Simplified Platform for Microring-Sensing using Wavelength Locking

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Abstract: We utilize a low-cost, robust method of wavelength locking microring resonators to implement a simplified platform for microring-sensing applications that requires only a single-wavelength laser source and directly maps resonance shifts to DC voltage values.

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With their small footprint, CMOS-compatible fabrication, and multiplexed operation, silicon microring resonators are ideal for use as measurement devices. Their high-refractive index provides them with a high sensitivity to such environmental factors such as temperature, and when chemically treated, they can be used as effective label-free biosensors [1,2]. The latter use has received wide attention for its potential to provide fast, compact, and cost-effective diagnostic instrumentation for applications in environmental monitoring, biochemistry, and healthcare; and as a testament to its utility, has been implemented commercially in that capacity.

The routine procedure for using the microring resonator as a sensor is to probe the resonance shift of the resonator as it is exposed to the environment or sample (Fig. 1a illustrates this resonance shift). The traditional technique for measuring this resonance shift consists of conducting fast spectral scans with a tunable laser and photodiode, or a broadband source, monochromator, and photodiode [2]. However, the use of costly, bulky, and sensitive equipment such as tunable lasers and monochromators is prohibitive to the desired deployment of microring resonators as low-cost, portable, and robust sensors [3].

We utilize wavelength-locking to demonstrate a greatly simplified platform for microring-sensing. Fig. 1b illustrates the concept of wavelength locking, where an integrated heater is used to automatically tune a microring resonator to match the wavelength of a laser source. Initially, the microring need to be tuned a distance $\Delta\lambda_0$ as shown in Fig. 1b. However, following exposure to the sample or environmental condition, a resonance shift $\Delta\lambda_{RS}$ will be induced in the microring. Subsequently, the microring will then be needed to tune $(\Delta\lambda_0 - \Delta\lambda_{RS})$ to match the laser wavelength. The voltage on the integrated heater required to tune to the laser wavelength will be altered, and is defined by Eq. (1), where R_H is the resistance of the heater, and $\partial\lambda/\partial P$ is the tuning efficiency of the heater.

$$V = \sqrt{R_H(\Delta\lambda_0 - \Delta\lambda_{RS})(\partial\lambda/\partial P)^{-1}} \tag{1}$$

By wavelength locking the resonator and sampling the voltage applied to the heater during the wavelength locked state we retrieve a direct measurement of the resonance shift, with no additional post-processing needed. Fig. 1b shows the implementation of our method, which requires only a single-point optical coupling (assuming on-chip photodiodes) of a single-wavelength laser (where the specific wavelength can be arbitrary).
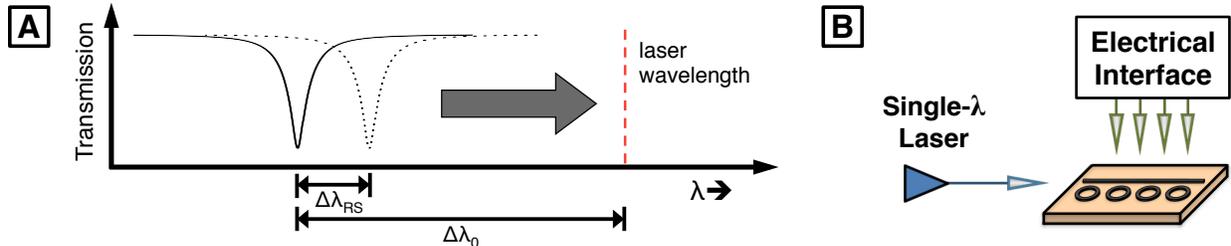

Figure 1: (a) Illustration of induced resonance shifts and wavelength locking. **(b)** Microring-sensing platform using wavelength locking.

The enabling innovation in this platform is the development of a simple, robust, and automated method to wavelength lock a microring resonator to a laser. The basis of our technique is the use of a dithering signal to generate an asymmetric error-signal [4]. The generated error-signal enables wavelength locking by allowing low-speed analog and digital circuitry to determine when the resonator and laser coincide in wavelength.

Fig. 2a shows the device we used in this demonstration, consisting of a 6-μm radius microring resonator with an integrated heater and drop-port defect-enhanced silicon photodiode. These opto-electronic components were interfaced with low-speed analog and digital circuitry (detailed in [4]) for the purpose of generating the required

error signal, and then subsequently using that error signal to efficiently establish wavelength locking. Fig. 2b shows the progressive wavelength locking of the resonance (originally at ~1559.2 nm) to a laser (at ~1560 nm).
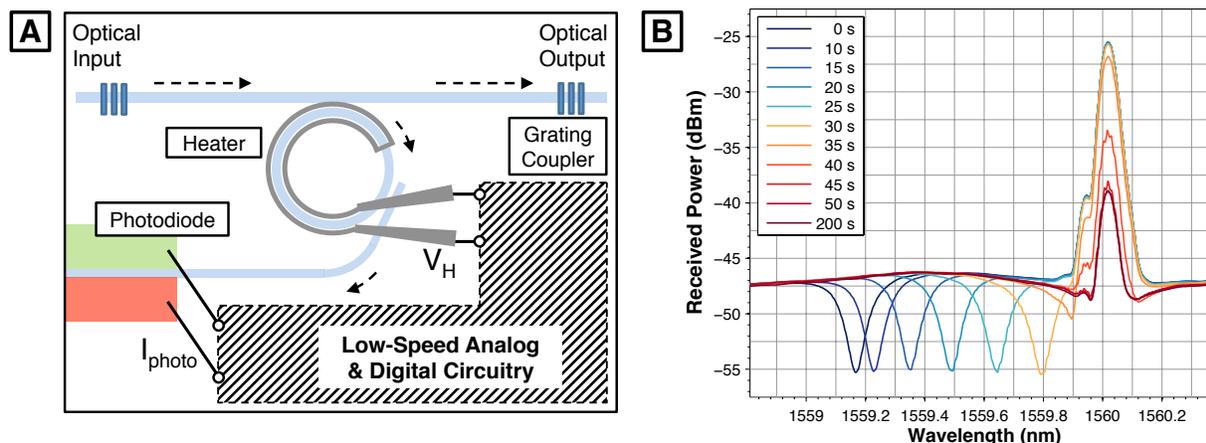
Figure 2: (a) The integrated microring resonator device used in the demonstration (not to scale) **(b)** Optical traces collected from an OSA show the automated wavelength locking of a microring resonance to a laser source.

Fig. 3a shows the voltage applied to the integrated heater by the automated wavelength locking system. At ~10 ms, the wavelength locking is initialized and the voltage is ramped until the resonance is matched to the laser wavelength. Once the lock is established, the voltage is sampled to measure $\Delta\lambda_{RS}$, as per Eq. (1). To test this method experimentally, we varied the resonance shift, $\Delta\lambda_{RS}$, by cooling the chip using a TEC. $\Delta\lambda_{RS}$ was measured using spectral scans, and simultaneously measured using our wavelength locking technique (Fig. 1b). Our proof-of-principle measurement was able to measure resonance shifts with $\sigma = 7$ pm (calculated against the fitted curve), validating its ability to measure resonance shifts accurately. Additionally we were able to show wavelength locking on the order of ~ms (Fig. 3a), showing that this method can perform much faster than traditional spectral sweeps.
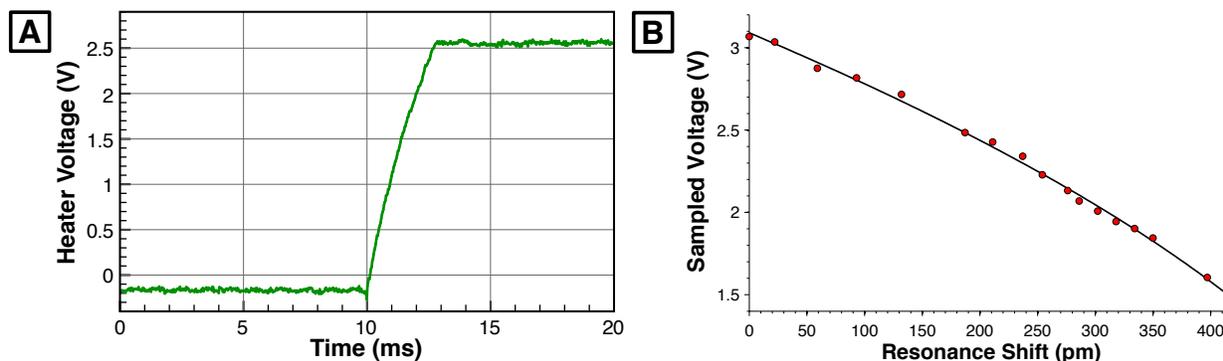
Figure 3: (a) Heater voltage during the automated wavelength locking. **(b)** Measured data points fitted to Eq. (1).

By requiring only a single-wavelength laser source (in contrast to a tunable laser or monochromator), our demonstrated platform is orders of magnitude more cost-effective, robust, and compact than current microring-sensing platforms. Additionally, this platform can simplify the multiplexed operation of microring sensors. For traditional spectral measurements, multiplexed microrings must be precisely offset in fabrication to prevent overlap in the spectral domain. In our platform, microrings can be fabricated with identical dimensions (spectrally overlapping), as the wavelength locking mechanism can sequentially probe and discern individual microrings. Finally, we note that for applications in which the integrated heater cannot be situated directly above the microring, there are demonstrated configurations that enable microring tuning while delocalizing the position of the integrated heater and microring [5].

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