A model for the refractive index of amorphous silicon for FDTD simulation of photonics waveguides

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Abstract - **This paper presents an analysis of the material quality influence for amorphous silicon waveguides for microphotonic applications. Material quality is taken into account by a model based on the absorption coefficient data obtained by Constant Photocurrent Measurement (CPM) in the near infrared region. The GUTL (Gauss-Urbach-Tauc-Lorentz) model has been presented as an extension of the standard Urbach-Tauc-Lorentz model and proposed as a predictor for the wavelength dependent optical constants of amorphous silicon in the near infrared spectra. Values produced for the GUTL model have been used as input for a set of FDTD simulations, taking in consideration different material qualities and waveguide dimensions directed to study the characteristics of amorphous silicon waveguides embedded in a SiO_2 cladding.**

I. INTRODUCTION

Hydrogenated amorphous Silicon (a-Si:H) has been reported by many authors as a possible candidate for being used in mass production of photonics circuits [1, 2, 3, The amorphous phase of silicon has been intensively studied and it is well known that the electronic and optical properties of the films are strongly influenced by deposition technique and conditions. Presence of defects and dangling bonds in the lattice results in a high density of localized states at energies below the energy gap, producing photon absorption in the near IR range at telecommunication wavelengths. Hydrogen can passivate defects and its concentration is strongly dependent, among other factors, on the deposition temperature. Hydrogen concentration determines the sub-gap absorption coefficient and it may produce small variations of the amorphous silicon optical functions [4, 5]. Dependence of the material characteristics on the specific deposition conditions should be considered in waveguide design stage, together with geometric variability.

II. REFRACTIVE INDEX OF A-SI:H

The optical constants of a-Si:H are generally represented by a Tauc-Lorentz model describing the real and imaginary part of the dielectric function [6], corrected by introducing an exponential term representing the Urbach tail (UTL model) [7]. Because of the reduced thickness of the typical a-Si:H solar cell (less than 1 μm), infrared absorption has never considered important for solar cell development and was often neglected. Sub-gap absorption has been intensively investigated as a mean for the characterization of the deep defect states. The Constant Photocurrent Measurement (CPM) [8] has been applied to the investigation of the light induced degradation of amorphous silicon, leading to a model for the defect states in a shape of two Gaussian distributions [9, 10], successfully used in numerical simulations of a-Si:H solar cells [11] and of photo-induced material degradation [12, 13]. The presence of defects in the network influences mainly light absorption in the infrared range which is interesting for photonic waveguides. We introduce an additional term to the Urbach-Tauc-Lorentz (UTL) model, describing photon absorption based on a Gaussian defect distribution (GUTL model). The parameters needed to define the Gaussian are extracted from a fitting of experimental data obtained by CPM measurements for different quality of material [12]. Figure 1 reports the CPM data we used in our study. Such a different level of material quality and increasing defect density may be ascribed to a realistic description of different PECVD deposition conditions and hydrogen content [5]. The proposed Gaussian subgap model defines the extinction coefficient (k) as a function of the photon energy (E):

$$k(E) = \frac{hc}{4\pi E}\left[\frac{E_1}{\sigma_G\sqrt{2\pi}}\exp\left(-\frac{(E-E_A)^2}{2\sigma_G^2}\right)\right] \quad (1)$$

Where c is the speed of light, h is the Plank's constant, E_A is the Gaussian peak localization, σ_G is the standard deviations and E_1 is a parameter describing the density of defects.

In Figure 2 are reported the numerical values obtained by fitting the experimental data with the model reported in Eq. 1. The localization of the Gaussian peak and its standard deviation do not reveal any significant dependence on the material quality; their value of about 1.3 eV 0.23 eV, respectively, are in agreement with the parameters usually describing the deep density of states of a-Si:H [11].The parameter E_1 shows a gradual increasing value and represents the increasing density of defects for the different samples analyzed.

III. FDTD SIMULATIONS

The three dimensional FDTD method of OptiFDTD simulator is used to analyze the waveguide structure with perfectly matched layer (PML) absorbing boundary condition. We have simulated light propagation with an a-Si:H straight waveguide surrounded by a SiO_2 cladding. Waveguide length is 15 μm, while its section dimension L ranges between 400 and 2000 μm (L) and H between 100 and 300 μm. The fundamental mode is guided through the

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a-Si:H waveguide for all the simulated distance. As an example, Figure 2 shows the Poynting vector inside two waveguides with different dimensions. In this figure it is reported the result obtained by a FDTD simulation of a waveguide with section and 1000×300 nm. The core material is a-Si: H sample A, surrounded by a SiO2 cladding. Simulation results about the transmission losses are reported in Figure 4. We have found that, considering a wavelength of 1550 nm, for a waveguide thickness of 300 nm, attenuation obtained with a good quality core material (sample A) remain in a acceptable range, having the same order of magnitude foreseen by the analysis of the extinction factor presented in in section 2. When the material quality degrades, the fundamental mode suffers a much higher attenuation and for small values of the waveguide size, losses assume very high values, neglecting their possibility of application.

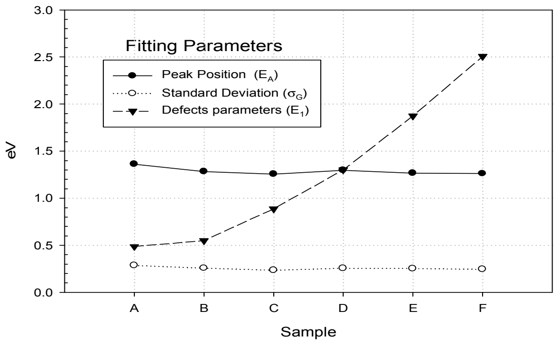

Figure 1 Fitting parameters obtained with CPM data using Eq.1

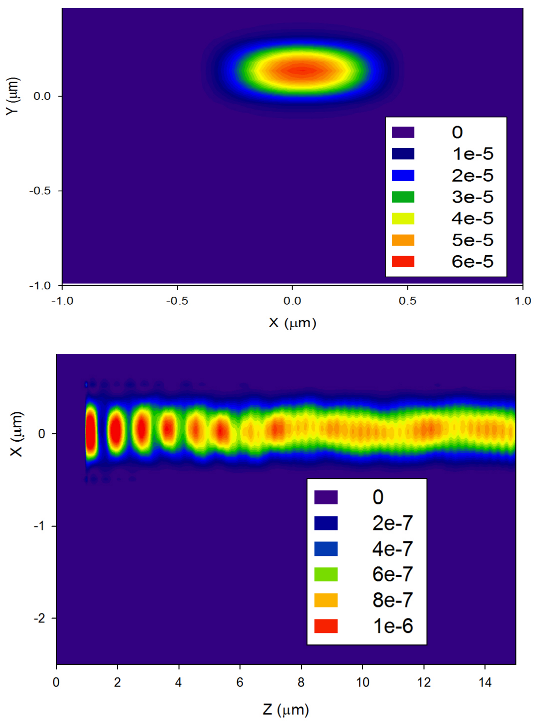

Figure 3.Poynting vector inside a waveguides. Results obtained with a FDTD simulation with a section 1000×300 nm Core material is a-Si: H sample A surrounded by a SiO_2

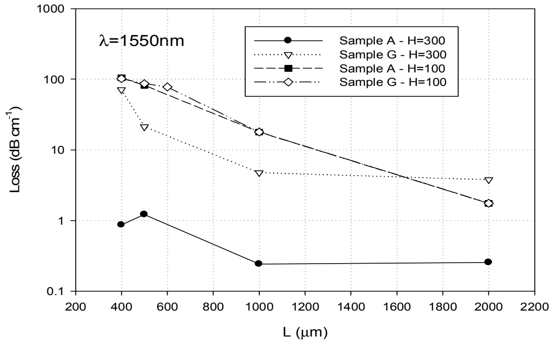

Figure 4. FDTD simulation of waveguide losses.

IV. ACKNOWLEDGMENT

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