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AlGaAs Bragg reflection waveguides for hybrid quantum photonic devices

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Abstract. Hybrid photonic devices represent a promising solution to the effective on-chip integration of all the components required for the generation, manipulation and detection of non-classical states of light encoding quantum information. We present an AlGaAs source of highly entangled photon pairs envisioned for the hybridization with silicon-on-insulator integrated platforms, in order to take benefit from the strong second order nonlinearity and the compliance with electrical pumping of the III-V platform and the maturity and CMOS compatibility of silicon photonic circuitry, enabling a wide variety of quantum information applications.

1 Introduction

Following the emergence of quantum information (QI) over the last three decades, the demand of physical systems supporting or generating controllable quantum states has drastically increased. Among all the currently available physical platforms for the development of quantum technologies, photons, thanks to their high speed and immunity to decoherence, are particularly suited for carrying QI and are employed not only in quantum communication protocols but also in quantum simulation and computing [1]. For this reason, the development of sources of single or entangled photons has been a major objective in the last decades. Currently, several material platforms are investigated for the implementation of integrated, robust, controllable, low-power consumption and high fabrication yield devices able to efficiently generate, manipulate, distribute and detect useful quantum states [2].

Silicon, and more specifically silicon-on-insulator (SOI), represents one of the leading platforms in integrated photonics [3], thanks to its good mode confinement, moderate optical losses, large-scale high-yield production capability, fabrication maturity (compatible with CMOS processes) enabling the realization of complex integrated optical circuits. Although nonlinear effects are accessible through its strong third order nonlinear susceptibility, it intrinsically lacks of second order nonlinearity. Furthermore, its indirect bandgap practically prevents it from achieving laser action via electrical pumping. AlGaAs, on the other hand, features both strong second order nonlinearity and direct bandgap, suitable for electrically injected photon-pair production [4], resulting perfectly complementary to silicon for the implementation of complex photonic chips combining the generation and manipulation of quantum states of light.

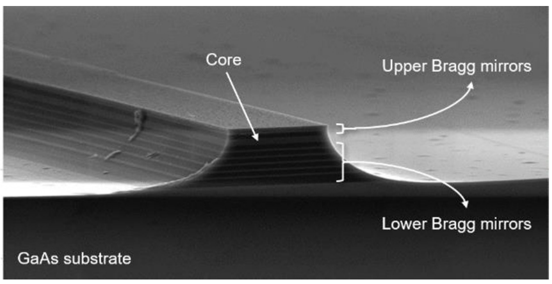

Fig. 1. Scanning electron microscope picture of the waveguide transverse section.

2 AlGaAs waveguides

The working principle of the nonlinear integrated AlGaAs photon-pair source is based on spontaneous parametric down-conversion (SPDC), where a 775 nm laser beam is coupled into the waveguide and generates photons in the telecom band. Bragg mirrors provide both a photonic bandgap confinement for the pump and total internal confinement for the down-converted photons. A scanning electron microscope image of the resulting device is shown in Figure 1, where the asymmetric distribution of the mirrors is designed for the hybridization. The pump and SPDC modes are characterized by different dispersion curves, allowing the phase-matching (PM) condition to be satisfied for all three possible PM types (Figure 2) and thus providing a high versatility in the

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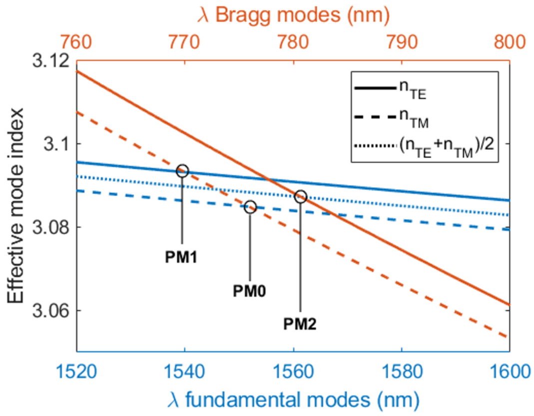

Fig. 2. Simulated dispersion curves of the pump and SPDC photons modes.

polarization of the emitted photons. A narrowband pump beam generates energy-time entangled photon pairs; polarization entanglement is also accessible with our sources, enabling the demonstration of entanglement-based quantum networks [5, 6].

3 Results and perspectives

The nonlinear response of the device is first characterized through second harmonic generation measurements: the three types of available PM are retrieved on the same chip. In particular, type 0 and type 2 PM offer a considerably high efficiency (~250% $W^{-1}cm^{-2}$). Photon pairs are then generated via SPDC, with a measured internal pair generation rate (PGR) larger than 2×10^{6} s^{-1} and a coincidence-to-accidental ratio (CAR) of ~800 (Figure 3.a) over a bandwidth of >90 nm. The non-classicality of the emitted photons is characterized through an energy-time entanglement measurement [7], using a fibered Franson interferometer in the folded configuration with a controllable phase delay. The broadband nature of the produced biphoton states combined with the PM versatility of the source offers a testbed to investigate the delicate interplay of chromatic and polarization dispersion in the energy-time entanglement visibility, paving the way to possible metrological applications. Visibilities up to 99% are observed (Figure 3.b) for both type 0 and type 2 generation processes. Such a high visibility, together with its intrinsic robustness to environment perturbations, makes energy-time entanglement a promising resource for QI applications, especially in quantum communication [8].

The perspective is to integrate the described source onto the SOI photonic circuits, in order to have access at the same time to the broadband, highly entangled photon pairs generated by the AlGaAs waveguide and to all the linear optical components available on the silicon platforms, allowing the realization of complex quantum photonic circuits. The design and fabrication of a hybrid AlGaAs/SOI device has already been accomplished, as well as its optical characterization in the classical regime. Preliminary results in the quantum regime open promising perspectives for the on-chip quantum state generation and manipulation with hybrid circuits.

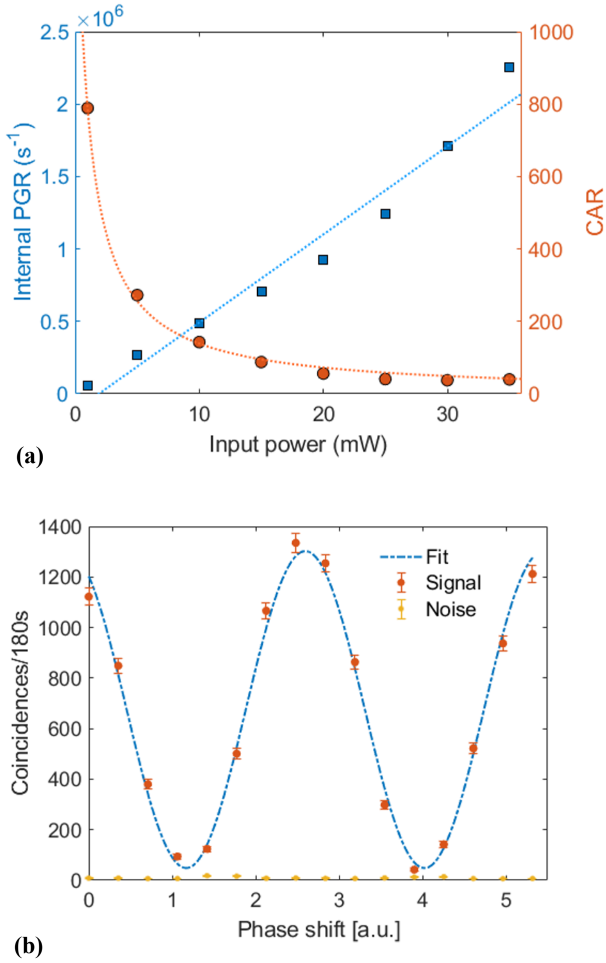

Fig. 3. Measured **a)** internal PGR and CAR and **b)** energy-time entanglement visibility.

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