Design of micro-optical parametric oscillators based on third-order nonlinearity

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On-chip coherent light generation is of interest for both classical integrated photonics and quantum optics. One promising approach employs microcavity-enhanced optical parametric oscillators (OPOs) based on third-order material nonlinearity (χ(3)). It is of interest to investigate the fundamental limits of micro-OPO performance, and find designs based on first principles that achieve the best possible performance given fixed material parameters. In this paper we propose a microphotonic geometry that permits access to all theoretically accessible degrees of freedom, and present a general design approach for OPOs based on degenerate four-wave-mixing (FWM) that achieve the maximum possible conversion efficiency.

We find unique solutions that show that in some cases the optimum designs require the external Qs of resonances of the triply-resonant cavity to be substantially different to achieve optimum power conversion efficiency from pump to signal/idler light output. The design approach is based on a coupled mode theory in time (CMT) model. We consider only three resonantly-enhanced, interacting frequencies (one signal, a degenerate pump and one idler). The model is solved analytically even in the presence of linear and nonlinear losses. We summarize our results in a set of normalized design curves that give the minimum pump power required for a given output power or conversion efficiency at a given signal frequency and given nonlinear material parameters, and relate the solutions to physical design intuition.

As an example, Fig. 1(c) shows the maximum efficiency as a function of material nonlinear loss coefficient (defined as Im[χ(3)]/Re[χ(3)]) and normalized input pump power. We discuss concrete example designs including microring-resonator-based OPOs in silicon at 1.55μm (with two photon absorption, TPA) and 2.3μm (no TPA) wavelengths as well as in silicon nitride (Si3N4). This work shows that unique microphotonic geometries can have new degrees of freedom that enable optimum parametric oscillators.

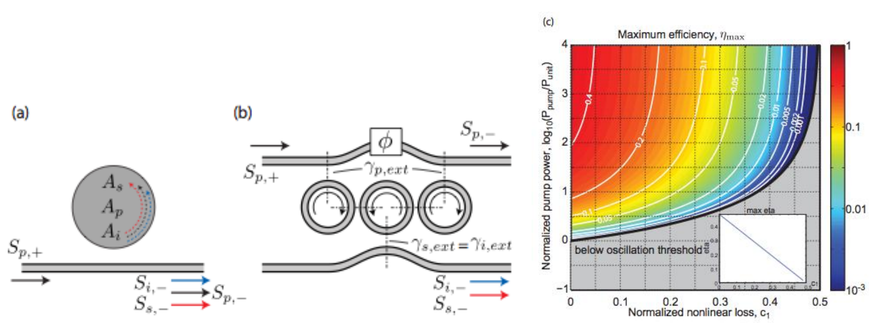

Figure 1: (a) Illustration of the micro-OPO model; (b) an example proposed multimode resonator based on 3 coupled microring cavities, showing an approach to unequal pump and signal/idler external coupling. (c) maximum efficiency vs. normalized pump power and nonlinear loss parameter with optimum OPO design.