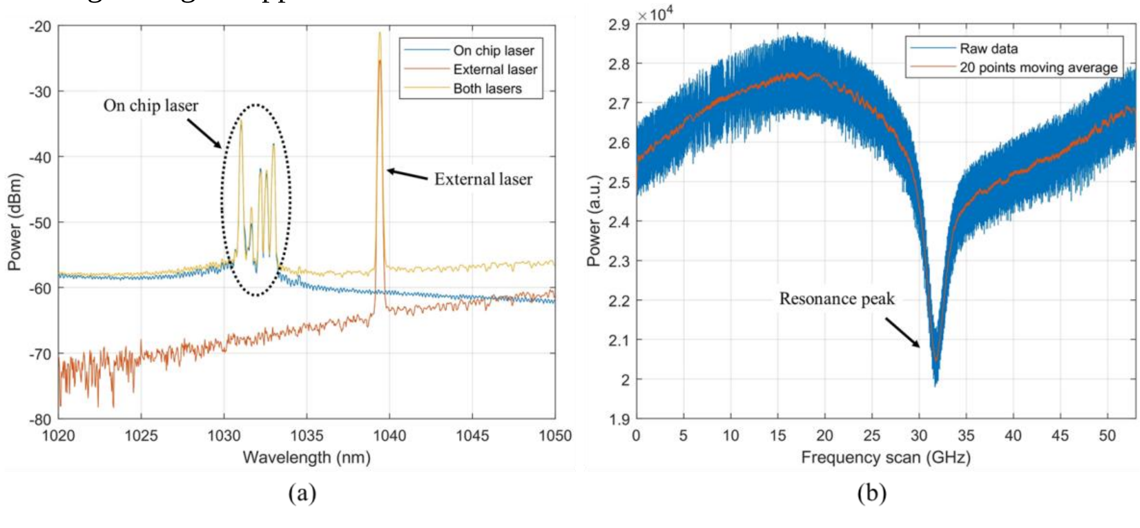

Fig.2. (a) Optical spectra of the on-chip laser alone, Toptica laser alone pass through the chip, and both of them at the same time. (b) Piezo scan of the Toptica laser across one of the ring cavity resonances. The center wavelength is set to 1040.970 nm, and the full piezo scan range is 53 GHz (~0.19 nm).

The ring cavity resonance peak frequency has been measured at different temperatures and their shift respect to the one measured at 25 ºC is shown in Fig.3. A temperature coefficient of - 1.22 ± 0.04 GHz/K has been calculated based on a linear fit of the measured data.

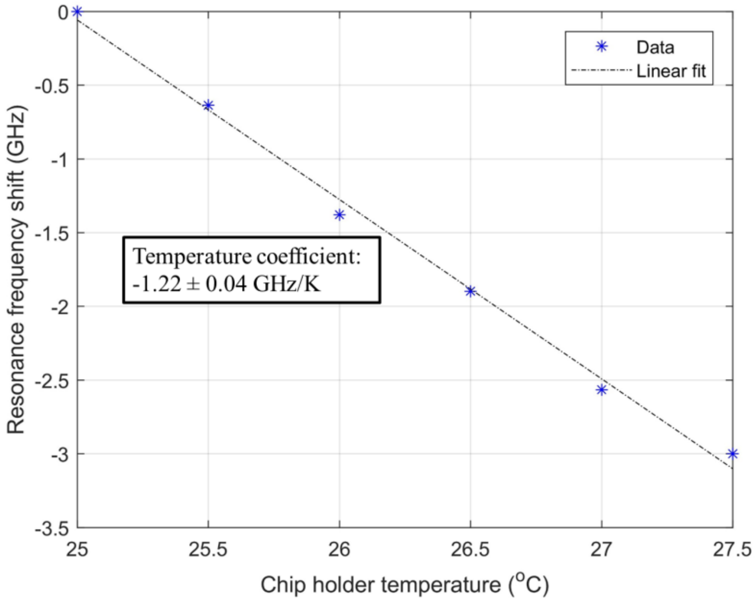

Fig. 3. Laser cavity temperature coefficient calibration.

A similar resonance frequency shift measurement is performed by keep the chip holder temperature at 25 ºC and increasing the pump power. The measured frequency shift is shown with the blue stars in Fig.4. Based on the measured temperature coefficient, the temperature at the waveguide is calculated and shown with orange circles in Fig.4.

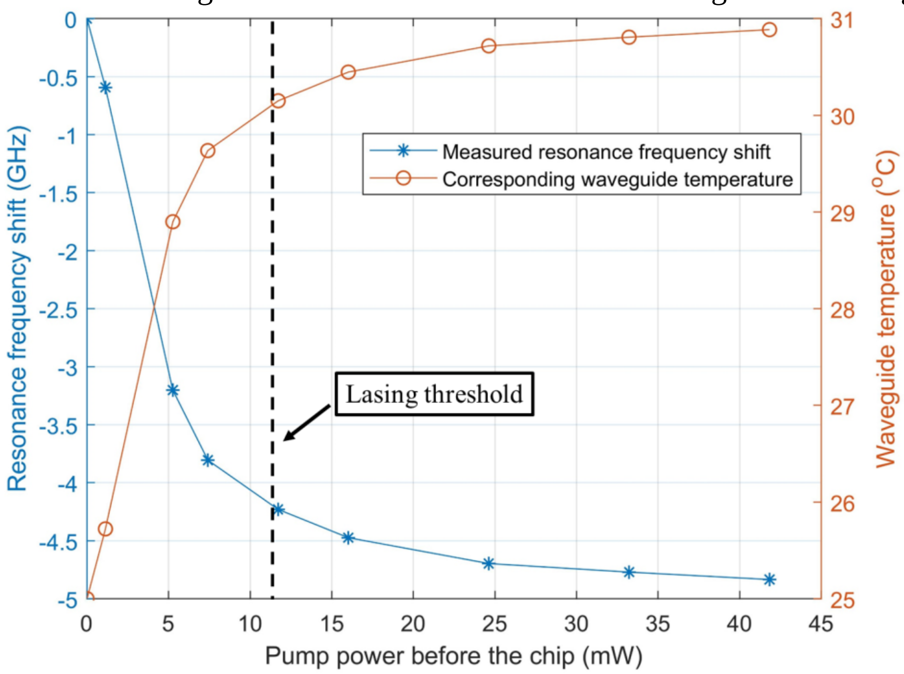

Fig. 4. Resonance frequency shift and the corresponding waveguide temperature as a function of pump power before the chip. The lasing threshold is 11.3 mW and marked with a dashed vertical line.

The waveguide temperature increases fast when the pump power is below the lasing threshold. The increase slows down as the pump increases. This behavior should related to the pump absorption rate and the quantum defect. It will be studied further in the future. The maximal waveguide temperature measured in this experiment is ~31 ºC, which is viable for biosensing. The small temperature slop above the threshold, enables a significant pump power increase before it causing any thermal problems to the biomolecules.

3. Conclusions

In this work, we demonstrate a method to measure the temperature of the waveguide inside a micro ring cavity during lasing. The results show a maximal temperature of ~31 ºC in our micro ring laser sensor. Biosensing with integrated laser micro cavities is therefore viable from the temperature point of view.

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