















**Table 2. Tabulate results of the CAR and pair generation rate for coincidence window durations covering FWHM and  $\pm 3$  standard deviations of the Gaussian fit to the coincidence histogram.**

Injection power	CAR (FWHM)	CAR ( $\pm 3\sigma$ )	Pair generation rate (FWHM)	Pair generation rate ( $\pm 3\sigma$ )
<b>With 8V reverse bias</b>				
4.8 mW	$37 \pm 1.3$	$19 \pm 0.6$	123 MHz	161 MHz
<b>No reverse bias</b>				
4.8 mW	$43 \pm 2.2$	$23 \pm 1$	59 MHz	75 MHz
1.1 mW	$359 \pm 16$	$125 \pm 3$	2.7 MHz	6 MHz
0.019 mW	$602 \pm 37$	$315 \pm 18$	827 kHz	1 MHz

#### 4. Discussion

In this letter we have studied photon pair generation in a silicon micro-ring resonator through SFWM. A maximum CAR value of  $602 \pm 37$  is measured for an injection pump power of 0.019 mW, corresponding to photon-pair generation rate of 827 kHz. The maximum photon pair generation rate of 123 MHz is achieved, at an injection pump power of 4.8 mW, by applying a 8 V reverse bias voltage across the p-i-n structure to mitigate the parasitic effects of free-carrier absorption (with an associated CAR value of  $37 \pm 1.3$ ). Increasing the reverse bias voltage beyond 8 V does not lead to a further increase in the photon pair generation rate, and we instead observe a reduction in this rate. We attribute this effect to a change in the coupling constant between the ring resonator and the bus through thermo-optic effects induced by the removal of the free carriers. As we increased the bias voltage, we indeed observed a shift in the resonance peak towards longer wavelengths jointly due to the dominant thermo-optic effect and a reduction in the free carrier dispersion. These free-carrier absorption parasitic effects are even more prominent for devices pumped with short laser pulses. For instance, Xiong et al [11] investigated pair generation in slow-light photonic crystal structures, and demonstrated clear saturation due to TPA and FCA at peak power of just 0.4W. Implementation of a p-i-n structure in such a device could extend the operation of these devices into a regime of higher pair generation rate.

While the photon pair rate increases with reverse bias, it is worth noting that the CAR is only slightly degraded. This degradation is expected from the increase of multi-pair terms due to the higher pair generation rate. However this effect was mitigated by an increase in the signal-idler collection due to the reduced FCA.

The results presented in this paper highlight the potential of silicon as a promising photon source for photonic quantum information processing and communications, with properties of low noise (suitable for example in high fidelity quantum operations) or high generation rate (suitable for example in high-rate quantum key distribution). It is interesting to note from comparing the CAR values shown in Fig. 2(b), we see that for the on-resonance conditions, the reverse-biased and un-biased case give similar values, whereas for off-resonance the CAR is much lower. This is likely due to noise from Raman scattering in optical fibers of the experimental setup which deteriorates the CAR for low photon-pair generation rates in the off-resonance case.

Currently the filtering of the pump, signal and idler photons are achieved using fiber optic components, but with improved architectures, on-chip filtering could also be performed by further taking advantage of resonant structures. The ring cavity also has the advantage of generating photon pairs having low spectral entanglement [21] when pumped with a pulsed source having a bandwidth greater than the resonance width. This will enable such ring sources to be used as high purity single photon sources, heralded on the measurement of one of the photon pairs. The relevant figures of merit (CAR and CC) for such a source should be taken by integrating the full coincidence peak (at least at  $\pm 3\sigma$ ) since selecting part of the peak would be equivalent to a loss on the heralded photon generated thus lowering the heralding efficiency of the source. The high CAR achieved makes these sources a good candidate for



low noise multiplexed single photon sources [22] which could in turn be used in a scalable manner to seed a linear optical quantum circuit.

The on-chip photon pair source reported in this paper is fully compatible with already demonstrated silicon quantum circuits [9] and high-efficiency waveguide integrated superconducting single-photon detectors [7,8]. It is therefore possible to realize in a single material system all the major components required for on-chip linear optics quantum information processing; low noise single photon sources, compact waveguide circuits and efficient single photon detectors. The next major challenge is to integrate all these components into a single unified technology platform, for which the silicon-on-insulator material system appears to be a promising candidate.

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