FP6-2002-IST-1-002131

PICMOS

Photonic Interconnect Layer on CMOS by wafer-scale integration

STReP - Specific Targeted Research Project

IST – Information Society Technologies

D53 - Report on performance of different approaches for fabricating passive photonic wiring circuit

Due date of deliverable: M21 – Actual date: M21

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Lead Contractor : IMEC — Revision: Final
Contribution Partners: STM, CEA

Dissemination Level: Public

1. Abstract

Two possibilities for the optical waveguides to be used for the passive interconnect circuits where considered:

- SOI-wire waveguides: fabricated from SOI-substrates and successively bonded on top of the CMOS-IC (following incorporation of sources and detectors).
- Low temperature PECVD deposited waveguides, which can be fabricated directly on top of the CMOS-circuits. As described in deliverable D5.1, SiN was selected for fabricating these waveguides.

The fabrication and properties of these waveguides where described in detail in PICMOS deliverables D5.1 (PECVD-deposited waveguides) and D5.2 (SOI-waveguides). The aim of this deliverable (D5.3) is to summarize the most relevant properties and to determine what waveguides are to be used for the project demonstrator.

The SOI-wire waveguiding system is today the most dense optical interconnect system described in literature. It allows for the smallest waveguide-to-waveguide spacing and the smallest low-loss bending radius. Although the SiN-waveguides allow for slightly less compact circuits, the attainable density is still sufficient for most practical applications however.

A main difference from the system point of view between both types of waveguides is the group index. The group index for SOI-waveguides is more than twice that for SiN-waveguides, resulting in an equally increased propagation delay (133ps/cm for SOI compared to 54ps/cm for SiN).

In terms of fabrication and integration, two main differences have to be noted:

- Silicon wire waveguides are fabricated on a separate substrate, which is successively bonded on top of the CMOS-circuits. The SiN waveguides can be fabricated by deposition directly on-top of the CMOS-circuits. Each approach has its own advantages (e.g. testability for SOI, inline integration for SiN).
- At this moment, no approach has been found for integrating ultra-compact sources (<100um^2) with the SiN waveguides. This is caused by the large difference in effective refractive index between the SiN-waveguides and the SOI-waveguides, which makes it difficult to devise a compact optical coupling scheme.

Although it is obvious that both waveguide systems have their own merits, we have chosen the SOI-waveguide system for the demonstrator in WP6. The main reasons for this were the facts that so far no reliable approach has been defined for integrating ultra-compact sources with SiN waveguides and that the SiN waveguide losses were too high at the PICMOS selected frequency of 1.55µm.

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2. Introduction

At the start of the project, two possibilities for the optical waveguides to be used for the passive interconnect circuits where considered:

- SOI-wire waveguides: fabricated from SOI-substrates and successively bonded on top of the CMOS-IC (following incorporation of sources and detectors).
- Low temperature PECVD deposited waveguides, which can be fabricated directly on top of the CMOS-circuits. As described in deliverable D5.1, SiN was selected for fabricating these waveguides.

The fabrication and properties of these waveguides where described in detail in deliverables D5.1 (PECVD-deposited waveguides) and D5.2 (SOI-waveguides). The aim of this deliverable (D5.3) is to summarize the most relevant properties and to determine which waveguides are to be used for the project demonstrator.

3. Global comparison and choice for demonstrator

The table below summarizes the basic waveguide characteristics for the two material systems, whereby we focussed on the properties relevant for designing an on-chip interconnect network. Values are measured from the waveguides fabricated within the PICMOS-project. For most of them, these are comparable to or better than international state of the art. Additional information and comparison with international state-of-the-art is given in the next sections.

For SOI the values are given for a wavelength of 1550nm, for SiN the values are given at 1300nm, where the losses are minimal[1].

	SOI (@1550)	SiN (@1300nm)
Fabrication method	Substrate: SOI DUV-litho (248nm) ICP-etch (Cl_2/HBr)	Substrate: Silicon, CMOS … PECVD-deposition of guiding layers DUV-litho (248nm)
Waveguide Dimensions (h x w)	220nm x 600nm	400nm x 800nm
Waveguide Loss	2.6dB/cm @ 1550nm	2dB/cm @1300nm
Group Index	~4	~1.62
Bend loss	0.090dB/90^o for *R*=1um 0.027dB/90^o for *R*=2um 0.004dB/90^o for *R*=5um	0.02dB/90^o for *R*=30um
Pitch (for crosstalk < -20dB/cm)	1.1um (predicted)	1.7um (predicted)
Splitter	MMI: (3x8um^2): 0.34dB loss, good balance. Y-junction: 1.5dB loss, imbalance <0.13dB	MMI : 0.5dB loss
Crossings	Standard: 1.4dB loss, -9dB X-talk Ellipt: 0.65dB loss, -30dB X-talk	-
Compatibility with		
• **Ultracompact source**	Yes	No[2]
• **Semicompact source**	Yes	Yes
• **Detector**	Yes	Yes

Table 1 Comparison of most relevant waveguide properties

The SOI-wire waveguiding system is today the most dense optical interconnect system described in literature. It allows for the smallest waveguide-to-waveguide spacing and the smallest low-loss bending radius. Although the SiN-waveguides allow for slightly less compact circuits, the attainable density is still sufficient for most practical applications however.

A main difference from the system point of view between both types of waveguides is the group index. Because of the higher refractive index of Silicon compared to SiN, the group index for SOI-waveguides is more than twice that for SiN-waveguides, resulting in an equally increased propagation delay (133ps/cm for SOI compared to 54ps/cm for SiN).

In terms of fabrication and integration, two main differences have to be noted:

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[1] Note that within PICMOS we have chosen 1550nm as the operating wavelength. However, there is no fundamental reason to choose this wavelength over 1300nm where the SiN waveguides show the lowest loss. Therefore, we should compare both systems at their best operating wavelength.

[2] At this moment, no efficient method has been defined to couple light from the ultra-compact sources to the SiN waveguides, which is related in the large difference in index between the SiN waveguides and the InP sources.

- Silicon wire waveguides are fabricated on a separate substrate, which is successively bonded on top of the CMOS-circuits[3]. The SiN waveguides can be fabricated by deposition directly on-top of the CMOS-circuits. Each approach has its own advantages (e.g. testability for SOI, inline integration for SiN).
- At this moment, no approach has been found for integrating ultra-compact sources (<100um^2) with the SiN waveguides. This is caused by the large difference in effective refractive index between the SiN-waveguides and the SOI-waveguides, which makes it difficult to devise a compact optical coupling scheme.

Conclusion:

Both waveguide systems have there own advantages and merits in terms of waveguiding properties and integratability. Therefore, no conclusive choice for any of both systems can be made solely from the waveguiding point of view. As a consequence, in practical situations, the choice for one of these two waveguiding systems will strongly depend of the particular application.

For the PICMOS demonstrator, the choice has been made based on input from other workpackages. Since, based on input from WP1 and WP3, there was decided to choose for the ultra-compact sources and since thus far no method has been found to integrate the latter with SiN waveguides, it was decided **to choose the SOI-waveguides for the PICMOS-demonstrator.**

[3] See also note on amorphous Si waveguides in section 4.1