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Structural studies on the microcrystallization of Si:H network developed by hot-wire CVD

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Abstract

Effect of H₂-dilution to the SiH₄ plasma, R(H₂), on the microcrystallization of Si:H network at a low substrate temperature (180 °C) has been studied by using hot-wire CVD. Structural characterization of the films has been performed by micro-Raman, ellipsometry, infrared absorption and X-ray diffraction studies. A dramatic structural transformation from amorphous to microcrystalline phase has been identified at an H₂-dilution beyond 92.0%, induced by high atomic H density in the plasma. A virtual saturation in overall crystallinity has been attained for H₂-dilution in the range $92.75 \leq R(H_2) (\%) \leq 93.75$, contributing crystalline volume fraction changing between 60% and 64%, the average crystalline grain size varying between 150 and 200 Å and bonded hydrogen content maintaining between 3.3 and 2.6 at%. A crystalline volume fraction of 86.6% was obtained along with a low bonded H-content of 1.76 at% at R(H₂) = 98.0%. However, at such extremely high H₂-dilution, overall crystallization is hindered due to enormous polyhydrogenation and formation of lesser dense network full of voids. Hence, microcrystallization in Si-network can be easily obtained in HWCVD, at a relatively low hydrogen dilution and low substrate temperature, without compromising much with the deposition rate arising out of those two stringent factors affecting in the conventional technique; and thereby, enhancing the technological acceptability of the deposition process presently dealt with.

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1. Introduction

The plasma-enhanced chemical vapor deposition (PECVD) has been most widely used in low-temperature processing of silicon (Si) thin films for fabrication of devices like solar cells and thin film transistors, as it produces high-quality materials uniformly on reasonably large area substrates. However, PECVD has some inherent limitations. The growing surface of the films could suffer from plasma damage or charge-induced damage. The design of the apparatus becomes complicated so as to minimize the electrical potential around the sample holder. In addition, since usually radio frequency (RF) plasma is used, the enlargement of the deposition area is limited due to standing wave of plasma.

As an interesting alternative to PECVD, hot-wire chemical vapor deposition (HWCVD) or catalytic chemical vapor deposition (Cat-CVD) has drawn considerable attention of materials scientists in recent years. In HWCVD, source gases undergo pyrolytic dissociation as well as catalytic cracking reactions on resistively heated filaments (catalysers) facing the substrate. The species are transported to the substrate and contribute to the film growth at low temperatures in the range 150°–400 °C, making the process compatible with the use of low-cost glass substrates. Relatively simpler design and cheaper set up may thus be used for HWCVD. This technique emphasizes soft reactions on the growing surface, free from ion bombardment. The deposition area could be expanded arbitrarily by enlarging the spanning area of the catalyser filaments. In HWCVD the gas utilization efficiency is 5–10 fold higher, thereby contributing to higher growth rate of the material than in PECVD. The HWCVD thus provides enormous promise for better technological feasibility towards commercial production of large area semiconductor devices, in general [1].

Hydrogenated microcrystalline silicon ($\mu\text{-Si:H}$) is a mixed phase material with a composition of crystalline grains embedded in an amorphous matrix. Because of the presence of both the components and their combined effects therein, $\mu\text{-Si:H}$ possesses properties like doping efficiency, carrier mobility and optical absorption which are of intermediate magnitude compared to those of their individuals. In view of possessing a favorable combination of higher doping efficiency, enhanced carrier mobility and reduced optical absorption compared to its amorphous counterparts, $\mu\text{-Si:H}$ attains enormous importance in amorphous Si-related thin-film technologies. Apart from its use as a component layer in photovoltaic devices and thin-film transistors, solar cells comprising entirely of $\mu\text{-Si:H}$ layers have also been realized with marked improvements in terms of light-induced degradation and near-infrared absorption of solar radiation.

High H_2 -dilution and high level of electrical excitation to the SiH_4 plasma are the two critical parameters facilitating the growth of $\mu\text{-Si:H}$ network in PECVD [2]. Both the parameters increase the atomic H density in the plasma, while the atomic Hydrogen-induced growth modulation demonstrates wide structural changes from amorphous to micro- and nano-crystalline configurations in Si:H network [3,4]. However, high H_2 -dilution retards the film growth rate and high electrical power causes surface damage of other component layers in the device. The combination of

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