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# High-Q Silicon-Germanium On-Chip Ring Resonator in the Mid-Infrared

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**Abstract:** We report a high-Q ring resonator in the mid-infrared in a silicon-germanium on silicon chip-based platform. The side-coupled ring exhibits a loaded Q-factor of 90,000 at the operating wavelength around 4.18  $\mu\text{m}$ .

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## 1. Introduction

The mid-infrared (MIR) wavelength range (between 3 and 13  $\mu\text{m}$ ) has a large potential for sensing applications, as many molecules have strong fundamental absorption lines in this range [1]. However, the high cost and bulky MIR technology has prevented a real breakthrough so far. The integration of MIR components on-chip can provide a crucial step towards large scale applications.

Ring (and racetrack) resonators are expected to play a crucial role in on-chip integrated sensing schemes. As was first demonstrated in the near-IR, they can be used to generate frequency combs [5], and could thus provide a broadband MIR light source, a key element of sensing devices that can operate in a wide spectral range. Resonators with a high Q-factor can also enhance the interaction between light and molecules [6]. Several ring resonators have been demonstrated in the MIR [6]. High Q-factors have been achieved predominantly on silicon-on-insulator (SOI, [7]) and silicon-on-sapphire (SOS, [8]) platforms, which, however, have high losses beyond  $\sim 3.5 \mu\text{m}$  and  $\sim 6.5 \mu\text{m}$ , respectively [1]. High-Q ring resonators in the MIR have been realized also with chalcogenide glass [9], although the material photosensitivity could translate in a low temporal device stability. In addition, group IV materials are preferable for cost-effective large scale fabrication. Silicon-germanium (SiGe) is a promising material, thanks to its CMOS compatibility and transparency window up to 15  $\mu\text{m}$  [1]. Low-loss SiGe waveguides operating in the MIR have been already demonstrated [2], and their nonlinear properties were exploited for supercontinuum generation [3]. So far, however, only one SiGe ring resonator demonstration has been reported, with a moderate 3,200 Q-factor around 8  $\mu\text{m}$  wavelength [4]. Here, we report a SiGe ring resonator coupled to a bus waveguide, which exhibits a loaded Q-factor of 90,000 at 4.18  $\mu\text{m}$ .

## 2. Fabrication and Ring Resonance Measurement

Our platform consists of an air-cladded 3.3  $\mu\text{m}$  thick and 3.25  $\mu\text{m}$  wide Si<sub>0.6</sub>Ge<sub>0.4</sub> core waveguide on a silicon substrate (Fig. 1a). The resonators were fabricated on a 200 mm CMOS pilot line at CEA-Leti using deep ultraviolet photolithography and deep reactive ion etching. A ring radius of  $R = 250 \mu\text{m}$  (Fig. 1b) was chosen to target a free spectral range (FSR) of 53 GHz. The coupling gap between ring and bus waveguide is 250 nm.

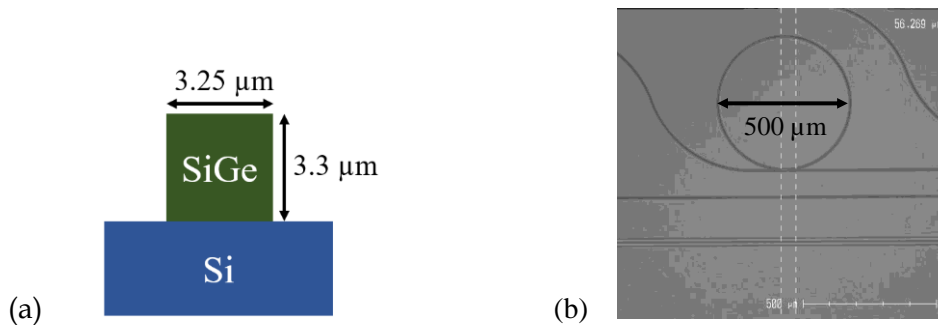


Fig. 1. (a) SiGe platform used for the ring resonator. (b) SEM picture of the ring resonator.

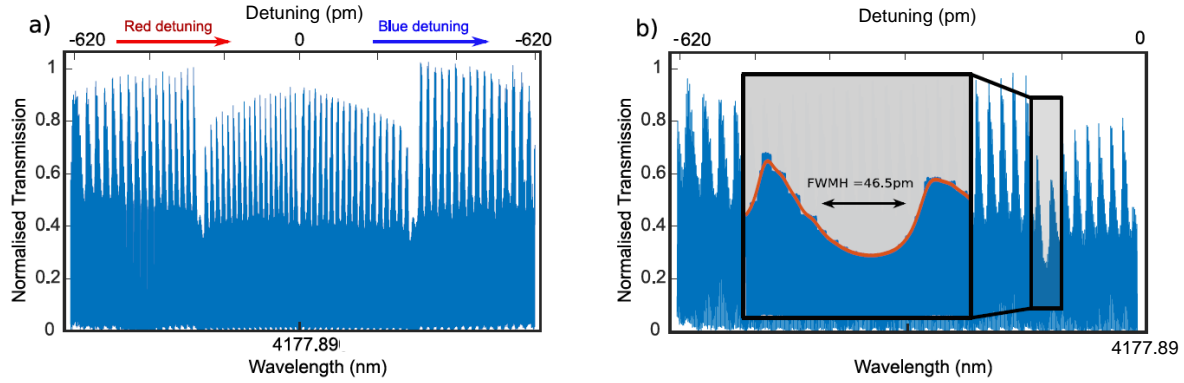


Fig. 2. (a) Wavelength scan (ramp up and ramp down) of the ring resonance with a cw QCL. The ring resonance at one specific wavelength can be clearly distinguished from the Fabry-Perot resonances, which occur due to the waveguide facet at input and output coupling. (b) Zoom-in on the ring resonance.

The ring resonance characterization was done using an Adtech 4.18  $\mu\text{m}$  distributed feedback quantum cascade laser (QCL) providing cw light. The out-coupled light was recorded by a Thorlabs Fourier transform optical spectrum analyzer (OSA). We did not utilize the spectral mode of the OSA but rather used it as a photodetector through the interferometry between the two delay beams to have less noise than with a normal photodetector. The emission wavelength of the QCL was modulated between 4177.27 nm and 4177.89 nm by applying a periodic triangular current modulation. The optical pump power was 20 mW.

Fig. 2a shows one period of the modulation recorded by the interferogram mode of the OSA. Over the whole wavelength range there are pronounced Fabry-Perot resonances, which result from the cavity formed by the two end-facets of the access bus waveguide. Nonetheless, the ring resonance can be clearly distinguished on this plot: it manifests as an additional dip occurring twice, during the wavelength ramp up and the ramp down, respectively. Fig 2b shows a zoom-in of the ring resonance. From this resonance we could retrieve a total (loaded) quality factor of  $Q = 90,000$ . We did not determine yet if we are at critical coupling. In any case, for the intrinsic quality factor a value much higher than  $10^5$  is expected.

#### 4. Conclusion

In conclusion, we have demonstrated a SiGe ring resonator operating around 4.18  $\mu\text{m}$ , with a loaded Q-factor of 90,000. These results set the basis for generating frequency combs in the MIR spectral range. The operation at 4.18  $\mu\text{m}$  was only limited by the availability of the QCL while SiGe allows for much longer wavelengths, so we expect to be able to demonstrate similar Q-factors deeper into the MIR.

#### 5. Acknowledgements

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