Simulation of Amorphous Silicon Waveguides

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Abstract —**This work reports results, obtained by a set of FDTD (Finite-Difference Time-Domain) simulations, about the characteristics of amorphous silicon waveguides embedded in a SiO2 cladding. Light absorption dependence on the material properties and waveguide curvature radius are analysed for wavelengths in the IR spectrum. Wavelength transmission efficiency is determined analysing the decay of the light power along the waveguides and the obtained results show that radiation losses should remain within acceptable limits when considering curvature radius as small as 3 µm at its most.**

Keywords:a-Si:H; FDTD simulation; Silicon photonics;

I. INTRODUCTION

The never ending demand for bandwidth are being strained by the limits imposed by their interconnections material physical properties. Using Si-based waveguides to distribute optical waves, would allow the integration of optical systems into existing integrated circuits as optical interconnects of various kinds [1].In order to have an optical waveguide able to propagate light, it is required a core with higher refractive index than the surroundings where the allowed modes can propagate through TIR (Total Internal Reflection) phenomenon.This is where a-Si (amorphous silicon) can play its part as an interesting core candidate for its refractive indexat near-infrared wavelengths is higher than that of c-Si. a-Sidefects can be passivated to some extent by incorporating hydrogen into the material, originating amaterial with excellent electrical quality and lower opticalabsorption: Hydrogenated Amorphous Silicon, (a-Si:H) [2].

One constraint of utmost importance in device development is the power budget. Newly developed device characteristics must meet the given specifications. Designing constraints often lead to changes of direction in order to get the wave field from one point to the next one.In order to provide a better understanding how power budget might be affected by these changes of direction, it has been conductedan analysis of power loss over a range of different waveguide curve's radius, keeping all other design parameters constant.

Table 1: Material properties used in the simulation

a-Si:H λ=880 nm	a-Si:H λ=1500 nm	SiO_2 λ=880 nm	SiO_2 λ=1500 nm
n = 3.7785	n = 3.4858	n = 1.4520	n = 1.4446
κ = 0.044001	$\kappa = 6.8713*10^{-6}$	κ = 0	κ = 0

II. SIMULATION

Assuming the use of a-Si:H as the core waveguide embedded in a SiO_2 cladding, several simulations were carried out in order to evaluate dependence of power loss, on distance and decreasing curvature radius. To simulate these structures numerical methods must be used and FDTD (Finite-Difference Time-Domain) [3] is one of the methods best suited for such a task. And all of our simulations were based on this algorithm. The simulation tool utilized throughout this paper is the Optiwave® OptiFDTD [4]. The optical properties of the materials [5] used in the simulation are reported in Table 1.

A. Photonic wire power decay

The first simulation scenario consists of an a-Si:H core waveguide,236 nm wide and 15 µm long, embedded in an SiO_2cladding 1 µm wide and with the same length of the waveguide. Two wavelengths (880 nm and 1500 nm) were considered in order to verify device's power loss frequency dependency and 2D simulations of a photonic wire were conducted. Figure 1 shows power decay verified at a wavelength **λ**=880 nm and Figure 2 shows results obtained at **λ**=1500 nm. As can be observed, although there are some losses at **λ**=1500 nm [6], at **λ**=880 nm the higher extinction coefficient κresults in much higher attenuation and after some micro-meters the mode vanishes completely.

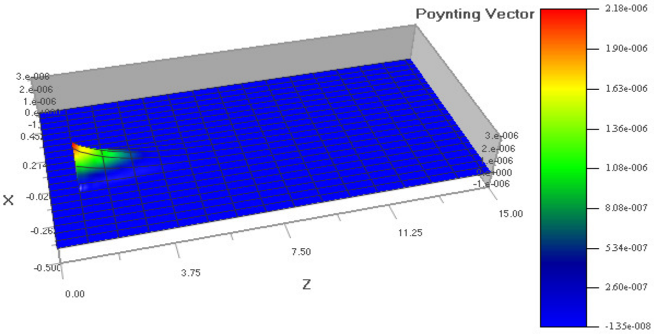

Figure 1 – Simulation of the Poynting vector on an a-Si:H waveguide fora wavelength of 880 nm.

B. Power loss as waveguide radius decreases

Using simulation tool script capabilities, a set of 100 simulations was carried out, with radius ranging from 12.9 µm to 3 µm on 100 nm steps. The script runs each simulation and the intensity of the light at three different observation output point is used to plot power decay as waveguide radius decreases, according to Equation1.

$$Total_{loss}[dB] = 10\log_{10}\left[\frac{abs(P3)}{P2}\right] \qquad (1)$$

where P2 and P3 represent the EM (electromagnetic) field intensity at points 2 and 3, respectively. Figure 3 shows power measured at the three measuring points (observation lines 1, 2 and 3) as arc waveguide radius is decreased. Looking at observation line 3 plot, one can see that the EM field intensity is decreasing as the arc waveguide radius increases, or reversely, the field intensity increases as radius decreases.

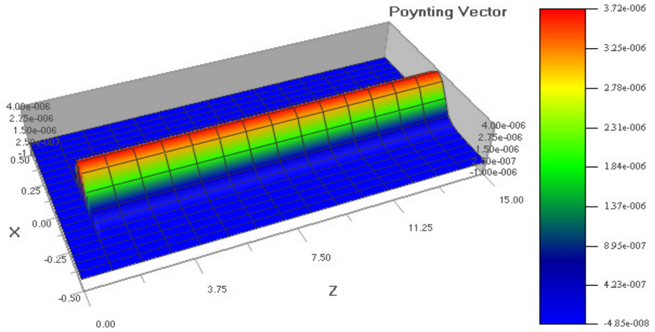

Figure 2 - – Simulation of the Poynting vector onan a-SiH waveguide for a wavelength of 1500 nm.

The explanation for this behaviour is that observation line 3 is sensing the total EM field intensity and that includes losses due to the intrinsic attenuation of a-Si:H by path unit (approximately 2.5 $dBcm^{-1}$) plus losses due to radiation as the EM field propagates through the arc waveguide. Through the use of Equation 2, which takes into account a-Si:H intrinsic attenuation and calculates the radiation losses verified along the arc waveguide, it was possible to normalize the collected data as arc waveguide radius increases.

$$Radiation_{loss}[dB] = Total_{loss}[dB] - loss_{\pi/2\times radius[\mu m]}[dB] \qquad (2)$$

Further analysis of data has been performed using a least squares algorithm, showing in Figure 4 a power decay due to radiation decreasing trend as arc waveguide radius increases.

III. CONCLUSIONS

As far as operating wavelength is concerned, a-Si:H shows a highly dependent frequency behaviour. Its extinction coefficient rapidly increases as operating frequency goes into visible and beyond spectrum range, namely within the 1st optical transmission window, originating power losses by path unit so high that it excludes its use as an optical interconnect.

However, when the operating frequency is within the 2nd or 3rd optical transmission windows, a-Si:H is practically transparent on these wavelengths, presenting losses that do not prevent its use as an optical interconnect. Also, a-Si:H can be deposited on almost any material at low temperatures (below 400 °C) which makes it compatible with CMOS technology. Power decay due to radius decrease on arc waveguides does not seem to be a serious constraint. This means that, although the designer must keep it in mind, radiation losses should remain within acceptable limits when considering arc's radius as small as 3 µm at its most.

For all the above mentioned reasons and some more such as, higher bandwidth transport capabilities and almost non-existent cross interference, an optical interconnect platform based on a-Si:H would present a serious alternative to contemporaneous electrical interconnects.

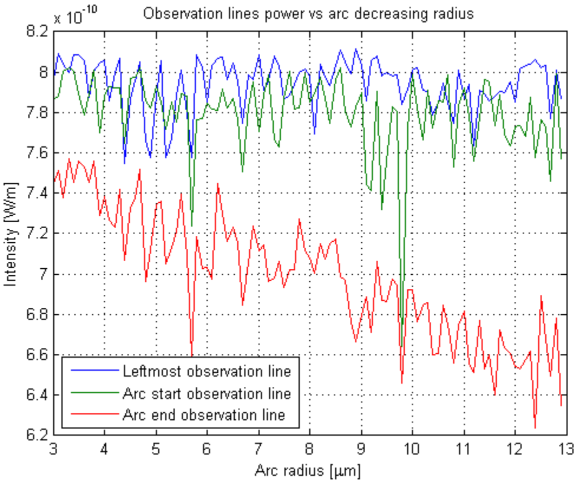

Figure 3 - Observed power decay as radius decreases.

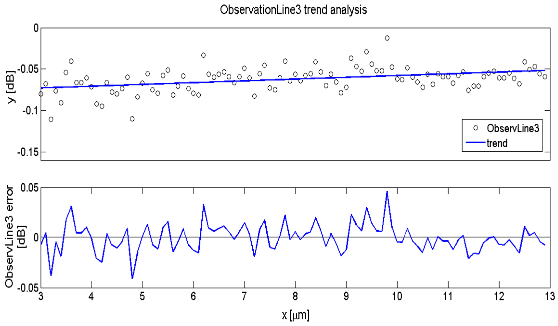

Figure 4 - ObservationLine3 trend (least squares algorithm).

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