Coupled Fabry-Perot Resonators: a Photonic Molecule on a Lithium Niobate-on-Silicon Nitride Platform via Micro-Transfer Printing

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***Abstract*— Conventional Fabry-Perot (FP) resonators face a trade-off between high quality-factor (Q-factor) and high transmission. This work presents side-coupled FP resonators fabricated on a lithium niobate-on-silicon nitride (LN-on-SiN) platform using micro-transfer printing (µTP) to overcome this limitation. This design enables simultaneous enhancement of both Q-factor and resonance transmission. The proposed photonic molecule induces resonance splitting, unlocking exciting possibilities for advanced functionalities like comb generation, lasing, and sensing.**

Keywords*— Photonic molecule, Fabry-Perot, Coupled resonators, Micro-transfer printing

I. INTRODUCTION

Photonics plays a crucial role in various fields, including communication, sensing, and renewable energy. However, a significant challenge lies in the absence of a single ideal material platform for photonic integrated circuits. While silicon enjoys widespread use, it has limitations. This has led to the exploration of alternative materials such as lithium niobate (LN) and silicon nitride (SiN). Micro-transfer printing is emerging as a promising technique for heterogeneous integration enabling the co-integration of these dissimilar materials [1].

FP resonators are fundamental building blocks in photonics, employed in a wide range of applications [2]. They consist of a cavity enclosed by two mirrors, typically distributed Bragg reflectors (DBRs). However, there exists a trade-off between achieving a high Q-factor and a high transmission level. Increasing the DBR reflectance improves the Q-factor by confining light within the cavity, but this comes at the expense of reducing the light entering and exiting the resonator, thereby lowering the overall transmission [3]. This inherent limitation restricts the ability of conventional FP resonators to achieve both high Q-factor and high transmission simultaneously.

In this paper, we design and fabricate a coupled FP resonators as a photonic molecule on LN-on-SiN platform utilizing µTP. Inspired by the similar behavior of their light modes and the electronic states in diatomic molecules, coupled resonators are called photonic molecules. We address the inherent trade-off between high Q-factor and high transmission in conventional FP resonators by side-coupling FPs. Unlike simple FPs, this approach enables simultaneous enhancement of both Q-factor and resonance transmission levels. Photonic molecules unlock functionalities beyond basic light filtering, including comb generation [4], lasing [5], and sensing due to the controlled manipulation of mode interactions facilitated by coupling resonators.

II. DESIGN AND SIMULATIONS

Fig. 1 depicts the electric field distribution of the transverse electric (TE) mode at the wavelength of 1550 nm in the LN-on-SiN platform. The thicknesses of both LN and SiN layers are 300 nm, with a SiN width of W_{SiN}=1200 nm. The proposed structure consists of two FP resonators, namely, the main and auxiliary FPs evanescently coupled to each other as shown in Fig. 2. The coupling of resonators alters the resonance modes, known as supermodes. This modification of the field distribution within the photonic molecule detunes the supermode frequencies from those of the individual resonators. The splitting of resonances can be controlled by the inter-FP coupling strength, which itself depends on the gap (G) and the coupling length between the resonators. Lumerical's VarFDTD tool was employed to simulate the proposed structure, with the transmission spectrum presented in Fig. 3 (a). The geometrical

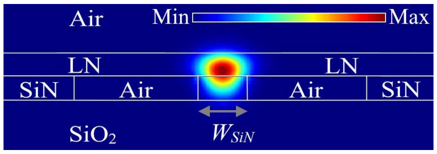

Fig. 1. The TE mode in the LN-on-SiN waveguide.

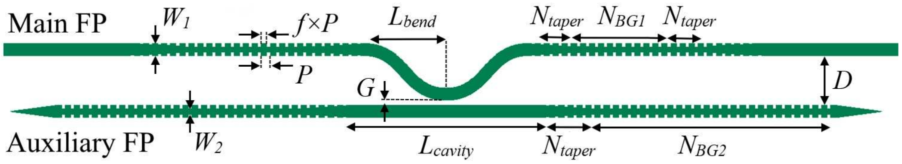

Fig. 2. The schematics of the side-coupled FP resonators. The patterned SiN layer is only shown in here.

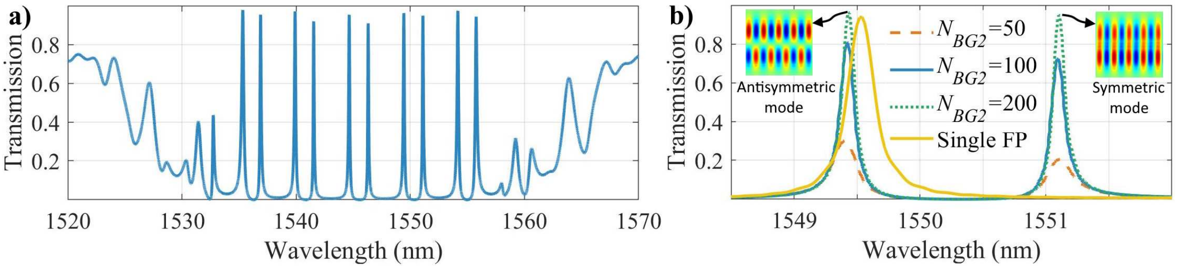

Fig. 3. a) Simulated transmission spectrum of the coupled FPs with N_{BG2}=200. b) Effect of increasing the reflectivity of DBRs in the auxiliary FP.

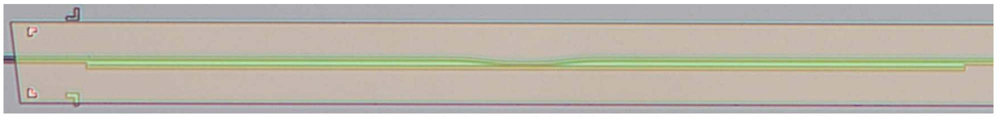

Fig. 4. The microscopic image of the fabricated structure.

parameters used in the simulations are P=430 nm, f=0.6, W_1=1200 nm, W_2=700 nm, G=300 nm, L_{bend}=50 µm, L_{cavity}=104.92 µm, D=7 µm, N_{BG1}=50, N_{BG2}=200, and N_{taper}=20. The length of the cavity is the same for both the cavities. Fig. 3(b) demonstrates that by increasing the DBR reflectivity in the auxiliary FP, we can achieve a simultaneous improvement in both the Q-factor and the resonance transmission - a significant advantage of the side-coupled FP resonators. Increasing the number of gratings in the auxiliary resonator from N_{BG2}=50, 100, to 200 leads to a significant improvement in Q-factor, reaching values of 6200, 11900, and 14100 at the wavelength of 1551.1 nm, respectively. Simultaneously, the transmission peak also increases to 0.20, 0.72, and 0.96, respectively. The Q-factor of a conventional FP with N_{BG}=50 is 5900. The antisymmetric and symmetric supermodes in the coupling region of the structure are shown in the inset of Fig. 3(b).

III. FABRICATION AND MEASUREMENTS

The fabrication process involves defining patterns in the SiN layer using positive tone electron beam resist, using electron beam lithography (ELIONIX) on a commercially available SiN wafer with 300 nm LPCVD SiN layer on a 8 µm buried oxide layer (BOX). Inductively coupled plasma etching with CHF$_3$ and O$_2$ gases achieves a 300 nm etch depth. Coupling gratings on both sides are defined similarly, with a 150 nm etch depth for higher coupling efficiency. LN coupons were fabricated from an X-cut LN-on-insulator wafer with a 300 nm LN layer [6]. The process involves defining and etching the LN coupon area (2400 µm × 100 µm) into the silicon substrate using photoresist. The coupons are then released by wet etching the BOX layer with buffered oxide etchant. Photoresist tethers hold the coupons during and after the undercut. Finally, a PDMS stamp in the transfer printer tool picks the thin-film LN coupons and prints them onto the patterned SiN substrate. Tether resist is subsequently cleaned with solvent. The fabricated structure is shown in Fig. 4. The measurement result for a structure with G=650 nm, P=435 nm, D=20 µm, N_{BG1}=100, N_{BG2}=1000, L_{bend}=200 µm, and L_{cavity}=419.775 µm is shown in Fig. 5. The other geometrical parameters are identical to those described in the previous section. The measured Q-factors of the split resonances are 19500 and 52200. This significant difference in Q-factors arises from the substantial difference in the reflectivity of the DBRs within the two FP resonators.

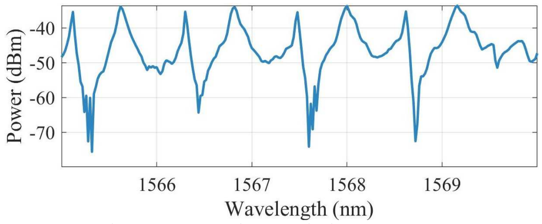

Fig. 5. Measured transmission spectrum.

IV. CONCLUSION

We have presented the design, simulation, and fabrication of side-coupled FP resonators on the LN-on-SiN platform using µTP. This approach offers a promising path towards tunable and programmable photonic molecules for comb generation, lasing, and sensing.

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