Monolithic Integration of InGaAs/AlGaInAs Mach-Zehnder Interferometers Using Quantum Well Intermixing

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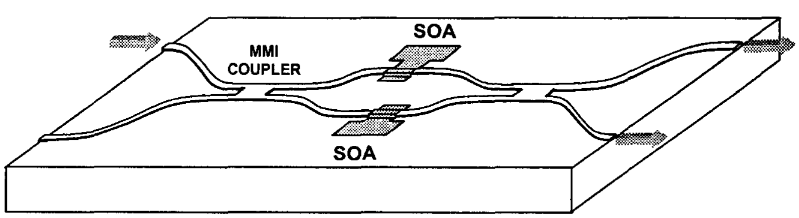
The realisation of monolithic optoelectronics devices often requires the integration of low-loss passive sections and active sections of different bandgaps on a single chip. Quantum Well Intermixing (QWI) is a well-known technique for the postgrowth modification of the absorption edge in quantum confined heterostructures[1]. QWI offers a flexible and low cost alternative to selective etching and regrowth for the fabrication of photonics integrated circuits.

We report on the monolithic integration of an InGaAs/AlGaInAs Mach-Zehnder (MZ) interferometer using QWI. Compared to conventional phosphorous-based quaternary, aluminium-based quaternary structures exhibit improved intrinsic thermal characteristics due to a larger conduction band offset

The material structure was grown on an n-doped InP substrate, with an active region consisting of six 7.0 nm-thick InGaAs wells with 8.0 nm-thick $Al_{0.2}Ga_{0.27}In_{0.53}As$ barriers. The multiple quantum wells are placed at the centre of a 500 nm-thick $Al_{0.2}Ga_{0.27}In_{0.53}As$ waveguide layer. A 1000 nm-thick InP upper cladding and a 200 nm-thick InGaAs contact layer completed the structure. Zn and Si were used as p-type and n-type dopants, respectively.

The Mach-Zehnder structure is schematically shown in fig.1. The total length of the device is 3.2 mm and it consists of two MMI couplers and two-phase modulator arms, connected to the input/output waveguides through curved waveguides. The waveguide radius is 600 μm, which proved to be a good compromise between bending losses and device compactness. The SOAs are 400 μm long and spatially shifted by 500 μm for future evaluation of the device performance as a terahertz optical asymmetric demultiplexer[2].



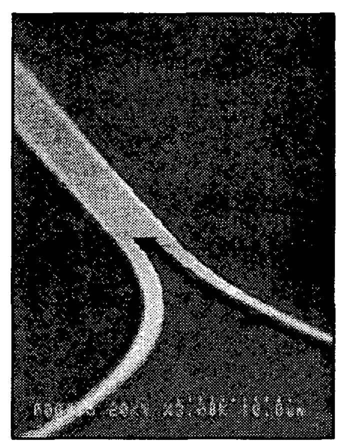


Fig.1 Schematic layout of the device (left). Micrograph of the MMI coupler with the two output waveguides (right).

The whole device was intermixed, except for the two sections comprising the SOAs. The passive sections were shifted by only 60 nm since it has been demonstrated that this provides the minimum of waveguide losses when using QWI[3]. The losses of the passive sections were measured with the Fabry-Perot technique on a set of straight intermixed

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waveguides. The samples show waveguide losses of around 5-6 cm^{-1} in a wavelength range down to 1.53 μm (fig.2).

The MZ modulator performance was assessed using a TE polarised beam from a tuneable laser in the range 1460-1580 nm. Fig.3 shows the transmitted optical signals at a wavelength of 1.55 μm for the bar and the cross state as a function of the current injected into one of the arms. The device exhibits a very efficient modulation with only a few mA of injection current. As the current injection is increased, the optical intensity in the arms becomes unbalanced and thereby the modulation efficiency is reduced. The fiber-to-fiber insertion loss was 22 dB at 1580 nm where the direct bandgap absorption of the active section is negligible. Compensation of the insertion losses can be achieved by integrating a SOA on the input waveguide[4].

In conclusion, monolithic Mach-Zehnder interferometers have been fabricated in InGaAs/AlGaInAs by QWI. The devices combine low-loss waveguides, MMI couplers and optical amplifiers. Waveguide losses in the passive sections are as low as 5-6 cm^{-1} at a wavelength of 1.55 μm and good modulation efficiency has been measured with current injection. Future work will include the assessment of the modulation efficiency using the quantum confined Stark effect and all-optical switching.

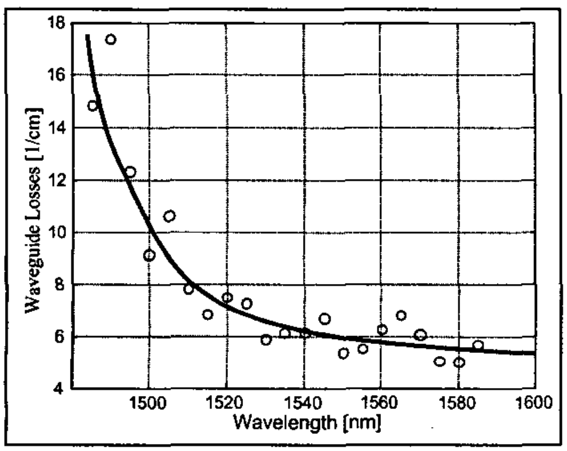

Fig.2 Losses as a function of the wavelength measured on a 1.5 mm long waveguide. The bandgap shift is 60 nm.

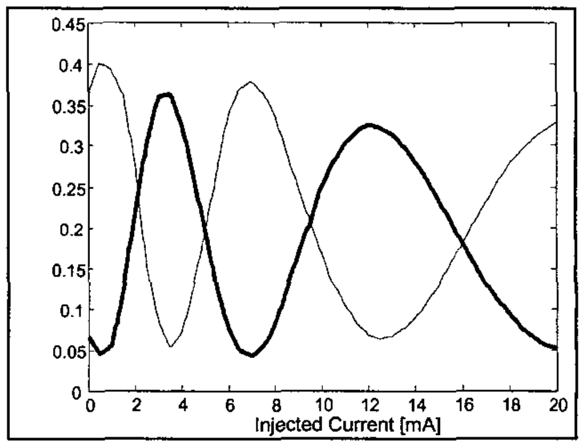

Fig.3 Transmitted optical signals in the bar (solid line) and cross state (dotted line) as a function of the injected current into one of the SOAs.

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