Integrated nonlinear photonics in AlGaAs-on-insulator devices

S. May[1], J. McPhillimy[2], C. Klitis[1], B. Guilhabert[2], M. Kues[1], M. D. Dawson[2], M. J. Strain[2], M. Clerici[1], M. Sorel[1,3*]

[1]School of Engineering, University of Glasgow, Glasgow G12 8QQ, UK

[2]Institute of Photonics, Dept. of Physics, University of Strathclyde, Glasgow G1 1RD, UK

[3] Institute of Technologies for Communication, Information and Perception (TeCIP), Sant'Anna School of Advanced Studies, Via Moruzzi 1, 56127 Pisa, Italy

*corresponding author, E-mail: marc.sorel@glasgow.ac.uk

Abstract

The heterogeneous integration of AlGaAs-on-insulator (AlGaAs-OI) has proven to be a powerful material platform for nonlinear optics. This talk will explore how chip-scale bonding and transfer printing techniques can be used for the fabrication of these integrated photonic chips for highly efficient second- and third-order non-linear applications.

1. AlGaAs-OI

The invention of the GaAs laser in 1962[1] first ignited interest in the GaAs/AlGaAs material platform for integrated photonics. It was not until the 1990s [2], however, that its full potential for nonlinear photonics was realised.

AlGaAs is highly appealing for nonlinear optics as it has one the highest second and third-order nonlinear coefficients of commonly used optical materials [3,4]. By varying the molar fraction of aluminum in the alloy, the bandgap of the material can be tailored between 1.42 - 2.16eV. This unique property provides an additional degree of freedom in device design, meaning a high nonlinearity can be obtained whilst avoiding two photon absorption (TPA) at telecommunication wavelengths [5]. Despite the many advantages of this mature platform, the dry etching of GaAs/AlGaAs waveguides still remains a challenging aspect of the fabrication process [6,7]. This problem in combination with a low refractive index contrast between AlGaAs layers ($\Delta n \approx 0.48$), only serves to exacerbate the ease by which the phase matching conditions or dispersion profiles required for nonlinear processes can be realised; often resulting in high propagation losses [8,9].

In 2015 it was found that integrating AlGaAs-on-insulator (AlGaAs-OI), by means of adhesive sample bonding, was an effective way to overcome the limitations of the GaAs/AlGaAs waveguide structure [10]. This novel solution drastically reduces the complexity of the dry etch process allowing for the fabrication of low loss, high confinement waveguides ($\Delta n \approx 1.82$). Using this material platform, we demonstrate for the first time, highly efficient second harmonic generation at telecommunication wavelengths [11] and the dispersion engineering of waveguides for supercontinuum generation (Fig.1). These nonlinear processes are fundamental for the generation of new wavelengths and are crucial for applications in spectroscopy, metrology and quantum optics.

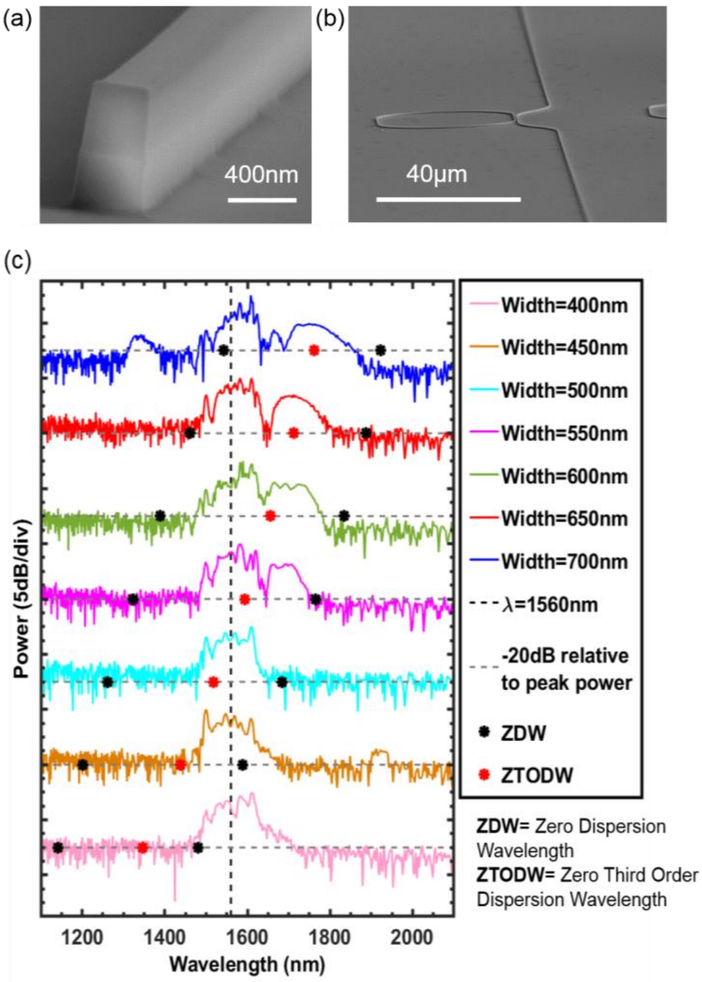

Figure 1: AlGaAs-OI devices: (a) 270nm thick $Al_{0.3}Ga_{0.7}As$-OI waveguide (b) Microring resonator (c) Supercontinuum generated in 3mm long AlGaAs-OI waveguides pumped with a 100fs laser with a center wavelength of 1560nm. Average coupled power to the waveguides is ~13mW.

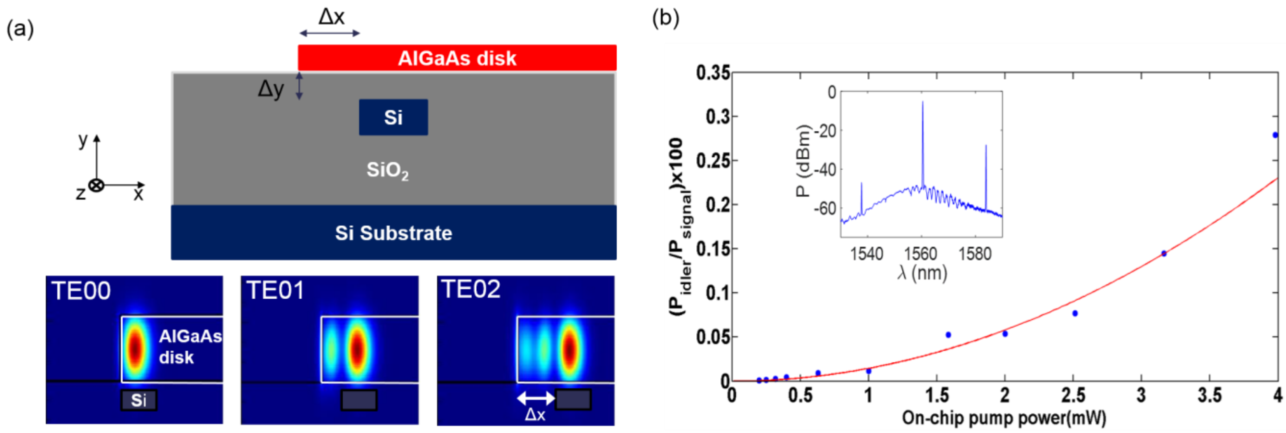

Figure 2: Transfer printing of an AlGaAs microdisk; (a) Schematic cross section of the vertical coupling from a single mode SOI waveguide to a multimode AlGaAs microdisk. Selective mode coupling to the microdisk can be achieved by varying the lateral offset relative to the SOI waveguide (b) Experimental results of FWM in a vertically coupled AlGaAs microdisk. The inset graph shows the measured FWM spectrum, clearly showing the idler, pump and signal peaks.

2. Transfer Printing

Tranfer printing (TP) is a pick and place technique for the hybrid assembly of photonic devices [12]. Unlike the chip-scale bonding method described previously, TP offers an adhesive free route to heterogeneously integrate AlGaAs on insulator or other non-native substrates. Using this approach we have demonstrated submicron accuracy TP of pre-fabricated AlGaAs microdisk resonators onto the silicon-on-insulator (SOI) platform, showing direct optical coupling to single-mode silicon waveguides for both lateral [13] and vertical coupling [14] schemes. Since silicon lacks the Pockels effect, and TPA sets a fundamental limit on its use at telecommunication wavelengths, this particular integration scheme is of great importance for the augmentation of silicon based photonics for nonlinear applications and provides an effective route towards 3D integrated photonic systems.

Utilising TP, we demonstrate how vertical coupling can be exploited for both selective mode coupling and efficient four wave mixing (FWM) (Fig. 2). Simply by varying the lateral offset of the microdisk relative to the underlying bus waveguide, fine control over the coupling to each of the modes of the microdisk can be achieved. This approach provides a unique way to engineer multi-modal nonlinear interactions; something that is challenging to realise in a monolithic platform. Performing FWM in the AlGaAs microdisk takes advantage of the superior nonlinear properties of AlGaAs and means that the photonic system is no longer bound by the constraints of the SOI platform. This experiment clearly illustrates the potential of TP for expanding the functionality of photonic integrated chips.

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