Photon-pair generation from two silicon micro-rings using the recycled optical power from a contra-directional pump-reject filter

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Abstract: Two micro-ring resonators are integrated with two contra-directional pump-reject filters in a pump-reuse configuration showing a 55% increase in the coincidence counts from both sources compared to a single source at 1mW input pump power.

1. Introduction

Scaling up the number of parametric heralded single photon sources (HSPS) on silicon is an essential requirement for complex photonic quantum processing applications [3]. An important metric in this regard is the total rate of high quality pairs generated from a single external optical pump source. Integrated pump-reject filters are needed to improve the quality of the signal and idler pairs they pass, but often the rejected pump power is sufficient to create useful photon pairs in a separate source. While different pump-reject filter types have been reported, the four-port contra-directional couplers (CDCs) we recently reported in conjunction with a micro-ring resonator (MRR) source [1,2] are particularly suited to make effective use of the residual pump power from the first source. An application of this pump recycling technique applied to a single pair of sources could be to provide independent heralded single photons to a quantum key transmitter, where one stream would provide a source of random numbers, and the second would feed the transmission channel [7]. Here we report a maximum increase of 55% is obtained in the coincidence counts from both MRRs compared to the pairs generated from a single MRR, both for a fixed 1mW input pump power. Calculations suggest that the PGR $\times$ CAR figure of merit [6] for this pump-reuse geometry would yield a similar peak value as compared to what would be obtained using a Y-splitter to separately pump the two sources with the same pump power, but that this figure of merit persists over a wider range of input powers in the case of the pump-reuse configuration.

2. Experimental results

The dual source circuit is formed by two MRRs (MRR1 and MRR2 as shown in Fig. 1), which had nominally identical dimensions of 240 nm wide coupling gaps, 18 μm radii and 425 nm wide ring waveguides (fabricated by Applied Nanotools). Each MRR is followed by a three-stage, cascaded from their through-ports, CDC pump-reject filter (CDC1 and CDC2) with nominally identical dimensions as reported in [2]. MRR1 is followed by a 5% tap coupler (tapC) to monitor its resonances. CDC1 performs two functions: first it rejects the pump power applied to MRR1, and second, it recycles the residual pump power output from MRR1 to be used as a pump input to MRR2 through the drop-port of the first CDC stage. MRR2 is thermally tuned to have the same wavelength as the pump and MRR1. CDC2 serves only to reject the residual pump after MRR2, to extract the photon-pairs from its output with maximum coincidence to accidental ratio (CAR). The quality factors of the MRRs were measured to be 3992 and 4690 for MRR1 and MRR2, respectively.

Figure 1(b) shows the total coincidence counts from both MRRs (MRR1 in blue and MRR2 in orange), recorded in a coincidence window of 256 ps with a total integration time of 20 min and 128 ps timing resolution for the Swabian time tagger at 1.65 V applied to MRR2 heater. The single photon detectors (SPDs) used in the coincidence setup shown in Fig. 1(a) are avalanche photodiodes. Figure 1(c) shows the CAR values extracted from the coincidence histograms for the data in Fig. 1(b), which are calculated using the formula $CAR = (CC - AC)/(AC - DC)$, where $CCandAC$ are the coincidence and accidental showing the error-bar values due to the high dark counts DC

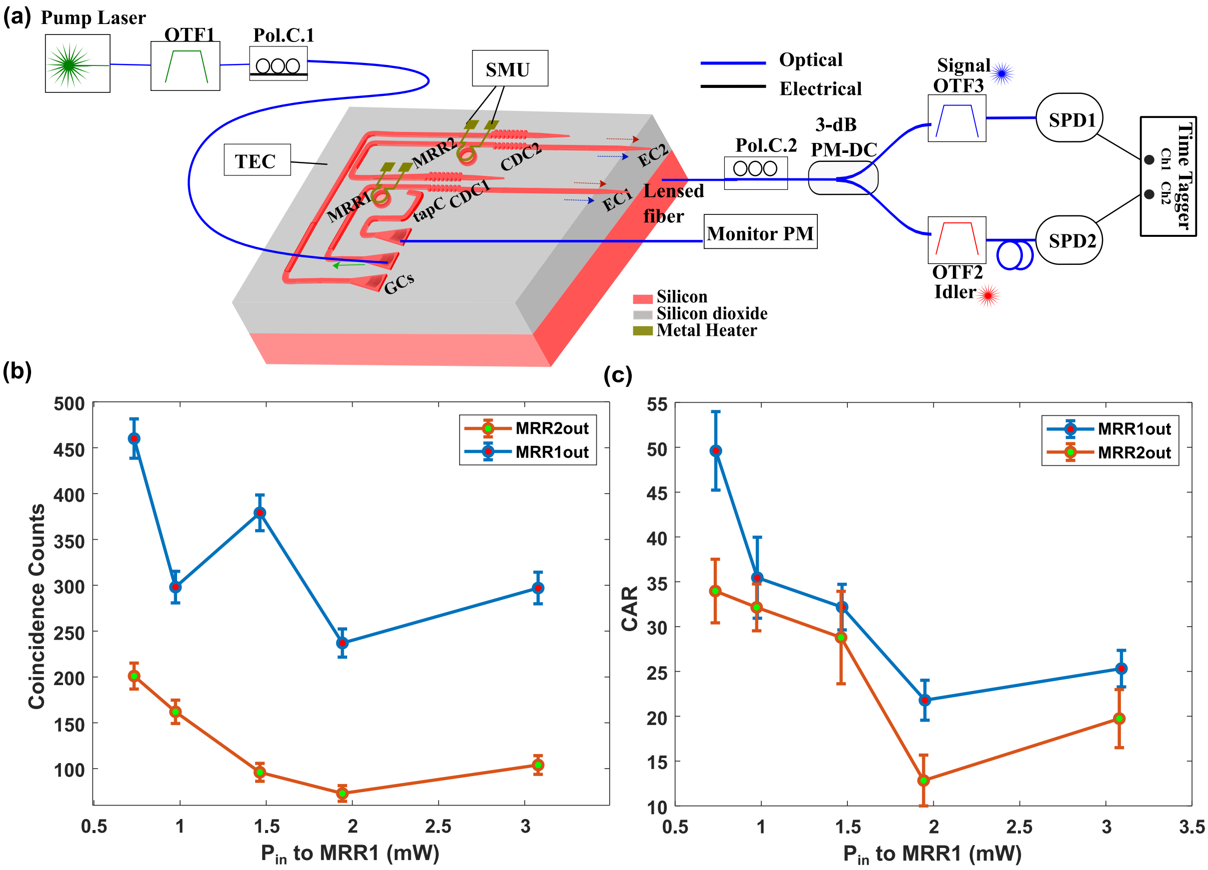

Fig. 1. (a) The coincidence setup used in characterizing the coincidence histograms from both MRR1 and MRR2 in the pump reuse circuit. OTF1,2,3: optical tunable filters. PM-DC: Polarization maintaining coupler. SPD1,2: Avalanche single photon detectors. Pol.C1,2: polarization controllers. TEC: thermo-electric cooler. SMU: source measurement unit. PM: optical power meter. Both CDC1 and CDC2 in the real chip are three-stage cascaded CDCs from their-through ports. (b) The total coincidence counts from MRR1 (blue upper curve) and MRR2 (orange lower curve) respectively vs. pump power input to MRR1 P_{in}, recorded in a coincidence window of 256 ps, at 1.65 V applied to MRR2 heater. (c) The coincidence to accidental ratios for MRR1 (blue upper curve) and MRR2 (orange lower curve) measured at 1.65 V voltage on MRR2-heater, computed using the formula $CAR = (CC - AC)/(AC - DC)$ showing the error-bar values due to the high dark counts of the single photon detectors [4].

of the SPDs [4]. However, when 1.65 V is applied to the heater of MRR2, both pump resonances of both MRRs are aligned to 1550.277 nm. While the pump laser is on and the heater voltage is on, we re-aligned the lensed fiber to the output of CDC2 to record the coincidence counts from the photon-pairs generated from MRR2 vs. the pump power recycled from CDC1 and injected to MRR2, as shown in the orange curve of Fig. 1(b). From these coincidence histograms, we estimated the CAR values of the photon-pairs generated from MRR1 (blue curve in Fig. 1(c)) and from MRR2 (orange curve in Fig. 1(c)) vs. the input pump power to MRR1.

We can define the pump reuse ratio, $\rho_R^{(2)}$, of this technique as the total coincidence counts generated from both MRRs connected in the circuit to the total coincidence counts generated from just MRR1.

$$\rho_R^{(2)} = 1 + \left(\frac{CC_2(Tf(P_{in}))}{CC_1(P_{in})} \right) . \tag{1}$$

where CC_1 and CC_2 are the coincidence counts measured from MRR1 (blue curve in Fig. 1(c)) and MRR2 (orange curve in Fig. 1(c)), respectively. P_{in} is the input pump to MRR1, and $Tf(P_{in})$ is the input power to MRR2 as a function of P_{in}, which is equal to $Tf(P_{in}) = T_{MRR1}T_{drop1}P_{in}$, where T_{MRR1} is the transmission of MRR1 and T_{drop1} is the drop-port transmission of CDC1. Figure 2(a) shows the experimental results in blue diamonds for the pump reuse ratio computed using Eq. 1 vs. pump input to MRR1. The estimated shape of the pump reuse is shown as

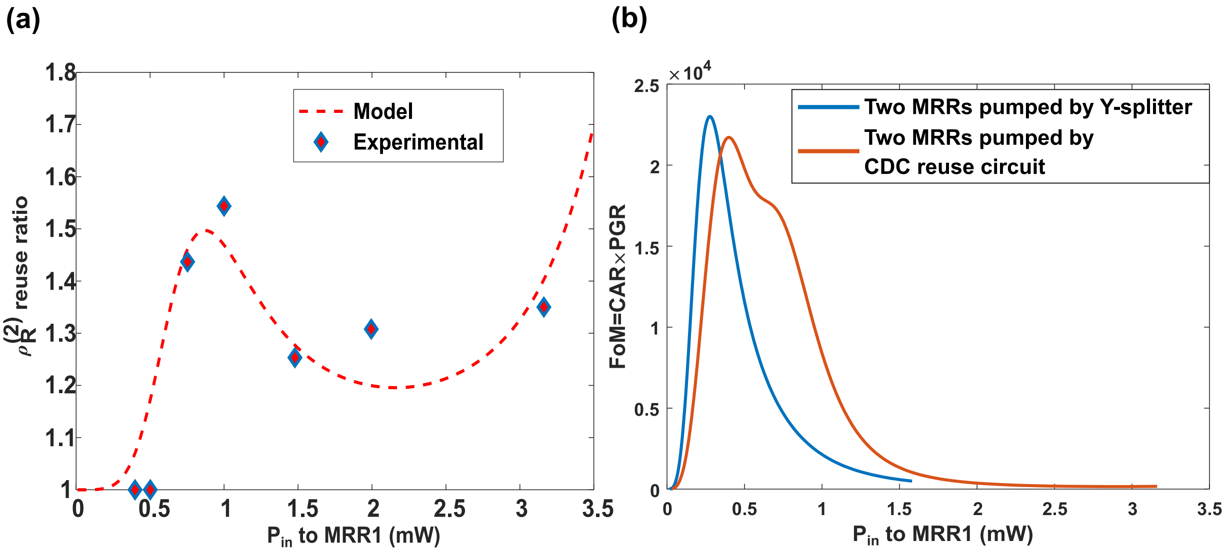

Fig. 2. (a) The red-diamonds is the measured reuse ratio using the data (shown in Fig. 1(c)) while the heater of MRR2 was on. The dotted red line is the reuse ratio estimated from a model that incorporates smooth fits to the power-dependent PGR data recorded for each MRR separately, along with a smooth fit of the recycled power from MRR1 injected into MRR2 when tuned in resonance. (b) The sum of the FoM for both MRRs in the case of them being pumped from the two ports of a Y-splitter is plotted vs. $P_{in}/2$ in the blue solid line, and the sum of the FoM of the two MRRs connected into the CDC reuse circuit vs. the input power of MRR1 P_{in} is shown in the orange curve.

a dotted red line in Fig. 2(a). In Fig. 2(b), we compare the theoretical sum of the figure of merit, FoM, given by $FoM = PGR \times CAR$ as defined in [6]. PGR is the pair generation rate from each MRR as defined in [2]. CAR is defined in [5], for two MRRs connected by a CDC in a pump recycling scheme to the case of two similar MRRs connected to the outputs of a Y-splitter. Which shows that the CDC pump distribution (recycling) outperforms the Y-splitter pump distribution at high pump powers.

3. Conclusions

This pump recycling technique applied to two MRR photon-pair sources (PPSs) shows a 55% increase in the coincidence counts from both MRRs compared to the pairs generated from a single MRR at 1mW input pump power to MRR1. This technique is a promising candidate for energy efficient scaling of the number of photon-pairs generated from many PPSs on SOI chips for large scale photonic quantum processing applications [3].

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