

# Measurement of intrinsic and laser heating-induced stress in microcrystalline silicon thin films



A.G. Kalampounias<sup>a,c,\*</sup>, E. Farsari<sup>b</sup>, E. Amanatides<sup>b</sup>, G.N. Papatheodorou<sup>b,c</sup>, D. Mataras<sup>b</sup>

<sup>a</sup> Department of Chemistry, University of Ioannina, GR-45110 Ioannina, Greece

<sup>b</sup> Department of Chemical Engineering, University of Patras, P.O. Box 1407, 26504, Greece

<sup>c</sup> FORTH/ICE-HT, P.O. Box 1414, GR-26504 Patras, Greece

## ARTICLE INFO

### Article history:

Received 9 September 2015

In final form 1 February 2016

Available online 5 March 2016

### Keywords:

Thin films

Plasma deposition

Raman spectroscopy

Microstructure

## ABSTRACT

In this work we employed a relatively simple experimental procedure to separate the mechanisms that contribute to the total stress of partially crystalline silicon thin films. Raman spectroscopy has been utilized to elucidate the influence of the laser irradiation ( $\lambda_0 = 441.6$  nm) on the  $\mu\text{c-Si:H}$  thin film by analyzing the observed peak shift of the Si–Si TO phonon mode in an effort to separate the different mechanisms that impose spectral changes after the applied laser treatment. When external mechanical stress is not applied, only two distinct mechanisms contribute to the frequency shift of the Raman band, namely the heating-induced stress and the internal stress due to the deposition conditions.

The use of the appropriate fitting procedure of the experimental spectrum allows the estimation of the observed frequency shift, which is attributed to both local heating due to the laser irradiation and the intrinsic tensile stress of the  $\mu\text{c-Si:H}$  films. In the limit where the laser is highly attenuated, the induced heating is negligible and we are able to isolate and evaluate tensile stress directly from the spectroscopic data in the context of current theoretical models. Beyond this limit, the values of internal and total stress have been used to calculate the laser-induced stress. Crystallinity seems to be the key factor to control the volume change induced by the displacement of the surrounding atoms, which is spread over medium in long-range order.

© 2016 Elsevier B.V. All rights reserved.

## 1. Introduction

Microcrystalline silicon thin films have been the subject of extensive research in the current field of semiconductor thin film technology due to their device-friendly properties for applications in several thin film devices, such as solar cells, thin film transistors, sensors and others [1]. Although the emphasis during the last decades lay on device work, very interesting fundamental results have been obtained and new techniques are coming to the fore concerning the microscopic characterization of stress in amorphous or microcrystalline hydrogenated silicon (a-Si:H or  $\mu\text{c-Si:H}$ ) thin films. The stress issue is essential for the successful design and the life-time of the microelectronic and photonic devices. Intrinsic stress develops in the films and substrates during and after processing of these devices and may cause problems with their functionality [1]. In this work, we develop and present a methodology to study both intrinsic and external stress in thin silicon films

based on Laser Raman Spectroscopy. The intrinsic stress is caused by either the film growth processes or/and the thermal expansion mismatch between the film and substrate, while the external stress is the result of laser-induced heating of the film.

Among other techniques typically used for the structural characterization of silicon thin films, Raman spectroscopy is proved as one of the most powerful tool in investigating important properties such as crystalline volume fraction, crystallite size, residual stress and hydrogen bonding and provide comprehensive understanding on important mechanisms involved. The careful determination and optimization of the above properties constitute a key factor in order to improve the material applicability [2].

However, the analysis of the recorded Raman spectra and the direct calculation of the specific film properties require special attention due to the possible coexistence of various effects that impose difficulties in their interpretation. It has been found that the Raman excitation laser induced crystallization [3], and the band frequency shifts due to (a) local heating and lattice anharmonicity, (b) tensile or compressive stress [4] and (c) reduction of the crystallites size [5].

\* Corresponding author at: Department of Chemistry, University of Ioannina, GR-45110 Ioannina, Greece. Tel.: +30 26510 08439; fax: +30 2610 997 849.

E-mail address: [angelos@chemeng.upatras.gr](mailto:angelos@chemeng.upatras.gr) (A.G. Kalampounias).

The main goal of this paper is to provide a framework for elucidating the extend of the abovementioned effects on the vibrational properties of the nanostructured materials. A continuous wave (cw) near UV-laser ( $\lambda_0 = 441.6$  nm) was utilized in order to induce and study these effects by irradiating  $\mu\text{c-Si:H}$  thin films with different power densities. The novel issues addressed here are (i) the elucidation of the effect of laser power density on the  $\mu\text{c-Si:H}$  thin film, (ii) the estimation of the intrinsic and laser-induced stress from Raman spectra of optical phonons and (iii) the separation of the different mechanisms that impose spectral changes after the applied laser treatment. The method is applied on silicon films deposited from high density plasma source and under extremely high film growth rates where material stress is expected to be an important issue.

## 2. Experimental details

Hydrogenated silicon thin films depositions were carried out in an Electron Cyclotron Wave Resonance (ECWR) plasma reactor. ECWR sources are inductively coupled sources within a static magnetic field. Fig. 1 illustrates the experimental set-up. The ECWR source (COPRA DN250 by CCR Technology) is placed vertically in a high vacuum chamber. It consists of a single turn copper coil which surrounds the plasma region and it is powered via a matching network by RF power of 13.56 MHz. Helmholtz coils are placed around the source in order to create the static magnetic field. The substrate holder is grounded and it is placed at a distance of 10 cm from the source.

An external heating system and controller allows the glass substrate heating to 200 °C, which is the typical temperature for  $\mu\text{c-Si:H}$  deposition in thin film solar cell devices. A system of flow meter

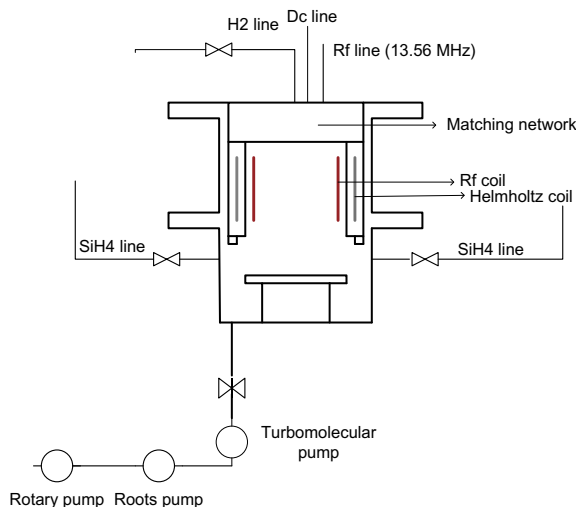


Fig. 1. Experimental setup used for the hydrogenated silicon thin film depositions. See experimental part for details.

controllers and valves is used in order to feed the reactor with the precursor gases. The hydrogen is fed directly in the plasma source while silane enters the reactor in the region between the substrate holder and the source. The pumping system, which consists of a rotary pump, a roots pump and a turbomolecular pump, is capable to maintain low pressure, in the range of  $10^{-2}$  mbar, even for high flow rates [6]. All materials presented in this work, were deposited by keeping the process pressure and the silane mole fraction equal to  $10^{-2}$  mbar and 43%, respectively. The input power varied in the range 300–800 W and for each condition the deposition time was adjusted in order to keep the film thickness in the range 600–700 nm. Films growth rate are relatively high ( $>1.5$  nm/s) so an intrinsic stress will be probably developed on the materials during the growth process. Partially crystallized ( $\sim 48.5\%$ ) amorphous films were used as starting material. The crystallinity is estimated using a methodology, which is described in detail in the results and discussion section.

Raman spectra, excited with the 441.6 nm line of an air-cooled HeCd laser (Kimmon Electric Co.), were measured with the UV-Vis micro-Raman Labram HR-800 spectrograph (Jobin Yvon). A narrow-bandpass interference filter was used for the elimination of the laser plasma lines. The excitation beam was directed to the sample compartment of a confocal open microscope attachment for punctual analysis. The focusing objective was a Long Working distance (8 mm)  $50\times/0.55$  Olympus lens. The spectra were obtained using the proper laser power on the specimen for a total integration time of 200 s. The Raman scattered radiation was focused on a confocal entrance slit (200  $\mu\text{m}$  width) of an achromatic flat field spectrograph with 800 nm focal length. A 1800-grooves/mm grating and a two-dimensional CCD detector cooled at 140 K were used for the dispersion and detection of the Raman photons, respectively. Details for the experimental setup can be found elsewhere [7,8].

The laser power at the sample was measured with an accuracy of  $\pm 10\%$  using the universal optical power meter by Melles Griot. The controller (13 PDC 001) was equipped with the 67-mm integrating sphere and detector (13 PDH 003). Power control was achieved through six power density filters suitable for the 441.6 nm laser line, with optical densities of 0.3, 0.6, 1, 2, 3 and 4. Details for the laser power levels used in this work are presented in Table 1.

## 3. Results and discussion

The laser power dependence of the Raman shift was measured for a partially crystallized ( $\sim 48.5\%$ ) amorphous film of  $\sim 0.65$   $\mu\text{m}$  thick deposited on crystalline silicon wafer and the measurements are presented in Fig. 2. These spectra were all excited by the 441.6 nm line utilizing all available density filters. All spectra exhibit an intense asymmetric peak located near  $521\text{ cm}^{-1}$  characteristic of crystalline phase. The asymmetry of the main band is due to the presence of a shoulder band in the low-frequency side of the main peak, which is assigned to the amorphous phase. Spectra presented in Fig. 2 correspond to the seven different laser power levels

Table 1  
Experimental details of the density filters used for the attenuation of the 441.6 nm laser line.

| Density filter | Power              | Nominal value ( $\text{mW}/\mu\text{m}^2$ ) $\lambda_0 = 441.6$ nm | Measured value ( $\text{mW}/\mu\text{m}^2$ ) $\lambda_0 = 441.6$ nm |
|----------------|--------------------|--|---|
| No attenuation | $P_0$              | 18.289   | 15.728  |
| D0.3           | $P_1 = P_0/2$      | 8.413  | 7.864   |
| D0.6           | $P_2 = P_0/4$      | 3.841  | 4.142   |
| D1             | $P_3 = P_0/10$     | 1.463  | 1.408   |
| D2             | $P_4 = P_0/100$    | 0.256  | 0.251   |
| D3             | $P_5 = P_0/1000$   | 0.018  | 0.017   |
| D4             | $P_6 = P_0/10,000$ | 0.007  | 0.007   |

Download English Version:

<https://daneshyari.com/en/article/5373028>

Download Persian Version:

<https://daneshyari.com/article/5373028>

[Daneshyari.com](https://daneshyari.com)