Supplementary information to
Chip-integrated visible-telecom photon pair sources for quantum communication

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This document contains the details of the experimental setup and additional data on optical parametric oscillation that occurs when the device is excited with increased pump power.

I. EXPERIMENTAL SETUP

The device is tested with the experimental setup shown in Figure S1, which illustrates the measurement configurations for cavity transmission, photoluminescence spectra, and coincidence counting. For the cavity transmission measurement, three tunable continuous-wave lasers are used to measure the transmission spectra of signal, pump, and idler bands, respectively. The laser wavelengths of cavity modes are calibrated by a wave meter with an accuracy of 0.1 pm. The pump laser is attenuated to sub-milliwatt levels with the polarization adjusted to transverse-electric-mode polarization. The pump light and the generated photon pairs are coupled onto and off the chip by lensed optical fibers with a focus diameter of 4 μm to 5 μm. The fiber-chip coupling losses are 3.9 dB/2.3 dB/4.2 dB per facet for signal/pump/idler respectively. No filters are required before the device, since both the laser amplified-spontaneous-emission noise and the Raman noise from fibers have frequencies that are far from visible or telecom bands. Signal and idler photons are coupled by separate waveguides and lensed fibers. The waveguides have photon extraction efficiencies of 84 %/20 % for signal/idler photons. The signal (visible) photons are separated from the pump residue by a dichroic mirror and a shortpass filter in free space. The idler (telecom) photons are separated by a longpass filter, which cascades two 980 nm/1550 nm fiber multiplexers to yield a pump isolation over 90 dB. The signal/idler photoluminescence after broad-band filtering is directed into gratings and recorded by InGaAs/Silicon detector arrays in a spectrometer. For the coincidence counting measurement, tunable filters with bandwidths around 100 GHz are used to purify the photon pairs from their adjacent modes. The filtering losses for signal/idler are 5.8 dB/5.6 dB in total. The signal photons are measured by a single photon avalanche diode (SPAD) with a multi-mode fiber coupling and the idler photons are measured by a superconducting nanowire single photon detector (SNSPD) with a single-mode fiber coupling. The detection efficiencies of the SPAD/SNSPD are 59 %/67 %, calibrated at the signal/idler wavelengths. A polarization controller (with a loss of 0.7 dB) is used to optimize the polarization for the SNSPD. Taking into account fiber-chip coupling, optical component loss, and detection efficiencies, the overall detection efficiencies for the on-chip signal/idler photons are 12.0 dB/12.2 dB. The Klyshko efficiencies are 3 %/0.2 % for the signal/idler photons.

II. OPTICAL PARAMETRIC OSCILLATION

In this session, we provide experimental data of optical parametric oscillation (OPO) to explain the decreased efficiency at the high-power end in Figure 5(d). Figure S2(a) shows the optical spectra close to pump band at various pump powers, recorded by an optical spectra analyzer. When the pump power is above 290 μW (yellow), OPO is clearly initiated for the modes spacing 8 free spectral ranges (FSRs) apart, and the power of the generated modes increases. At 460 μW power (blue), side bands also emerge 1-FSR alongside the 8-FSRs OPO modes. As shown in Fig. S2(b), cavity transmission traces indicate that the pump power is partially consumed by OPO. When the optical power is below 290 μW, the cavity transmission exhibits triangle-shape thermal bistability with a constant transmission dip of 28 %, where the microring is slightly under-coupled. When the optical power further increases, the OPO is initiated and the pump power is consumed inside the cavity. This consumption is an additional loss channel respect to the intrinsic cavity loss and thus makes the cavity more under-coupled. As a result, the cavity transmission dip increases to 32 %, 37 %, and 41 % for the yellow, red, and blue traces, respectively. Figure S2 shows that when the optical pump power increases, the competitive process (i.e., OPO close to pump band) decreases the pump power in the cavity and thus leads to a lower generation efficiency for the visible/telecom photon pairs.

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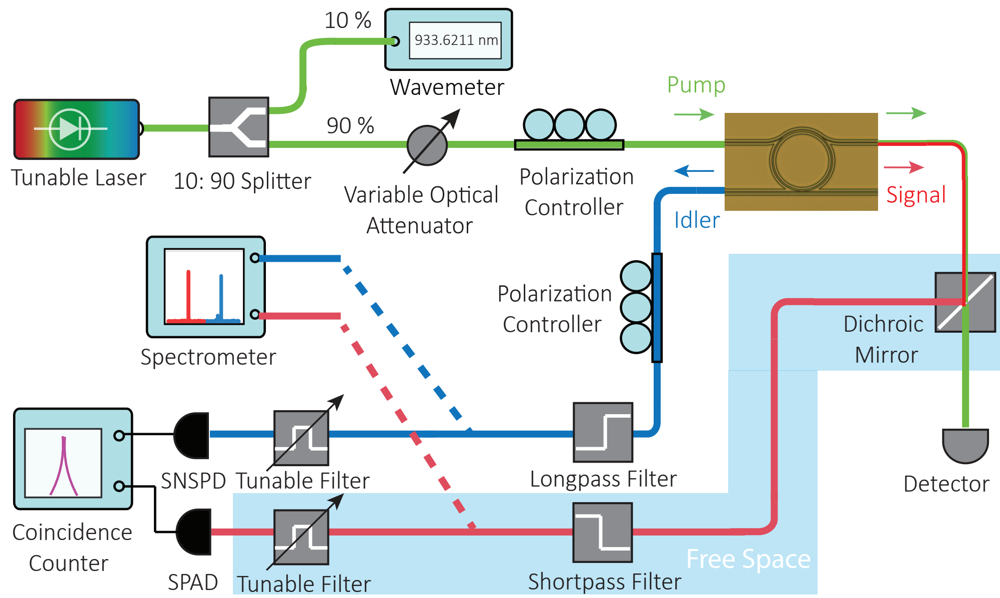

FIG. S1: **Experimental Setup**. Cavity transmission, photoluminescence spectra, and coincidence counting are recorded by this experimental setup. Solid lines show the setup for the cavity transmission and the coincidence counting. Dashed lines indicate the setup for the photoluminescence spectra. The shaded area indicates free-space operation, whereas the unshaded area indicates fiber optical components. SNSPD: superconducting nanowire single-photon detector. SPAD: single-photon avalanche photodiode.

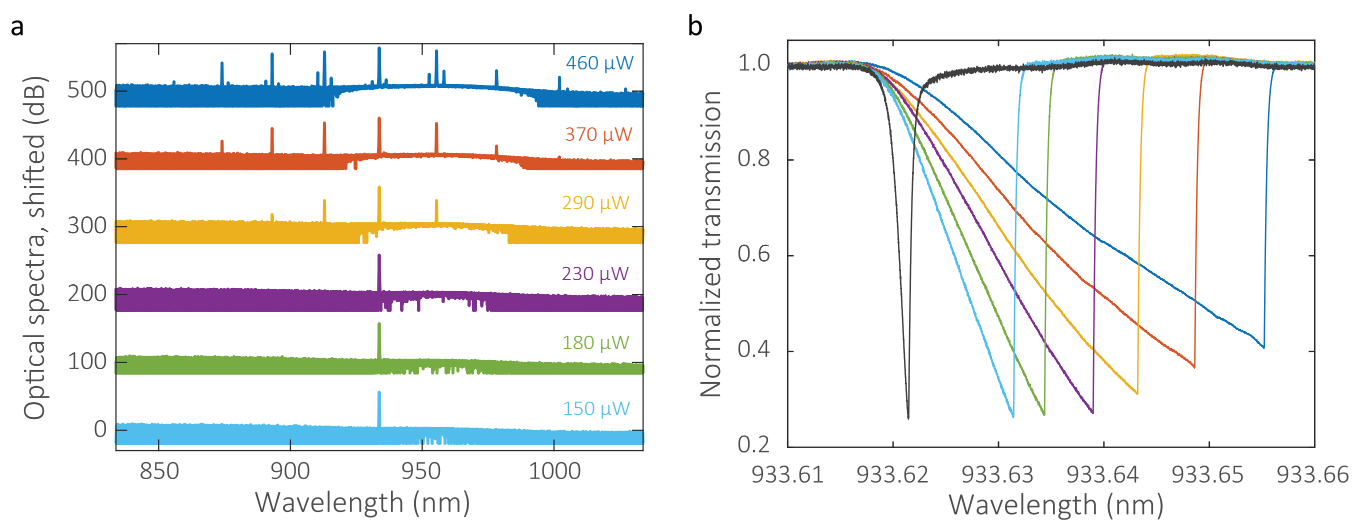

FIG. S2: **Optical Parametric Oscillation**. **a**, Optical spectra with pump power varied from 460 μW (top) to 150 μW (bottom) with a step of 1 dB. The spectra are spaced by 100 dB. **b**, Cavity transmission traces of pump resonance at various pump powers. The black trace has a low pump power of 15 μW and exhibits no thermal bistability. The other traces have pump powers from 150 μW (left) to 460 μW (right).

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