National Aeronautics and Space Administration

Integrated source of photonic entanglement

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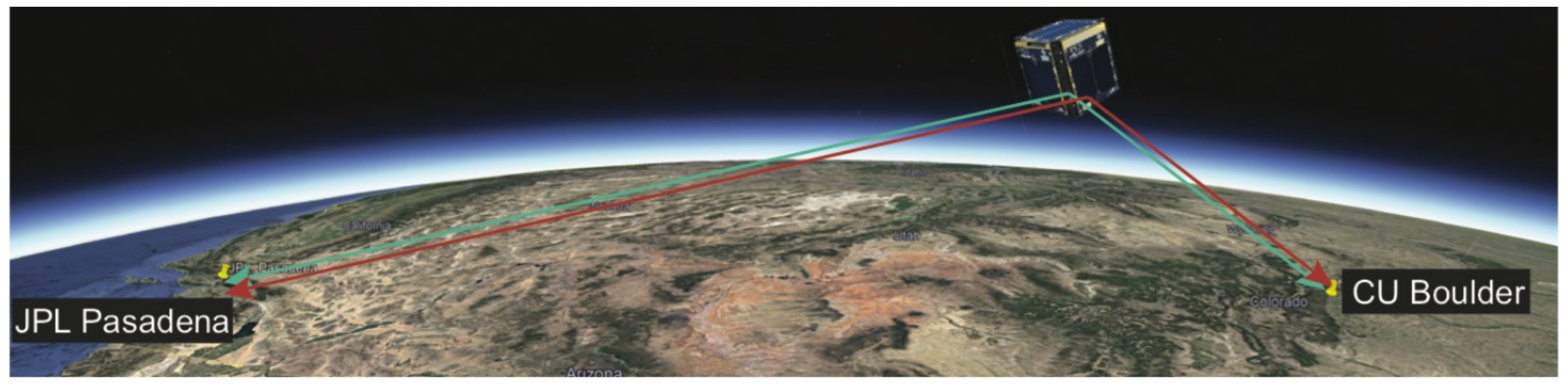
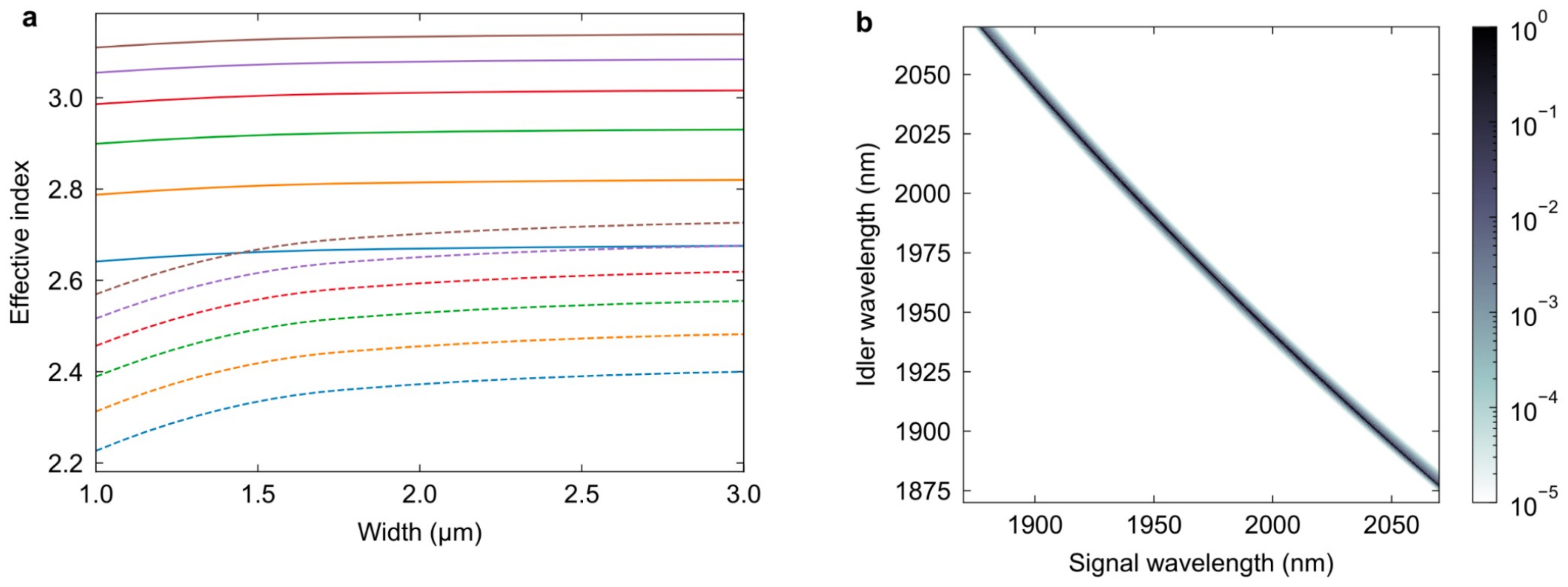
Objectives

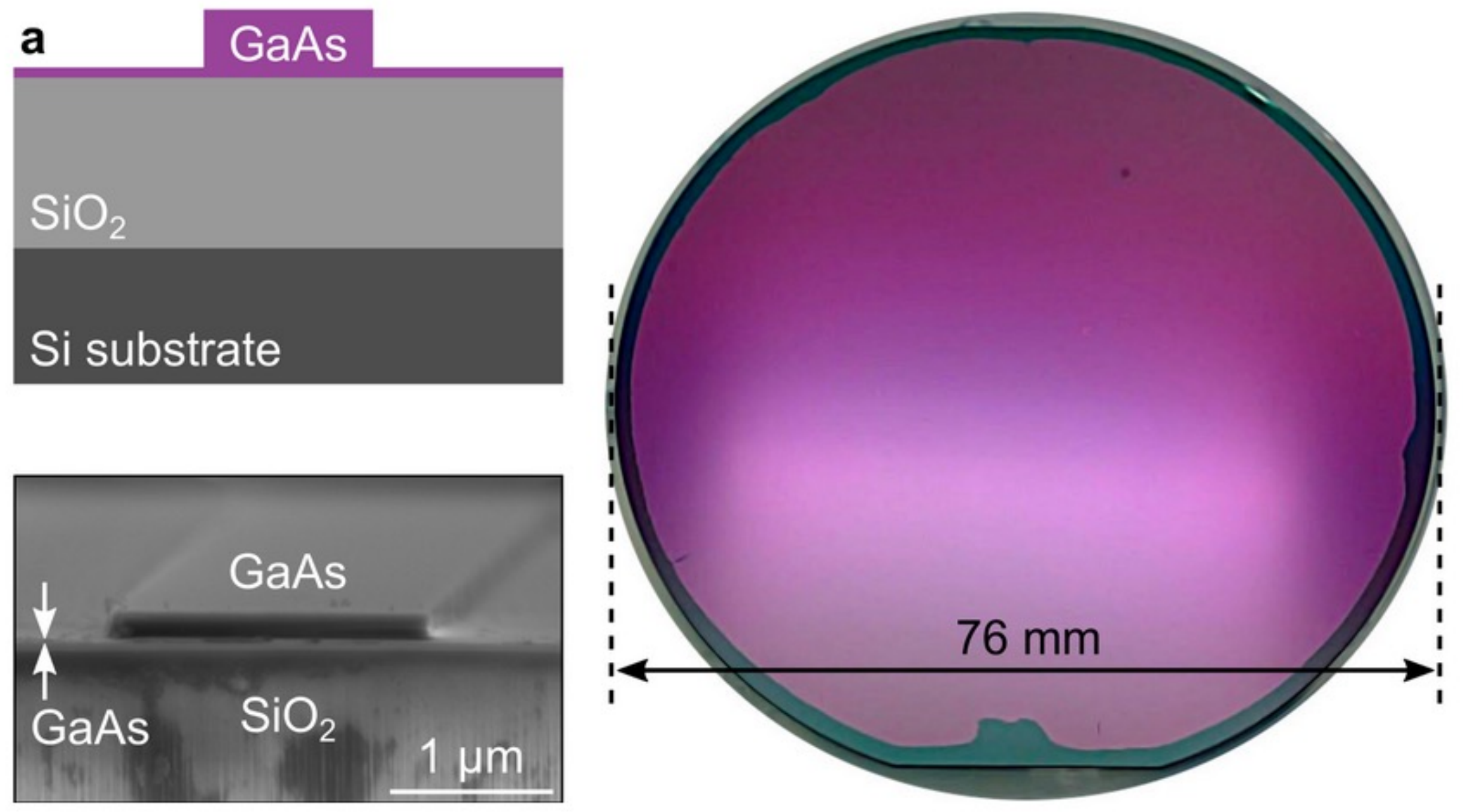
The goal of this project was to develop the building blocks required for a bright, high-speed, compact, and low-power source of high-quality entangled photons suitable for future use in a quantum satellite. Current sources of entangled photons, including those used on recent quantum satellites, are mostly based on bulk-optics sources that are difficult to align, have large power requirements, and are not very bright. Moreover, the majority of satellite sources are designed for visible wavelengths.

This, one year-only, grant investigated two emerging nonlinear optics platforms for generation of spontaneous parametric down-converted photons at near-infrared wavelengths (1.5 - 2.1 μm) - namely nanophotonic GaAs and thin-film lithium niobate. Entangled photons at 1.5 - 2.1 μm have the advantage of being much further away from the peak of the blackbody emission of the Sun while still being far enough from the blackbody emission of the sky and other terrestrial objects, meaning it might be possible to operate in a wider variety of ambient lighting conditions. In addition, NASA has already invested in single-photon detection ground stations at 1.55 μm for deep-space optical communications, meaning quantum entanglement sources at this wavelength can leverage this existing architecture, in the future.

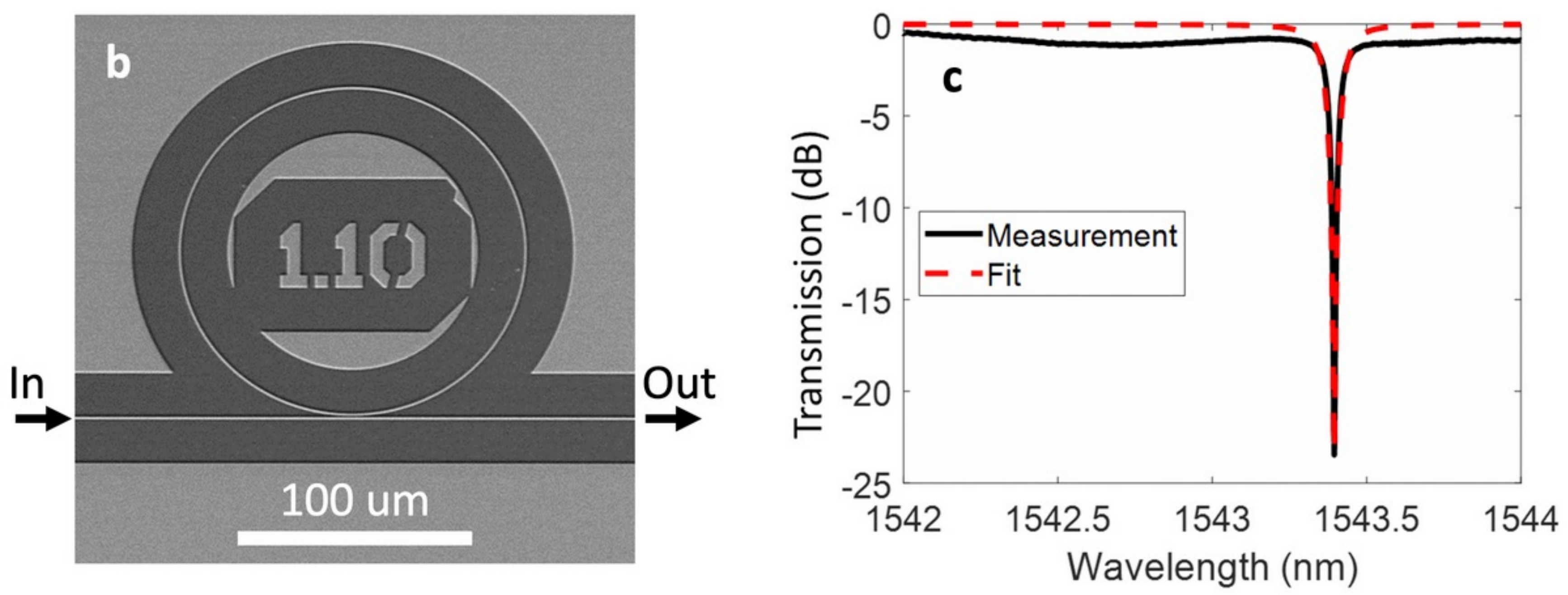




(a) Effective index simulation where different colored lines represent varying waveguide thicknesses between 200 nm and 300 nm in steps of 20 nm. The solid lines show the effective indices for the TM pump modes and the dashed lines show the indices for the TE signal modes. (b) The joint spectral intensity (JSI) spectrum for SPDC is calculated from the indices in (a).



(a) Picture of GaAs wafer/waveguide.



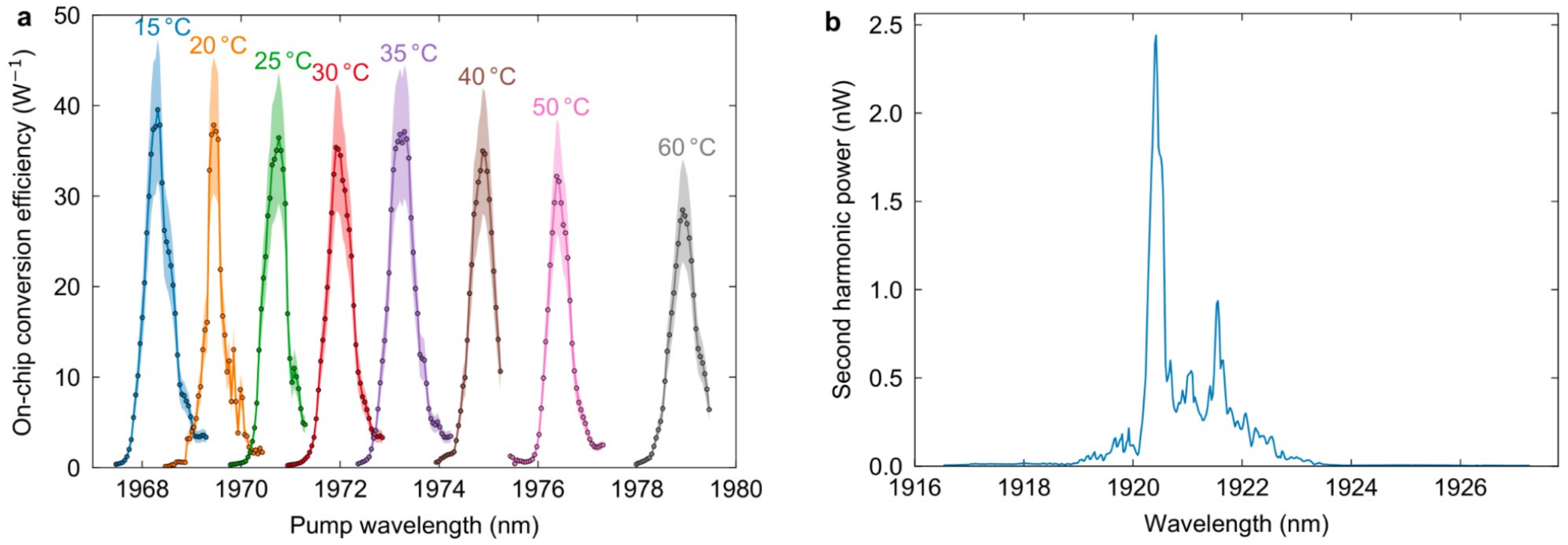
(b) Micrograph of an etched thin-film lithium-niobate (TFLN) waveguide and ring resonator, which is used for evaluation of the waveguide optical loss. (c) Optical resonance measurement of the TFLN ring resonator, with a fit indicating waveguide loss of 3.6 dB/cm.

Approach and Results

Sources of photonics entanglement are most commonly based on a nonlinear interaction known as spontaneous parametric down-conversion (SPDC) - where a single photon at 0.75-1 μm spontaneously splits to create 1.5-2 μm daughter photons. The efficiency of SPDC improves with increase in optical intensity in the nonlinear media, making integrated nano-photonic waveguides the ideal way to reduce the power requirements of the source, due to the tight optical confinement. Two of the most promising platforms for integrated nonlinear optics are GaAs [1] and thin-film lithium niobate (TFLN) [2] hence these platforms were chosen for this investigation.

By optimizing the GaAs surface treatment prior to bonding, at CU/NIST Boulder, we measured 1.5 dB/cm propagation loss at 2 μm and 16.8 dB/cm at 1 μm. Although this loss is higher than other platforms, the large second-order nonlinearity and the high confinement contributed to our demonstration of the highest second harmonic generation (SHG) conversion efficiency of any material platform for a single-pass device (non-resonant). In a 2.9 mm-long waveguide, we measured 39.5 W^{-1}, corresponding to a normalized efficiency of 476 $W^{-1}cm^{-2}$ [1].

The best way to confine the optical mode in TFLN, the platform of choice studied at JPL, into a small volume, is to partially etch a rib-waveguide. By using a predominantly physical etch we succeeded in defining a ring resonator structure, to measure the waveguide loss of 3.6 dB/cm at 1.55 μm, which is sufficiently low for SPDC sources. The outlook for this platform is to develop high-resolution periodically-poled regions in the TFLN, prior to patterning of the waveguides. After characterization of the SHG and SPDC efficiencies, these sources can also be configured into an entanglement source.



(a) SHG for various temperatures in GaAs. (b) SHG spectrum of a device mounted on the SPDC measurement setup at room temperature.

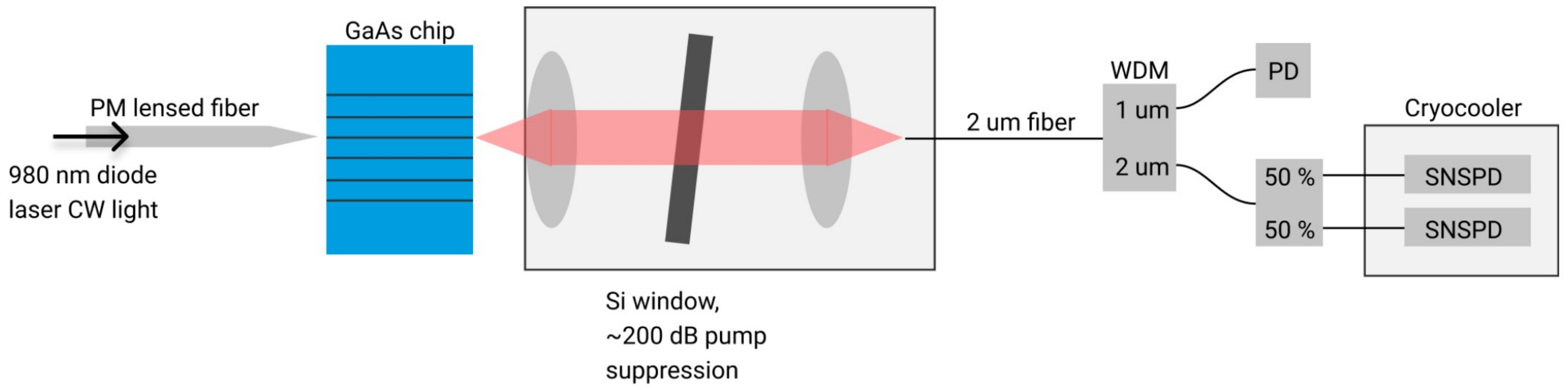


Diagram of SPDC experimental setup for GaAs waveguides, which is the next step in this project.

References

[1] E. J. Stanton, J. Chiles, N. Nader, G. Moody, N. Volet, L. Chang, J. E. Bowers, S. W. Nam, and R. P. Mirin, "Efficient second harmonic generation in nanophotonic GaAs-on-insulator waveguides," Opt. Express **28**, 9521 (2020).
[2] J. Zhao, C. Ma, M. Rüsing, and S. Mookherjea, "High Quality Entangled Photon Pair Generation in Periodically Poled Thin-Film Lithium Niobate Waveguides," Phys. Rev. Lett. **124**, 163603 (2020)

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