Si CMOS ring resonator device for synthetic dimension photonics
合成次元フォトニクス用 Si CMOS リング共振器デバイス

Yokohama National University[1], Tohoku University[2], The University of Tokyo[3], °Armandas Balčytis[1], Tomoki Ozawa[2], Yasutomo Ota[3], Satoshi Iwamoto[3], Jun Maeda[1] and Toshihiko Baba[1]
横国大院工 [1] 東北大学 [2] 東京大学 [3], °バルチティス アルマンダス [1], 小澤知己 [2], 太田泰友 [3], 岩本敏 [3], 前田惇 [1], 馬場俊彦 [1]
E-mail: armandas.balcytis@gmail.com

We present a synthetic frequency dimension on a Si CMOS ring resonator with a phase shifter modulator section, depicted in Fig. 1(a). It enables a fully integrated realization of effects previously demonstrated using a 13.5 m length fiber loop[1)]. Here, total ring circumference was $l \approx 4.1$ mm to ensure a sufficiently small equidistant mode spacing, shown in Fig. 1(b). Most of the optical path proceeds via a 3-µm-wide waveguide with 0.4 dB/cm expected loss, minimizing mode dissipation. As a result, ring quality factor was $Q = 42{,}000$, corresponding to a $2\gamma = 4.5$ GHz photon decay rate. When the resonator is driven at its free-spectral range (FSR) rate of $\Omega_R = 20.4$ GHz a frequency lattice spanning a 280 GHz bandwidth was established and sideband intensity enhancement was observed.

The synthetic dimension dispersion relations, plotted in Fig. 1(c-f), were acquired for the first time for a Si integrated photonic device by compiling 2D plots of time-resolved ring transmittance over a $T = 50$ ps modulation period as a function of input laser detuning. Modulations at Ω_R and $2\Omega_R$ frequencies, corresponding to nearest- and second-nearest-neighbor coupled 1D tight-binding models, were employed. When both of these modulations are applied concurrently with different relative phases, a one-dimensional triangular ladder with an alternating magnetic flux can be simulated. Such coupling regimes can give rise to synthetic dimension band structures that are asymmetric around the $k = 0$ point. Since in our synthetic frequency lattice the analog of the wavenumber k corresponds to time, this suggests the breaking of time-reversal symmetry and the onset of nontrivial topological effects[2,3)].

The research is conducted as a JST CREST project Grant Number JPMJCR19T1. Tomoki Ozawa is supported by JST PRESTO Grant No. JPMJPR19L2. Armandas Balčytis is an International Research Fellow of JSPS.

References:

1) A. Dutt et al., Nat. Commun. **10** (2019) 3122. 2) T. Ozawa et al., Rev. Mod. Phys. **91** (2019) 015006.
3) T. Ozawa et al., Phys. Rev. A **93** (2016) 043827.

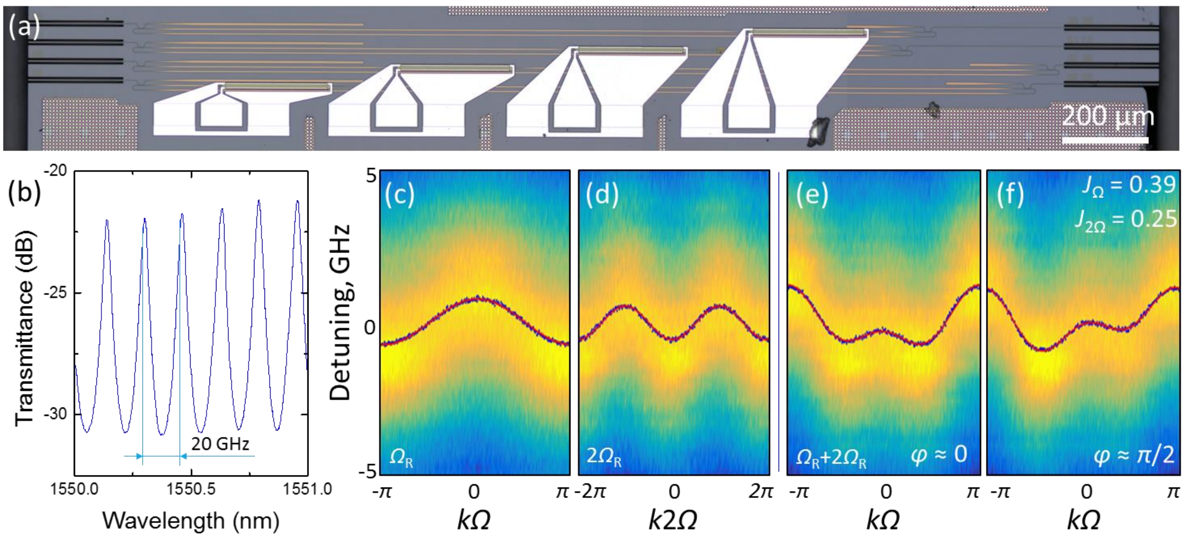

Fig. 1 (a) Micrograph of 4 modulator-equipped SOI ring resonators for synthetic frequency dimension. (b) Transmittance spectrum spanning 6 FSR (20 GHz) intervals. Synthetic frequency dimension bands at different on-resonance modulation regimes (c) $\Omega_R = 20$ GHz, (d) $2\Omega_R = 40$ GHz, (e,f) simultaneous Ω_R and $2\Omega_R$ with with different relative phases. Solid lines are 1D tight-binding model $\varepsilon_k = 2J_\Omega\cos(k\Omega+\varphi)+2J_{2\Omega}\cos k2\Omega$ fits.