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To cite this article: S I Pavlov *et al* 2020 *J. Phys.: Conf. Ser.* **1461** 012126

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Emitting properties of *a*-Si:C:H films with a gold submicron grating

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Abstract. In this study reflection and photoluminescence spectra of *a*-Si:C:H thin film with gold grating on it was examined theoretically and experimentally. The hydrogenated amorphous amorphous silicon-carbon alloy films were fabricated by the PECVD technique. Arrays of gold stripes with different gold width were created by lift-off e-beam lithography. Reflection, and PL spectra has been measured by a Fourier imaging spectroscopy. The theoretical calculations are in a good agreement with experimental results. From the PL spectra it follows, that the TE polarization gives sharper and more efficient PL signal than the TM polarization, and PL efficiency almost does not depend on gold stripes widths. It was shown that only in TE modes the PL outcouples from the gratings owing to the fact that there is no plasmon's affect in this polarization.

1. Introduction

Surface nanostructuring for material optical properties tailoring is of great interest for different applications in photonics and optoelectronics. The effect of metallic nanostructures on the luminescent characteristics of emitters has been observed in a variety of different molecules and quantum dots [1-3].

In developing new photonic devices, it is necessary to take into account that they should be embedded into existing technological processes. One of the promising materials from this point of view is hydrogenated amorphous silicon carbide (a-Si$_{1-x}$C$_x$:H) that can be obtained by the plasma-enhanced chemical vapour deposition (PECVD). Thin films of such material exhibit a high-intensity photoluminescence (PL) in the visible spectral range at room temperature. In addition, in a-Si$_{1-x}$C$_x$:H films the energy gap can be varied in a wide range from 1.8 to 3.6 eV by changing the content of carbon. Consequently, the spectral position of the PL peak changes within the range from 2 to 3 eV [4], with the refractive index varying within the range from 2 to 3 [5].

In [6] strong increasing/decreasing PL intensity in the a-Si$_{1-x}$C$_x$:H based 1D-photonic crystals related to the change in the photonic local density of states via engineering of the dielectric environment is demonstrated. In [7] the effect of surface plasmon-polaritons, localized surface plasmons and quasiguided modes on modification of silicon nanocrystals photoluminescence in presence of gold nanostripes is studied.

In this paper we present technological, experimental and theoretical studies of reflectivity and PL spectra of the *a*-Si:C:H films with different gold stripe widths grating.

2. Methods

2.1. Sample preparation

The sketch of the sample is shown in figure 1. The samples were deposited on fused quartz substrates and consist of *a*-Si:C:H films between the ITO layers. The *a*-Si:C:H films were fabricated by the PECVD technique in a capacitive reactor at various relative flows of silane (SiH_4) and methane (CH_4). The optical thickness of the layers was monitored in-situ by the laser beam's interference patterns.

Arrays of gold stripes were created by lift-off e-beam lithography as follows. 300nm thick positive e-beam resist PMMA 950K (Allresist, Gmbh) was spin-coated on the substrate and electron beam lithography was carried out using SEM JSM 7001f (JEOL, Japan) equipped with EBL-system 'Nanomaker' (Interface Ltd, Russia). After developing of the e-beam pattern, 40nm gold were deposited by thermal evaporation and lift-off process is performed forming gold stripes on ITO which is known to be adhesive layer for gold.
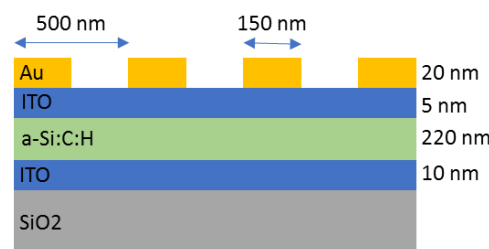

Fig. 1. Sketch of sample's structure: ITO/*a*-SI:C:H/ITO films covered with periodic array of gold nanostripes.

2.2. Measurements

Reflection, and photoluminescence spectra has been measured using a Fourier imaging spectroscopy setup. The dispersion of refractive index n was determined by the method of spectral ellipsometry on an M-2000 instrument manufactured by J.A. Woollam Co., Inc. Measurements were made on single *a*-Si:C:H film with the thickness of 400 nm. The value of absorption k in the spectral range 500–1100 nm that is important for the study is relatively weak.

2.3. Calculations

The reflection and PL spectra of the spatially-periodic structures were calculated using the Fourier modal method in the scattering matrix form [8]. In this method, the solutions of Maxwell's equations for each layer are found by expansion of the electric and magnetic fields into Floquet-Fourier modes (plane waves). The exact solution can be presented as an infinite series over these modes.

3. Results

The experimental reflection and PL spectra as well as theoretical calculations of the sample with gold stripes width 150 nm are shown in figure 2. Reflection spectra are measured with use of unpolarized light, so both TE and TM modes are visible. In the calculated reflection spectrum, features attributed to separate TE and TM modes are marked.

One can see good agreement between theoretical calculations and experimental results unless minor difference that can be attributed to deviation of real samples parameters from that used in calculation. Value for n used in calculation was obtained from measurements of separate sufficiently thick sample (see 2.2). In addition the refractive index of *a*-Si$_{1-x}$C$_x$:H strongly depends on carbon content and may differ from the reference sample.

As the width of gold stripes changes TE modes are less shifting compared to TM modes. This phenomenon can be explained by the fact that TE-polarized light does not excite surface plasmons, and, hence, does not interact with grating.

From the PL spectra it follows, that the TE polarization gives sharper and more efficient PL signal than the TM polarization. PL efficiency almost the same for different gold stripes widths, decreasing only due to less area covered by gold.
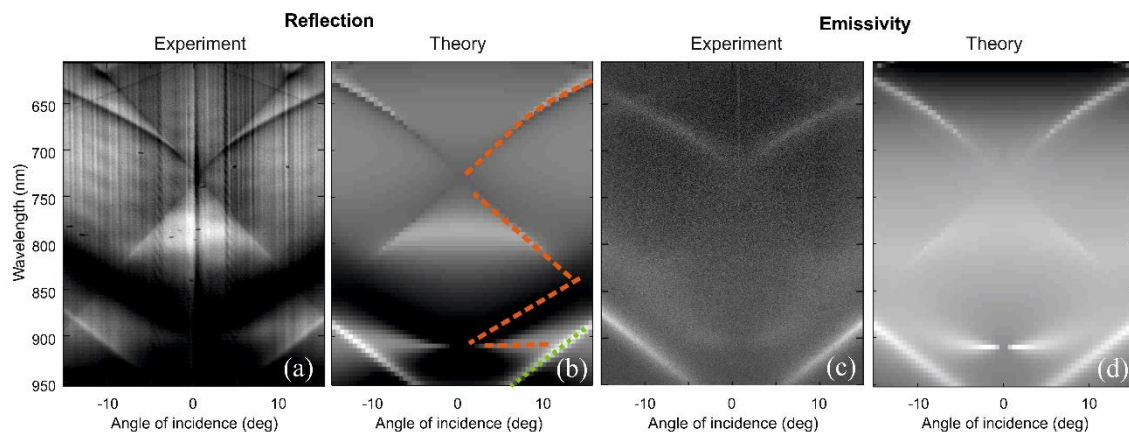

Fig. 2. Experimental (a, c) and theoretical (b, d) reflection and PL spectra. In (b) red dashed line and green dotted line highlight TM and TE mode features respectively.

4. Conclusions

In this study the reflection and photoluminescence spectra of a-Si:C:H thin film with metallic grating on it were examined theoretically and experimentally. We show that only in TE modes the PL outcouples from the gratings owing to the fact that there is no plasmon's affect in this polarization.

Acknowledgments

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