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ScienceDirect
Thin Solid Films 516 (2008) 814–817
www.elsevier.com/locate/tsf

Hot Ta filament resistance in-situ monitoring under silane containing atmosphere

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Available online 23 June 2007

Abstract

Monitoring of the electrical resistance of the Ta catalyst during the hot wire chemical vapor deposition (HWCVD) of thin silicon films gives information about filament condition. Using Ta filaments for silane decomposition not only the well known strong changes at the cold ends, but also changes of the central part of the filament were observed. Three different phenomena can be distinguished: silicide (stoichiometric Ta_XSi_Y alloys) growth on the filament surfaces, diffusion of Si into the Ta filament and thick silicon deposits (TSD) formation on the filament surface. The formation of different tantalum silicides on the surface as well as the in-diffusion of silicon increase the filament resistance, while the TSDs form additional electrical current channels and that result in a decrease of the filament resistance. Thus, the filament resistance behaviour during ageing is the result of the competition between these two processes.

Keywords: a-Si:H; Hot-wire deposition; Hot filament control; Silicides

1. Introduction

Hot wire chemical vapor deposition (HWCVD) is a possible alternative to plasma-enhanced chemical vapor deposition (PECVD) for depositing thin silicon films without settling for a lower film quality at higher deposition rate [1]. While the process gas (silane) decomposes on the filament surface, solid silicides can occur on the filament surface, which leads to a lower deposition rate due to screening and degradation of the catalyst [2]. Therefore, three different processes are observed on the Ta catalyst filament surface when exposing it to a silane atmosphere: 1) growth of silicon rich silicides (stoichiometric Ta_XSi_Yalloys) on the filament surface, 2) diffusion of Si into the Ta filament surface region and, likely, formation of Ta rich silicides [3], and 3) thick silicon deposit (TSD) formation on the surface [4].

The resulting rather short filament lifetime is a main obstacle to use the HWCVD method to produce thin silicon films. Likely, a better understanding of the filament degradation will help to increase the catalyst lifetime and enhance the reproducibility of the HWCVD deposition process.

In a previous investigation it was shown that the filament degradation depends on silane partial pressure in chamber during thin-film deposition process [4]. This investigation deals with the changes in the filament resistance related to the different degradation phenomena of the Ta catalyst mentioned above.

2. Experimental details

A HWCVD multi-chamber system described elsewhere [5] was used for the deposition of thin silicon films. For standard deposition, a W-shaped tantalum filament (~35 cm long, 0.5 mm in diameter), silane pressure 1 Pa was used. The filament temperature was controlled in the middle part by a two-colour pyrometer (Keller PZ40). When the temperature of a filament is nonuniform along the catalyst, the temperature was determined in the central area showing the maximum luminescence.

The electrical power applied to the filaments as well as filament conductivity versus time were carefully monitored (at the power supply device output) during catalyst use. After every deposition process the temperature of the filaments was

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0040-6090/$ - see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.tsf.2007.06.143

increased in vacuum (up to 2100 °C) in order to keep the filament surface relatively clean. This annealing procedure enables a higher reproducibility of thin silicon film deposition.

In addition, Ta filaments in ribbon geometry were used (65 × 3 mm, 50 μm thick) to understand changes of the catalyst during ageing, since this catalyst geometry enables secondary ion mass spectroscopy (SIMS) investigations. No differences in the filament resistance behaviour during the ageing process were observed between wire and ribbon shape filaments in spite of a difference in bulk-to-surface ratio.

It should be mentioned that the purity of the Ta wire as well as the Ta ribbon used, with 99.99%, was not very high. For previous depositions of amorphous silicon hydrogenized (a-Si:H) films Ta wires of higher purity (99.9999%) were also used, but since there was no clear indication of an increase of the film quality, the cheaper low purity material was further used. However, it should be mentioned that the degradation behaviour of Ta catalyst material of higher purity and therefore its behaviour of resistance might be different from that obtained in this investigation.

3. Results and discussion

Routine measurements of the *J–V* characteristics of W-shaped tantalum wire filaments showed that the resistance of the filaments continuously increases (up to finally 125% of initial value, see Fig. 1) during its lifetime (the time of a filament usage). A similar increase of resistance was observed by the Utrecht research group [6]. Previous investigations already revealed that the quality of films declines with the time of filament use [2,7] and the deposition rate decreases when the voltage on the filament is kept constant [1,8]. The reason for the drop in deposition rate is a decrease of the filament temperature [8]. Most probably, the decrease of the filament temperature is a result of the resistance increase.

It is important to note that the filament temperature is an important technological parameter (instead of applied voltage),

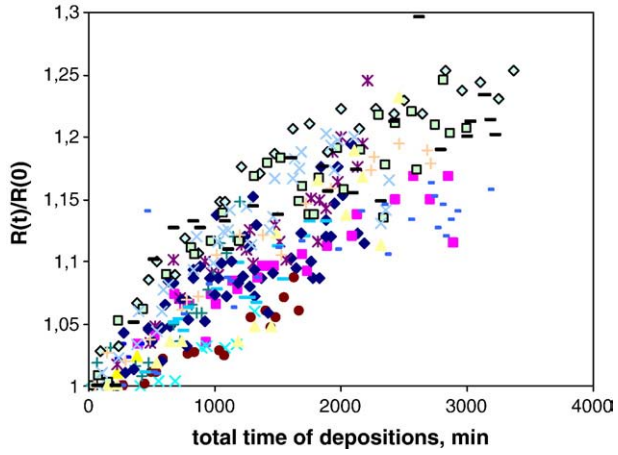

Fig. 1. Change of the normalized resistance of 26 different Ta wire filaments as a function of total deposition time. Each data point represents one deposition procedure for 10... 120 min at temperature 1575 ± 25 °C.

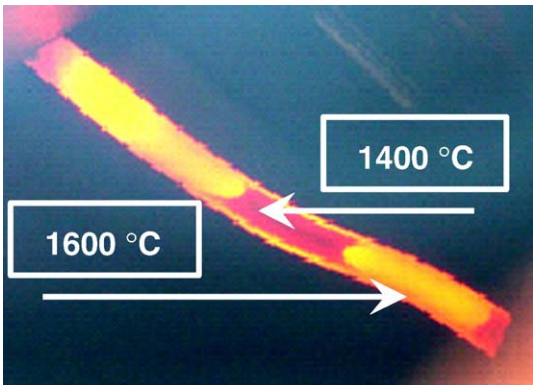

Fig. 2. Photograph of a Ta ribbon filament in deposition chamber after operation for 100 min in a pure silane atmosphere with a pressure of 12 Pa.

since the species generate on the surface of the hot filament and therefore deposition rate and film quality are highly dependent on it [9]. Hence, to keep a constant temperature of a catalyst during the use, a readjustment of the *J–V* settings is required. At the end of the filament lifetime it is necessary to apply about 60% more power in order to maintain the previous filament temperature. The effect of the power enhancement could be attributed to 1) the increase of the filament thickness at "cold ends" that results in a stronger heat transfer to supporting contacts, 2) the increase of the filament surface due to cracks and fissures on surface and therefore stronger heat transfer to gas, or/and 3) the increase of filament heat capacity due to Ta_XSi_Y alloying.

It is important to note that an increase of deposition rate (up to 130% of initial value) and decrease of the quality of the deposited films (e.g. the ratio photo-to-dark conductivity ($\sigma_{ph}/\sigma_{dark}$) decreased for one order of magnitude) after keeping constant the filament temperature were observed for used filaments, too, most probably due to increase of the surface area of the catalyst. Also a different radical chemistry and/or higher silane decomposition due to the filament surface augmentation could be reasons for the observed increase of the deposition rate with the filament lifetime.

The analysis of the filament composition shows that the nature of the filament ageing involves the growth of Ta silicides at the surface [3,4]. Optical light and electron microscopic investigations demonstrate the strong corrosion of the filament due to the growth of silicides [3]. The comparison of the SIMS spectra of the filaments used for different deposition process regimes indicates that the increase of the resistance is also correlated to the silicon concentration in the filament [4].

The growth of silicides on the filament surface plays a crucial role. For example, when thickness of silicides is about 100 μm while the filament diameter is 500 μm, it is about 90% of the filament volume. Therefore the observed *increase* of the catalyst resistance is attributed to the formation of stoichiometric and, probably also, non-stoichiometric Ta_XSi_Y alloys out of Ta filament material.

It is important to note that at high filament temperatures the silicides can be amorphous or crystalline, and they show a complicated dependence of their properties on temperature