Thin Solid Films 575 (2015) 25–29

Contents lists available at ScienceDirect

Thin Solid Films

journal homepage: www.elsevier.com/locate/tsf

# Dual hot-wire arrangement for the deposition of silicon and silicon carbide thin films

Tao Chen, Bharath Bangalore Rajeeva [1], Johannes Wolff, Andreas Schmalen, Friedhelm Finger *

*IEK-5 Photovoltaik, Forschungszentrum Jülich, Jülich 52425, Germany*

ARTICLE INFO

Available online 12 October 2014

*Keywords:*
Silicon
Silicon carbide
Thin film
Filament
Hot wire
CVD

ABSTRACT

A dual hot-wire arrangement has been designed and investigated for the deposition of various thin film materials by the hot-wire chemical vapor deposition (HWCVD) technique. Tantalum and rhenium wires were used for silicon and silicon carbide depositions with hydrogen diluted silane and monomethylsilane, respectively. It is shown that the both types of filaments are mechanically stable after alternate depositions of silicon and silicon carbide with a total deposition time of about 80 h. Good material quality of the deposited films is demonstrated. By taking advantage of this dual hot-wire arrangement, it is possible to deposit both kinds of thin film materials with the individual optimum deposition conditions in a single HWCVD chamber.



## 1. Introduction

The advantages of the hot-wire chemical vapor deposition (HWCVD) technique (also known as Catalytic Chemical Vapor Deposition (Cat-CVD) [1]) for thin film depositions have been widely reported [2–5]. Using HWCVD, high-quality amorphous and microcrystalline silicon materials (a-Si:H and μc-Si:H) and related high-performance solar cells and thin film transistors have been fabricated [2–6]. Besides silicon, HWCVD technique also shows its superiority in depositing stoichiometric microcrystalline silicon carbide (μc-SiC:H) material with mainly cubic SiC polytype at low substrate temperatures [7–11]. Such wide band-gap μc-SiC:H material is an outstanding window layer for solar cells, such as silicon thin film solar cells [12,13] and silicon heterojunction solar cells [14–17]. In terms of the deposition process, it is of great technical interest and importance to deposit varieties of materials in one processing chamber. This is widely adopted for the chambers equipped with the plasma enhanced chemical vapor deposition (PECVD) technique. However, the preparation of various materials in one single HWCVD chamber can be problematic. This is mostly related to the core part of filament material for the HWCVD technique. Fig. 1 shows the filament age of tungsten (W), tantalum (Ta) and rhenium (Re) filaments for μc-SiC:H depositions with hydrogen diluted monomethylsilane ($SiH_3CH_3$, MMS) [18]. The filament temperature of all filaments was kept at about 2000 °C. Neither Ta nor W filaments could last more than 8 h of deposition time under these conditions. Instead, the Re filaments showed a long-term stability of not less than 48 h, indicating its suitability for μc-SiC:H deposition with MMS. However, the Re filaments broke once the deposition of silicon material with hydrogen diluted silane was carried out with these filaments. Hence, the filament material needs to be selected properly according to the utilized gas precursors. Instead of hunting for a filament material suitable for various kinds of gas precursors or suitable for growth of various material, a simple and straightforward design of the filament holder is proposed by our group. This modified filament holder allows the installation of several wire sets of different filament material at one time. Without interrupting the deposition procedure, only the intended wire set is enabled to prepare the material with its proper gas precursors. In the present work, a dual hot-wire arrangement with Re and Ta filaments is firstly investigated for the depositions of μc-SiC:H and intrinsic silicon material, respectively. The individual optimum deposition conditions, such as filament material and gas precursors, are applied in a single process chamber. The process stability and the quality of the material prepared with this new set-up are studied.

## 2. Experimental details

The dual hot-wire arrangement contains an in-house designed filament holder, which allows independent activation of the two (or more) types of filament materials. Switching between the wire sets (Ta or Re filaments) is realized by easily exchanging the DC power connection outside of the chamber. A schematic drawing of the filament arrangement is shown in Fig. 2. Three Re and three Ta filaments were used (Re, purity 99.99%, Rhenium Alloys Inc. USA; Ta, purity 99.9%, Goodfellow Cambridge Limited, UK). The diameter of all wires is 0.5 mm. No pre-treatment is applied for either wire material before the installation. The distance between two wires of the same type is about 3 cm. The dual hot-wire arrangement was installed in a single hot-wire chamber deposition system with deposition gas supplies for silicon and microcrystalline silicon

* Corresponding author.
*E-mail addresses:* t.chen@outlook.com (T. Chen), f.finger@fz-juelich.de (F. Finger).
[1] Also at BITS, Pilani – K. K. Birla Goa Campus, Goa 403726, India.

http://dx.doi.org/10.1016/j.tsf.2014.10.028
0040-6090/

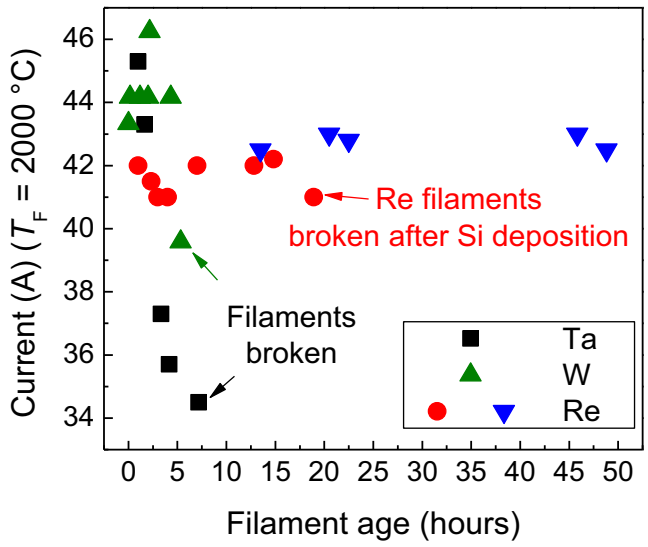


**Fig. 1.** Current provided to the filaments vs. filament age for tungsten (W), tantalum (Ta) and rhenium (Re) wires for silicon carbide deposition with MMS gas and hydrogen. Each data point stands for one deposition. The filament age refers to the sum of deposition time when the filaments are used.

carbide (μc-SiC:H) preparation. The distance from filament to substrate is about 7 cm. The deposition parameters are summarized in Table 1. Monomehylsilane (MMS) and silane ($SiH_4$) both diluted in hydrogen ($H_2$) were used for the SiC and Si depositions, respectively. A wide range of silane concentration (*SC*), defined by the gas flow ratio of $SiH_4$ to the total gas flow, i.e. $SC = [SiH_4]/([SiH_4] + H_2])$, were used to prepare amorphous and microcrystalline silicon (a-Si:H and μc-SiC:H). The silicon thin films were co-deposited on glass and Si-wafer substrates. For the μc-SiC:H material, we focused on deposition conditions developed earlier for highly transparent window layers [13,19]. A gas mixture of MMS diluted in hydrogen with a concentration of 0.3% was used, and the Re filament temperature was fixed at 2000 °C. These μc-SiC:H window layers were deposited on chemical etched TCO substrates for cell preparation.

## 3. Results

Depositions of Si and SiC materials were done in several consecutive sequences to investigate the durability of the filament materials and the possible influence on the material quality of thin films. The durability of this dual hot-wire arrangement is demonstrated by the results of accumulated film thickness as a function of the deposition time shown in Fig. 3. In Fig. 3(a), the deposition sequences started with the Ta filaments for silicon deposition. After 9 h of silicon deposition (about 2 μm thick), the Ta filaments were switched to off-state (indicated by the horizontal dashed line) and the Re filaments were activated (indicated by the solid line) for SiC deposition. One piece of the three Re filaments broke during the deposition. The preparation of SiC material continued with the other two pieces of Re filaments. When we switched

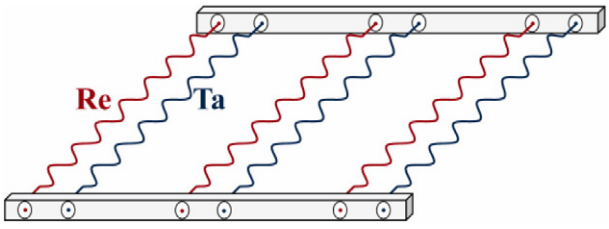


**Fig. 2.** Scheme of the array of tantalum and rhenium filaments in the dual hot-wire arrangement.

**Table 1**
Deposition parameters of silicon and μc-SiC:H thin films using the dual hot-wire arrangement.

| | μc-SiC:H thin films | Silicon thin films |
|---|---|---|
| Wire material | Rhenium | Tantalum |
| Substrate temperature | 275 °C | 200 °C |
| Filament temperature | 2000 °C | 1700-1800 °C |
| Gases | MMS + $H_2$ | $SiH_4$ + $H_2$ |
| Gas concentration | $c_{MMS}$ = 0.3%* | *SC* = 2%-10%** |
| Deposition pressure | 75 Pa | 6 Pa |

Note: *$c_{MMS}$: MMS concentration, defined by the gas flow ratio of MMS to $H_2$, i.e., $c_{MMS} = [MMS] / ([MMS] + [H_2])$; **SC: silane concentration, defined by the gas flow ratio of $SiH_4$ to $H_2$, i.e., $SC = [SiH_4] / ([SiH_4] + [H_2])$.

to Ta filaments again for the second deposition sequence, the Ta filaments broke. In all, this dual hot-wire arrangement starting with Ta filaments in the first deposition sequence ended up with a total deposition time of about 25 h. In Fig. 3(b), the deposition of μc-SiC:H thin films

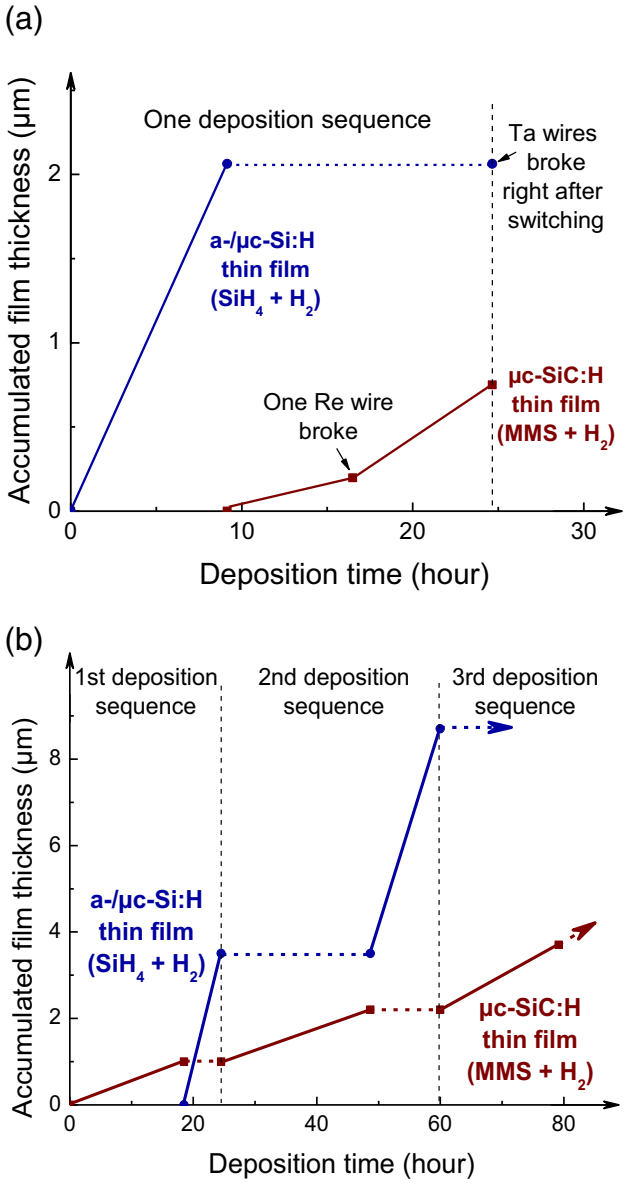


**Fig. 3.** Deposition sequence of a-/μc-Si:H and μc-SiC:H thin films using the dual hot-wire arrangement. (a) The first deposition sequence started with Ta filaments for silicon deposition; (b) The first deposition sequence started with Re filaments for silicon carbide deposition.