Supplementary material

Silicon nitride waveguide polarization rotator and polarization beam splitter for chip-scale atomic systems

Kevin Gallacher,[1] Paul F. Griffin,[2] Erling Riis,[2] Marc Sorel,[1] and Douglas J. Paul[1]

[1]University of Glasgow, James Watt School of Engineering, Rankine Building, Glasgow, G12 8LT, U.K.

[2]Department of Physics, SUPA, University of Strathclyde, Glasgow G4 0NG, United Kingdom

Self-aligned Etch Process

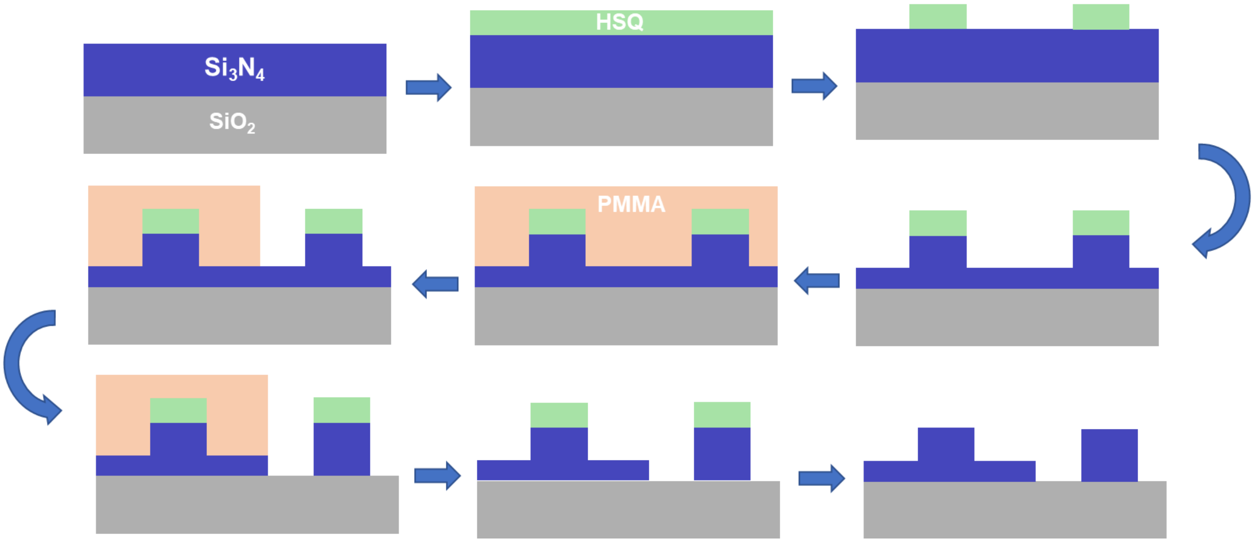

Figure S1. Fabrication process flow of the self-aligned etch process to realize rib and ridge waveguide structures on the same chip.

The self-aligned etch process involves patterning the ridge and rib waveguides together with hydrogen silsesquioxane (HSQ) electron-beam lithography resist. After exposure to high-energy electrons, HSQ transitions to a silica-like film resistant to standard polymer cleaning. After development, this hard mask is used to partially etch the Si_3N_4 to the required depth to form the rib waveguides. Next, poly-methyl-methacrylate (PMMA) resist is spun and patterned by electron-beam lithography to open windows to etch the remaining Si_3N_4 to form the required ridge waveguides. The PMMA is then stripped using acetone, followed by HSQ removal using dilute HF (10:1). In this way, the ridge and rib waveguides are integrated on the same chip without alignment between etch stages.

Experimental Setup

Figure S2 shows a schematic diagram of the experimental characterization setup. The polarization extinction ratio (PER) was measured by using a high extinction ratio (> 60 dB) linear polarizer (Thorlabs LPVIS050-MP2) at the input and output of the waveguide. The input polarization was accurately set by using a half-wave plate (Thorlabs AHWP05M-980) and a polarimeter (Thorlabs PAX1000IR1/M).

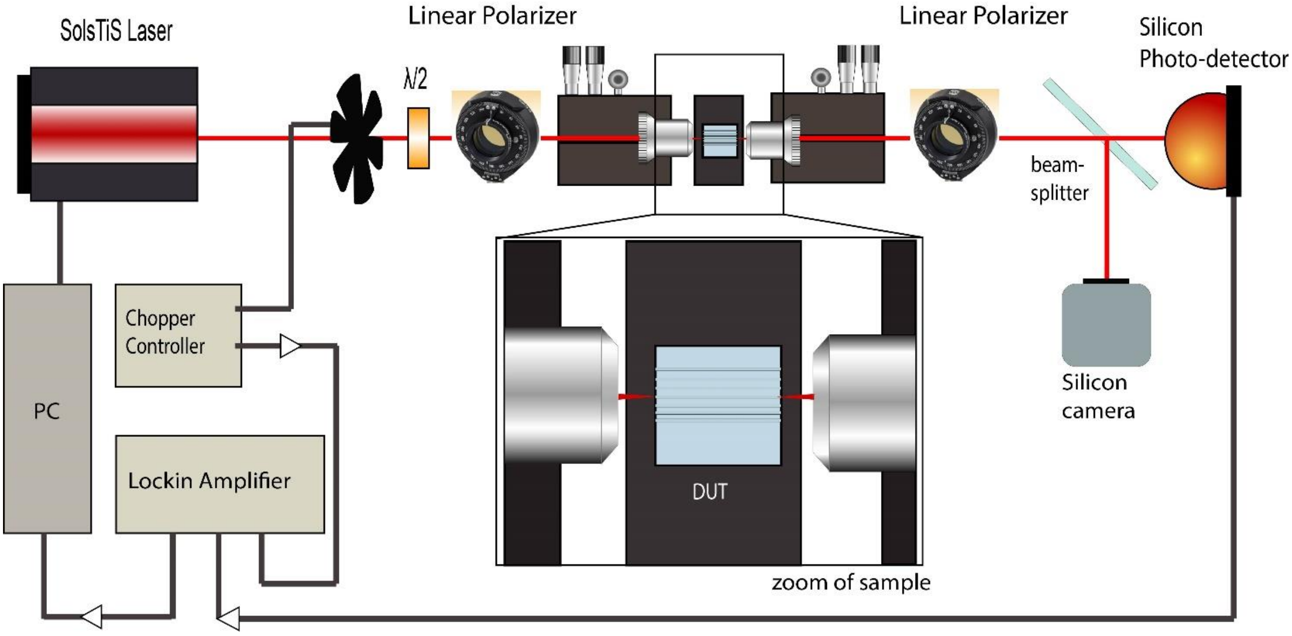

Figure S2. A schematic diagram of the waveguide experimental characterization setup to measure the polarization extinction ratio (PER) and insertion loss (IL) of the fabricated devices.

Asymmetric Directional Coupler Polarization Beam Splitter

The asymmetric directional coupler polarization beam splitter (ADC-PBS) design is based on higher-order coupling between the TM0-TM1 modes. This is achieved by phase matching between a single-mode waveguide and a multi-modal bridge (see Fig. S3 (left)). The TE0 mode is not phase-matched to the bridge waveguide for waveguide width dimensions of 502 and 1300 nm (see Fig. S3 (right)).

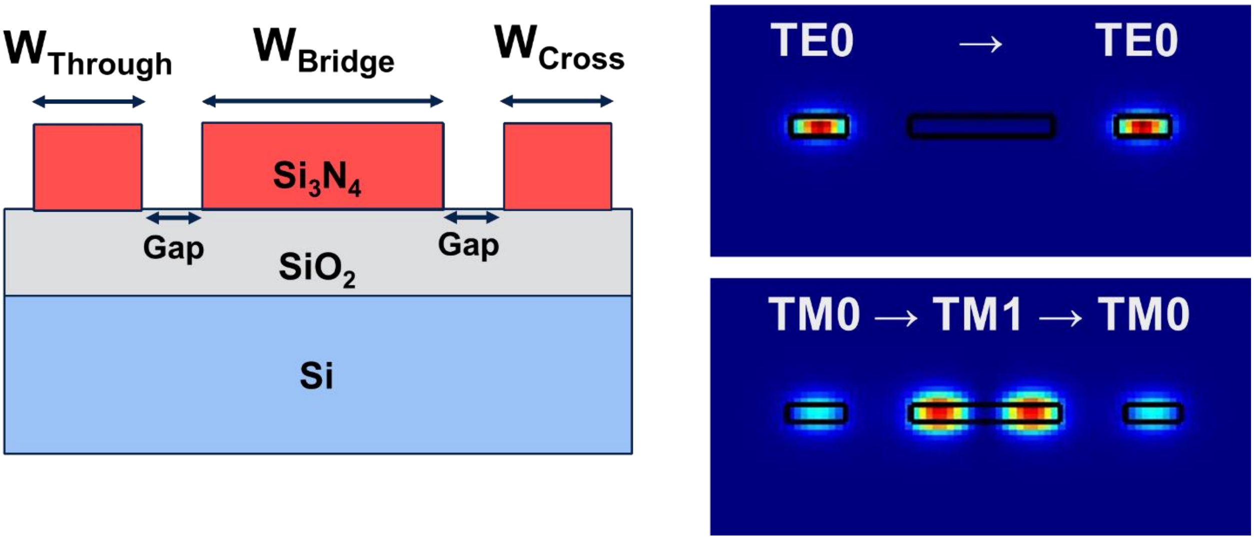

Figure S3. (left) A cross-sectional diagram of the asymmetric directional coupler polarization beam splitter with a multi-modal bridge waveguide for higher-order mode conversion between the TM0-TM1. (right) The simulated electric field profiles of the coupled TE and TM modes.

An ADC-PBS based on this approach will selectively cross couple only the TM polarized guided mode, whereas the TE mode will pass straight through unperturbed. This guarantees a high PER for the cross-coupling port, but the IL and PER of the through port, which are intrinsically linked, will be severely compromised for lithography errors greater than 5 nm. Fig. S4 shows the simulated PER versus coupling length for the cross and through ports when there is not any fabrication error (b) and when the width changes (Δw) from -10 to 10 nm from the nominal design. It is clear that the PER of the cross port is highly tolerant to error but to ensure a low insertion loss requires less than a 10 nm deviation (see Fig. S4 (d)). The through port PER is dramatically reduced for even a 5 nm deviation.

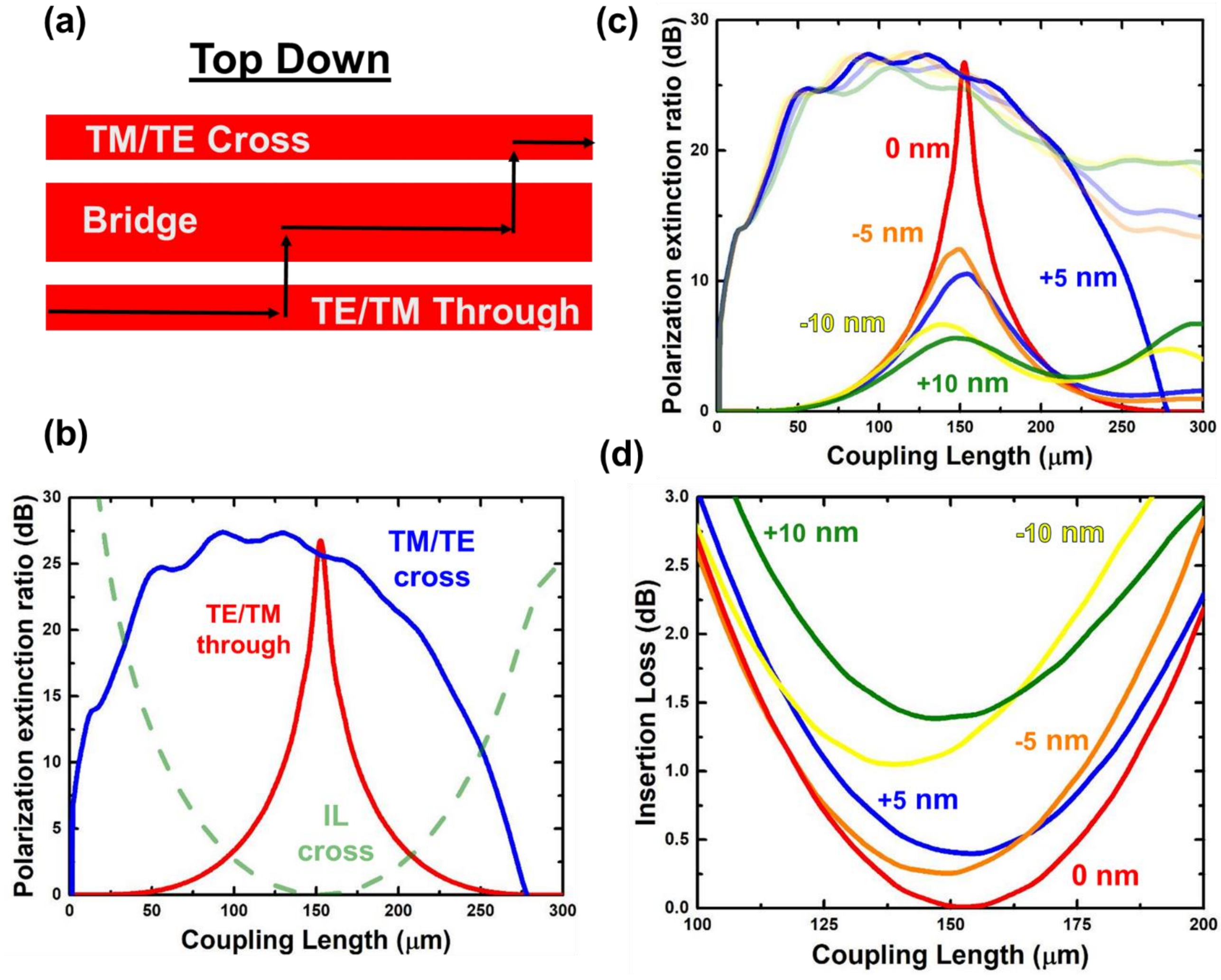

Figure S4. (a) A top-down schematic diagram of the ADC-PBS with a multi-modal bridge waveguide for higher-order mode conversion between the TM0-TM1. (b) The simulated polarization extinction ratio (PER) for the cross (TM/TE) and through (TE/TM) ports. (c) The simulated PER for the cross and through ports as a function of fabrication error ($-10 \leq \Delta w \leq 10$ nm). (d) The simulated insertion loss for the cross port as a function of fabrication error ($-10 \leq \Delta w \leq 10$ nm).