Development of a SiGe Arrayed Waveguide Grating in the 2185-2285 cm^{-1} range

Julien Favreau, Jean-Michel Hartmann, Pierre Labeye, Jean-Marc Fedeli,

CEA-LETI, MINATEC Campus, 17 Rue des Martyrs - 38054 GRENOBLE Cedex 9, France

[*]jean-marc.fedeli@cea.fr

***Abstract*: In this paper, we present the design, process and characterization of an AWG based on a SiGe step index waveguide platform, operating at 4.5 µm (2185-2285 cm^{-1}). A transmission of -1.6 dB and a crosstalk below -12 dB are demonstrated.**

Keywords— AWG, silicon photonics, multiplexer, gas sensing, MIR.

I. INTRODUCTION

Many gases present strong absorption lines in the mid IR (2-10 µm) giving much interest for spectroscopic gas sensing. Moreover, the advent of new Mid-IR laser sources such as Quantum Cascade Laser (QCL) eases the highly specific detection of these gases by a simple absorption measurement. Unfortunately, QCL are weakly tunable (typically over 3 cm^{-1}), thus limiting the use of one laser for one gas. Nevertheless, a promising way for broadening the tunability of this spectroscopic solution is to use an array of QCL, with different emission wavelengths in conjunction with a wavelength multiplexer. A particularly promising one is the Arrayed Waveguide Grating (AWG). Indeed, AWG have been extensively studied in the Telecom wavelength range and different technical solutions have been proposed to transfer these AWG to the Mid-IR range [1]. For instance, AWG based on SOI waveguides have been proposed by Muneeb *et.al.* [2] who demonstrated an AWG working at 3.8 µm. Nevertheless, this technical solution, due to the absorption of the SiO2 buffer layer is limited to wavelength below 4 µm. Malik *et.al.* [3] proposed a solution based on Ge-On-Silicon waveguides with a demonstration at 5 µm.

In a recent paper [4], we proposed a new waveguide platform based on SiGe graded index waveguides. This material presents an important transparency range from 3 µm to 8 µm as well as a full compatibility with CMOS fabrication tools. However in order to increase the compactness of this kind of multiplexer, a new platform based on step index SiGe has been developed. We present, in this paper, the design, process and characterization of an AWG working at around 4.5 µm.

II. AWG DESIGN

In order to explore the possibilities of the SiGe/Si waveguides platform over the whole 3-8µm spectral band, we have developed a fast AWG design tool based on Gaussian approximation of waveguide fundamental mode and Fourier diffraction optics. A precise description of AWG working principle can be found in literature [5]. Fig. 1 shows the basic principle of an AWG working in the de-multiplexing way.

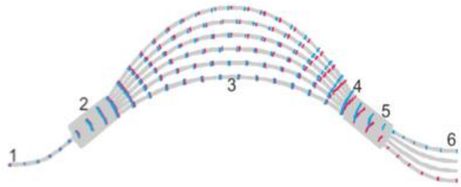

Fig. 1. Sketch of an AWG. Principle of operation in the de-multiplexing way. (1) Single mode waveguide. (2) Planar waveguide. (3) Arrayed Waveguide. (4, 5) Recombination area. (6) Single mode output waveguides.

In order to improve the spectral response of the AWG, especially between two adjacent channels, we introduced a MMI coupler. The effect of the MMI [6] is to flatten the spectral response of each AWG channel in order to obtain a higher intensity output over the entire spectral range. Fig. 2 shows the influence of the MMI on the spectral response of the central channel.

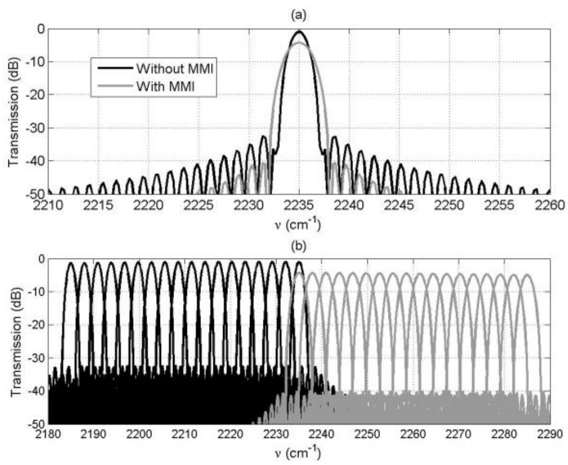

Fig. 2. (a) Influence of the MMI coupler on the spectral response of the central channel of the AWG. (b) Spectral response of the AWG with and without MMI.

III. AWG PROCESS

To make array waveguide grating devices, SiGe/Si waveguides technology have been preferred. This technology is developed in the 200 mm fabrication platform at CEA-LETI with microelectronics equipment. Those low loss and large bandwidth waveguides have been specially designed for integrated gas sensing applications. The core layer of the waveguide is constituted of a step index $Si_{60}Ge_{40}$ layer grown by reduced pressure epitaxy with 2.7 µm thickness. The core is structured to define all the passive functions by DUV photolithography and SiGe deep reactive ion etching processes. To complete the fabrication, the patterns are fully embedded in a 4.2 µm thick epitaxial Si layer deposited by reduced pressure-CVD. This layer constitutes the cladding layer for the waveguides and is thick enough to ensure a complete optical isolation of the AWG from ambient atmosphere. This is of primary importance as those devices are specially developed for gas sensing applications. Fig. 3a shows a view of the final 200mm wafer and Fig.3b a SEM image of a cleaved output of a waveguide. No void and good cleaved surfaces are noticeable. The initial spacing pitch of 100 µm between adjacent waveguides, i.e. compatible with DFB QCL arrays geometry, is progressively decreased down to few microns as required by the design at the entrance of the first diffractive area of the AWG. From the technology point of view, the minimum spacing size is limited by the subsequent gap filling with Si epitaxial cladding layer which impose a trench not larger than 2 µm. Due to technological uncertainties sixteen additional exit waveguides have been added to compensate eventual refractive index discrepancies. Note that in this AWG type, MMI structures have been added at the output waveguide junction.

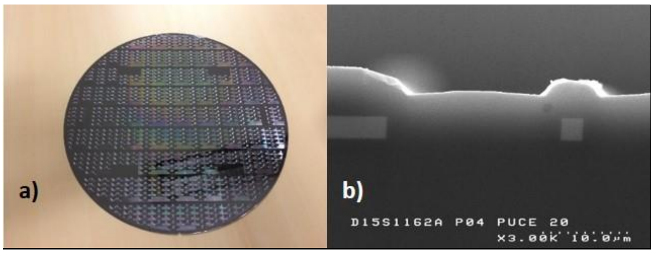

Fig. 3. (a) 200mm wafer with compact AWG. (b) Details of a SiGe input waveguide.

IV. AWG CHARACTERIZATION

Basic passive devices (lines, bends, and splitters with MMI) were first characterized in order to verify the quality of fabrication and to calibrate the testing apparatus. The AWG were characterized in the de-multiplexing way with a Fabry-Perot QCL working in pulsed mode. A broadband QCL light is injected in one of the 17 outputs and the light coming out of the 35 input waveguides is spectrally analyzed with a FTIR spectrometer. The AWG presents a low loss normalized transmission (-1.6 dB) with a cross talk below -12 dB (see Fig. 4). The whole transmission spectrum appeared to be spectrally shifted by +7.14 cm^{-1}. This can be explained by the SiGe refractive index value not sufficiently accurate at the time of the design. Technological discrepancies may also introduce phase errors [7]. The maximum shift from channel spacing measured for the AWG central output is $\Delta\sigma_{Input22}$=0.13 cm^{-1}, which is a 4 % variation from the designed 2.94 cm^{-1} channel spacing.

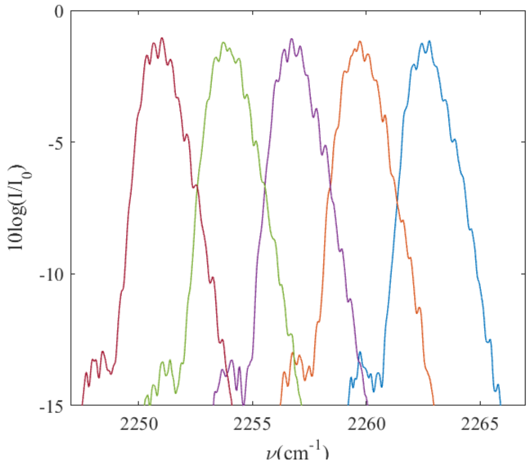

Fig. 4. Normalized spectra measured for 5 outputs of the AWG.

V. CONCLUSION

So we will present the design, process and characterization of a 17x35 AWG working in the 4.5 µm range. The normalized transmission of the AWG is around -1.6 dB with a cross talk below -12 dB. This technology can be extended to other MIR wavelength range till the absorption of the Si cladding reach a too high level.

Acknowledgement:

The research leading to these results has received funding from the European Community's H2020 under MIRPHAB project: **www.mirphab.eu**

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