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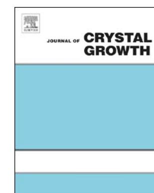

The microstructure evolution of hydrogenated microcrystalline germanium promoted by power gradient method

Xinyu Wang, Jian Ni*, Chang Li, Xiaoxiang Sun, Zhenglong Li, Hongkun Cai, Juan Li, Jianjun Zhang*

College of Electronic Information and Optical Engineering, Nankai University, Key Laboratory of Photo-electronics Thin Film Devices and Technique of Tianjin, Tianjin 300071, China

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ABSTRACT

This paper studies the microstructure evolution of hydrogenated microcrystalline germanium (μc-Ge:H) thin films deposited by plasma enhanced chemical vapor deposition (PECVD). There is an amorphous incubation layer formed in the initial deposition stage of μc-Ge:H thin film. It is demonstrated that the thickness of incubation layer can be reduced by high hydrogen dilution and high discharge power method. However, at high hydrogen dilution, the deposition rate of μc-Ge:H appears a sharply decrease. Using a high discharge power can compensate the deposition rate decrease but lead to decrease of average grain size and appearance of micro-void in the μc-Ge:H thin film. In addition, by comparing two thickness groups of μc-Ge:H thin films deposited at different discharge powers, it is noticed that the evolution process relates to the formation of crystal nucleuses. Thus, a power gradient method is proposed to understand the mechanism of nucleation and crystal growth in the initial deposition process of μc-Ge:H films. Finally, by power gradient method, the incubation layer thickness of μc-Ge:H thin films has been decreased to less than 6 nm. Moreover, Raman scattering spectra shows a 38 nm μc-Ge:H film has a crystal fraction (X_C) of 62.4%. Meanwhile, the mobility of TFT devices shows the improved electrical property of μc-Ge:H film deposited by power gradient method.

1. Introduction

Hydrogenated microcrystalline germanium (μc-Ge:H) thin films prepared by plasma enhanced chemical vapor deposition (PECVD) have a high optical absorption coefficient and a narrow optical gap closing to 0.66 eV [1,2]. This promises μc-Ge:H thin films can be widely used in narrow band gap photovoltaic devices and thin film transistors (TFTs) [3,4]. It was reported that the growth mechanism of μc-Ge:H thin films is basically similar to the hydrogenated microcrystalline silicon (μc-Si:H) which has been extensively studied [5–9]. In the initial growth process, at first, a layer of amorphous germanium (a-Ge:H), called incubation layer, appears on substrate, and then crystalline grains appear and grow up. There is a region that amorphous structure gradually evolves into microcrystalline structure [10–12]. However, in this region, a thick incubation layer deteriorates all film and device performance. In the application of solar cells, since photo-generated carriers are transported along the growth direction in intrinsic layer, defects in incubation layer increase carrier recombination rate. Furthermore, when the film is thin, a high amorphous content causes electrical properties deteriorate and lead to TFT performance decrease.

In order to reduce incubation layer thickness and promote microstructure evolution, many methods have been adopted in μc-Si:H thin films studies, like high hydrogen dilution and two step growth methods [13–16]. A high crystalline volume fraction of μc-Si:H films was obtained by using high hydrogen dilution, however, it caused a sharply decrease of the deposition rate simultaneously [17,18]. To further improve the crystalline fraction (X_C), two step deposition method [15] or named hydrogen plasma treatment method was studied. By using a film treated by H_2 plasma for few minutes as a seed layer, the film following deposited on this layer has a high crystalline fraction.

In this paper, we study the properties of initial deposition stage and the microstructure evolution of μc-Ge:H films. At first, we show that the same as μc-Si:H, the high hydrogen dilution method is an effective method for reducing the incubation layer thickness of μc-Ge:H thin films. And then, by comparing two thickness groups of μc-Ge:H films deposited under different discharge powers, we find that a higher power can further promote the microstructure evolution and compensate the decrease of deposition rate caused by high hydrogen dilution. We illustrate the evolution of crystal fraction and surface morphology

* Correspondence to: College of Electronic Information and Optical Engineering, Nankai University, Tianjin 300071, China.
E-mail addresses: elsevier_jianni@163.com (J. Ni), jjzhang@nankai.edu.cn (J. Zhang).

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with the thickness increase of μc-Ge:H films. Finally, a power gradient method is proposed to understand the nucleation mechanism. Furthermore, we find this method is helpful for further reducing the thickness of incubation layer and controlling crystalline fraction and average grain size to achieve a homogeneous distribution of the crystal grains. Meanwhile, TFTs are used to evaluating the electrical properties of μc-Ge:H films since the mobility can be extracted from current-voltage characteristics.

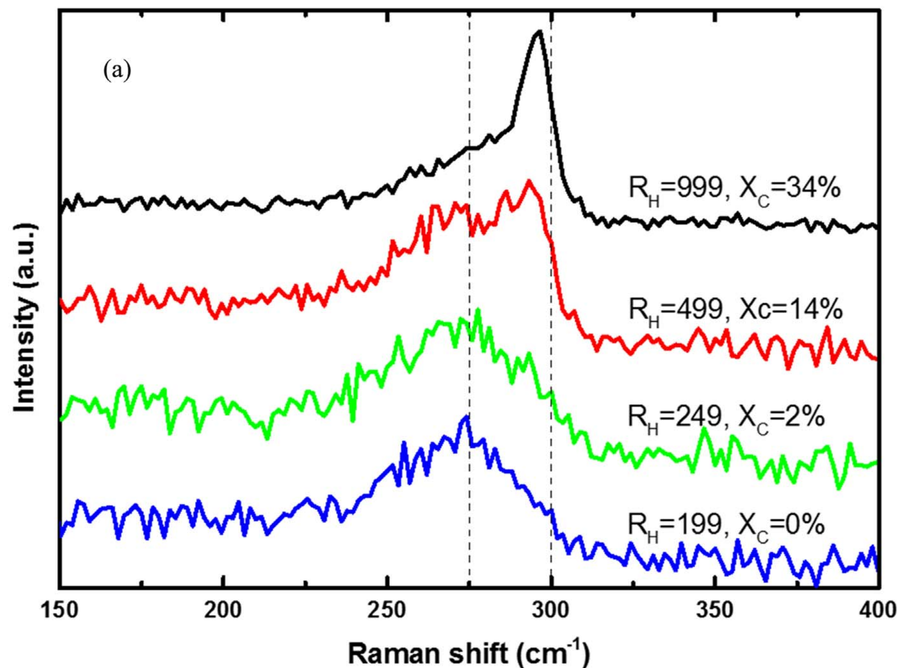
2. Experimental details

All μc-Ge:H samples were deposited on glass substrates (Corning 7059) in a six-chamber-cluster RF-PECVD system using a GeH_4 and H_2 gas mixture, at a total gas flow of 200 sccm, a chamber pressure of 1 Torr and a temperature of 260 °C. The crystalline volume fraction and the microstructure evolution of μc-Ge:H films were investigated by Raman scattering spectroscopy, using an InVia Renishaw Raman system with a He-Ne laser excitation at 514.5 nm. The structural properties of μc-Ge:H thin films were observed by transmission electron microscope (TEM). Atomic force microscopy (AFM Seiko SPA-400) was carried out to observe the surface morphology. X-ray diffraction measurements was carried out using a Philips X'pert Pro diffractometer with Cu-Kα radiation at 45 kV and 40 mA. The electrical performance of the TFT devices was measured using a Keysight Technologies B1500A Semiconductor Device Analyzer. All devices were tested in air at room temperature.

Table 1
Deposition parameters and crystalline fractions of μc-Ge:H samples.

Sample	R_H	Power (w)	Time (min)	Thickness (nm)	X_C (%)
R999	999	15	17	25	34
R499	499	15	13	25	14
R249	249	15	8	25	2
R199	199	15	6	25	0

The μc-Ge:H samples (R199, R249, R499 and R999) prepared at different hydrogen dilution ratios (R_H=[H_2]/[GeH_4]) have a same thickness of 25 nm by controlling the deposition time. The groups of P05 and P35 were prepared at the RF discharge power of 5 W and 35 W respectively, and R_H=999. Furthermore, another group (G1-G4)



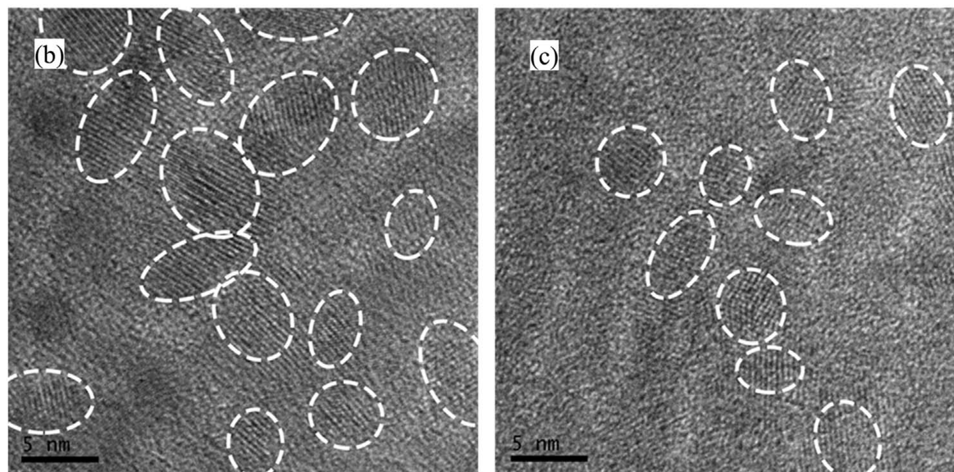


Fig. 1. Raman and TEM measurements of μc-Ge:H prepared under different hydrogen dilution ratios. All these samples have a similar thickness about 25 nm. (a) Raman spectra. The signal intensities are normalized to the maximum values. Dashed lines represent the peak of crystalline Ge at 300 cm^{-1} and amorphous Ge at 275 cm^{-1}. (b), (c) TEM images of sample R999 and R499 (5 nm scale). The Ge crystal regions are surrounded by the white dotted circles.

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