Multi-port Silicon Nitride Fabry-Pérot Cavity with Apodized Bragg Gratings for Dispersion Compensation

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***Abstract*—We demonstrate a multi-port Fabry-Pérot cavity with apodized Bragg gratings for dispersion compensation in silicon nitride. The gratings induce anomalous dispersion to counterbalance the waveguide's normal dispersion, enabling precise control of the cavity's dispersion for applications like optical frequency comb generation in silicon photonics.**

***Index Terms*—dispersion compensation, gratings, fabry-pérot, silicon nitride**

I. Introduction

Integrated Bragg gratings are important for many applications. In particular, their filtering properties make them attractive for wavelength-division multiplexing (WDM), while their reflection characteristics make them suitable as mirrors in distributed-feedback (DFB) lasers, and distributed Bragg reflectors (DBR). They have also been widely used as dispersion compensating elements in optical fibre [1].

Bragg mirrors have been deployed as dispersion engineering elements in microcavities recently [2]. They are suitable for devices requiring net anomalous dispersion, such as mode-locked lasers [3], where the gratings act as dispersion compensating elements, countering the normal dispersion in the rest of the Fabry-Pérot (FP) cavity. Kerr frequency comb generation has been demonstrated using nanofabricated FP resonators, which are formed with photonic-crystal-reflector (PCR) mirrors. These reflectors enabled the resonators to achieve anomalous dispersion [4]. FP cavities offer the advantage of using dispersion compensating gratings to control the net dispersion, which is independent of the geometry of the waveguide. A novel design using apodized gratings as dispersion compensating elements in an FP cavity is presented.

II. Device Design and Simulation

The schematic of the designed FP cavity is illustrated in Figure 1. The device consists of a silicon nitride (SiN) waveguide placed between two integrated Bragg reflectors. We place a directional coupler in the middle of the cavity in order to couple the light into the cavity. This four-port architecture allows for independent control of both the 100% reflectivity and the Q-factor, with the latter engineered through the directional coupler. Unlike traditional designs [3], it uncouples these parameters, allowing for precise Q-factor adjustments without affecting the reflectivity. Figure 1 (b) shows the scanning electron microscope (SEM) image of the fabricated FP cavities featuring dispersion compensating gratings on both sides.

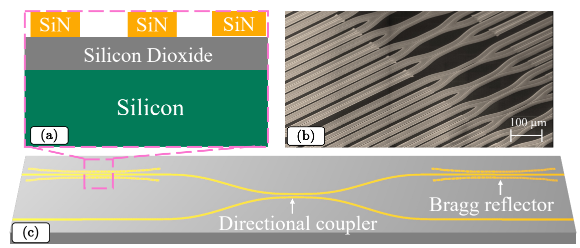

Fig. 1. Device under test with (a) its cross-section where the SiN thickness is 300 nm, (b) the scanning electron microscope (SEM) image of the fabricated Fabry-Pérot cavities with the dispersion compensating gratings on each side, as mirrors, and (c) the multi-port dispersion compensated FP cavity.

The 300 nm thick SiN waveguides exhibit normal dispersion across the C-band wavelength range. Since our application requires net anomalous dispersion, we need to introduce a dispersion compensating element to the cavity, in order to balance the normal dispersion of the device cross-section. We design apodized gratings to enable the engineering of the 300 nm waveguide's normal dispersion by varying the strength of the perturbation along its length. The minimum gap between the perturbation and the waveguide is chosen to be 50 nm, to achieve the sufficient perturbation strength for the target bandwidth: 15 nm. We simulate the apodized gratings by modeling the perturbation strength, κ, as a function of the gap between the perturbation and the waveguide. The devices use a quadratic apodization profile for the targeted amount of anomalous dispersion. We then obtain the gap as a function of the normalized length of the grating. The simulated performance of the apodized gratings and the total cavity, including the group delay, the reflectivity and the group delay dispersion (GDD), is summarized in Figure 2.

The GDD, D_λ, is found by taking the derivative of the group delay, τ_g, as a function of wavelength [5]. Anomalous

Engineering and Physical Sciences Research Council (EPSRC) (No. EP/S022139/1)

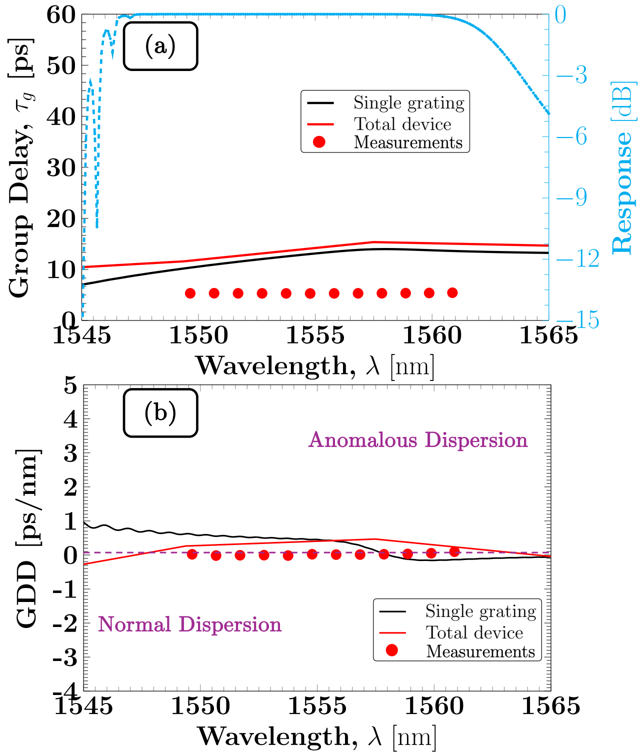

Fig. 2. Performance of the apodized gratings and total dispersion of the dispersion compensated cavity, along with experimental data points. (a) Group delay and response and (b) the group delay dispersion, GDD, as a function of wavelength across the band of interest.

dispersion is achieved when $D_\lambda > 0$. According to the simulation results, the device design results in a grating with a bandwidth of approximately 15 nm, and with a flat GDD profile in that wavelength range. An overall flat and near-zero GDD of the whole device, taking into account the SiN waveguide and the two gratings, is needed to ensure minimal variation of the cavity's FSR with wavelength, thus supporting the nonlinear four-wave mixing process. This stability is crucial for achieving coherent, evenly spaced spectral lines, which are necessary for generating a wideband comb [6].

III. Cavity Net Dispersion Results

We present the measurement of the FP cavity with the apodized dispersion compensating gratings. Figure 3 shows the free spectral range (FSR) of the FP cavity found from the spectral response. The FSR shows a 2.7% variation across the wavelength range of interest, which is significantly smaller than the 6.8% variation observed in a microring resonator on the same sample. This wavelength range, highlighted in blue, corresponds to the region measured for the microring resonator. These findings confirm the effectiveness of using a dispersion compensating element to achieve reduced FSR variation. Figure 2 presents the data points for the group delay and the GDD of the dispersion compensated cavity. As seen, the measured cavity exhibits a range of anomalous dispersion when the wavelength is greater than 1553 nm. This

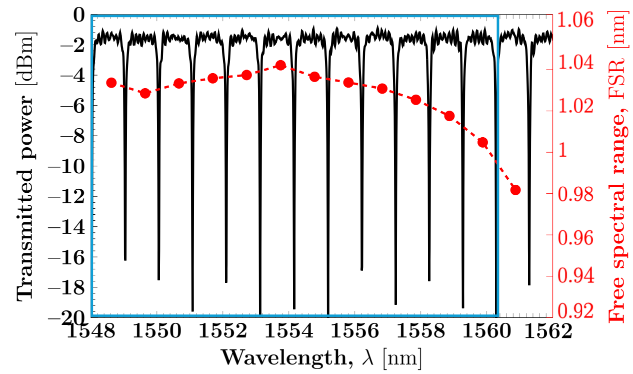

Fig. 3. Experimental FSR (in red) found from the spectral response (in black) of the FP cavity with 1000 μm length gratings on either side, with a Q factor of approximately 55'000.

confirms the successful dispersion compensation of our device, where the inherently normal dispersion of the silicon nitride waveguide has been compensated by the anomalous dispersion of the dispersion compensated gratings.

IV. Conclusion

In conclusion, we have demonstrated the successful integration of dispersion compensating apodized gratings within an FP cavity to achieve net anomalous dispersion. This approach enables precise dispersion engineering, which is crucial for applications like optical frequency comb generation. In addition, we introduced a novel four-port architecture enabling independent control of the reflectivity and the Q-factor. The apodized grating design is validated through experimental measurements, with the cavity's spectral response showing a nearly constant FSR across the bandwidth of interest. This confirms the successful implementation of dispersion compensation within the silicon nitride device.

Acknowledgment

The authors would like to acknowledge the Engineering and Physical Sciences Research Council (EPSRC) for financial support (No. EP/S022139/1) as well as EP/T019697/1 CORNERSTONE 2 for the device fabrication.

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