EFFECT OF INTERELECTRODE SPACE ON PROPERTIES OF SiH_4/H_2 DEPOSITION DISCHARGES OPERATING AT DIFFERENT RADIO FREQUENCIES

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Abstract

The combined effect of excitation frequency and the variation of the interelectrode space on properties of highly diluted silane in hydrogen discharges used for the deposition of μc-Si:H, is presented. For constant operation voltage, the increase of the electrode gap leads to a continuous increase of the power consumed in the discharge at 30MHz, while at 50MHz changes on the interelectrode space has almost no effect on the total power dissipation. At both frequencies the increase of the interelectrode space leads to an optimum in radical production that as frequency increases is displaced to lower electrode gaps. Film growth rate appears an optimal that coincides to the maximum of radical production at both frequencies, revealing that μc-Si:H deposition rate strongly depends on radicals (SiH_2, Si_2H_4) that undergo rather fast reactions in the gas phase.

Keywords: Electrode gap, Radio-Frequency, μc-Si:H, PECVD, silane

1. INTRODUCTION

Hydrogenated microcrystalline silicon (μc-Si:H) is an attractive material for device applications such as thin film silicon solar cells [1]. The increase of the driving frequency (13.56MHz<f<100MHz) has been proposed from several groups in order to improve deposition processes [2]. Specifically, for the deposition of μc-Si:H from highly diluted SiH_4 in H_2 discharges earlier studies have shown that the increase of frequency from 13.56MHz to 70MHz is followed by an increase of the deposition rate and is beneficial for the growth of microcrystalls [3]. However when using higher RF frequencies than 13.56MHz all other deposition parameters as power, total pressure and silane partial pressure, need to be re-optimized. One parameter often neglected or its optimisation is based on empirical approaches, is the discharge geometry, in terms of interelectrode space. Previous works of this group have revealed the influence of the variation of electrode gap on radical production [4] and on power dissipation [5] using the conventional frequency of 13.56MHz and for a-Si:H deposition process.

The present work is focused on the effect of the electrode gap on the properties of highly diluted SiH_4 in H_2 discharges that operate at frequencies of 30MHz and 50MHz and aim to the optimal conditions for the deposition processes of μc-Si:H. For that purpose deposition rate measurements have been performed in highly diluted SiH_4 in H_2 discharges and the different electrodes gaps that optimize film growth rate at both frequencies is discussed in relation to the effect of interelectrode space on the power dissipated in the discharge and on the spatial distribution of radicals production.

2. Experimental

Film deposition studies have been performed in a capacitively coupled Ultra High Vacuum (UHV) parallel plate reactor, with a base vacuum of 10^{-9} mbar. The grounded (deposition) electrode with 90mm diameter is mounted on an ultra high vacuum linear motion feed through, allowing the variation of the interelectrode space. In the present study the distance between the two electrodes have been varied from 1.0cm to 2.5cm.

The RF electrode has been powered through an L-type matching network by a Dressler WLPG 101D wideband (5-125MHz) generator. The method used for the measurement of the real power consumed in the discharge has been presented in detail elsewhere [6]. Spatially Resolved Optical Emission Spectroscopy has been used for recording emission intensities of excited radicals. In-situ Laser Reflectance Interferometry (LRI) have been used to measure film growth rate.

3. Results

The dependence of the power consumed in 0.5Torr, 2% SiH_4 in H_2 discharges, on the interelectrode distance is presented in fig. 1. More precisely, power has been measured for electrode gaps between 1.0cm to 2.5cm and for frequencies of 30MHz and 50MHz. For the 30MHz discharges peak-to-peak voltage V_{pp} has been set constant at the value of 140Volt, while for the 50MHz excitation, V_{pp} have been maintained constant at the lower value of 50Volt. Although the lower of the applied voltage at 50MHz, as can be observed from fig. 1, power dissipation is almost the same for both frequencies at intermediate electrode distances

(1.5-1.7mm). The drop of the voltage that is required to operate discharges at the same power level as frequency increases, has been reported as one of the main advantage of higher frequency operation in thin film deposition [7]. However this property as can be observed from fig. 1 will strongly depend on the choice of the electrodes gap. In the case of 30MHz increase of interelectrode space is followed by a continuous increase of power dissipation that is doubled as electrode gap increases from 1.0 to 2.5cm. This behaviour appears significant similarities to the results that have been previously reported from this group concerning interelectrode space effect on power dissipation in 13.56MHz deposition discharges [5]. In this study, the increase of power dissipated in the discharge as interelectrode space increases has been attributed to the continuous increase of current flux towards the increasing grounded surface and this is also the case in the 30MHz operation. The increase of discharge contact with the reactor walls as electrode gap increases, is also supported from measurements of DC-self-bias in the powered electrode that as interelectrode space increases from 1.3cm to 2.5cm takes more negative values, varying from –18.5Volt to –36Volt. If one takes into account the constant applied voltage (V_{pp} =140Volt), the more negative values of self-bias voltage result to a continuos increase of the discharge asymmetry term $|V_{dc}/V_{RF}|$.

In contrast to the 30MHz case, at 50MHz the increase of the interelectrode space has almost no effect on the total power dissipation that remains almost constant over the entire range of electrode gaps. The different behaviour can be explained by taking into account that

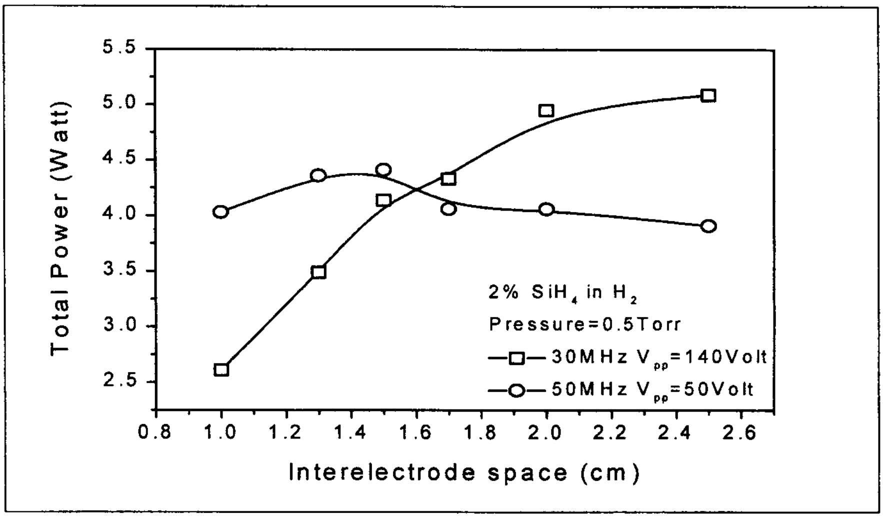

Figure 1: Power dissipation in 0.5Torr 2% SiH_4 in H_2 discharges at 30MHz (V_{pp}=140Volt) and 50MHz (50Volt) as a function of interelectrode space

the rather lower value of the applied voltage and the thinner of the sheaths at 50MHz, result in a better confinement of the discharge between the two electrodes. The flux of electrons towards reactor walls is also not favoured due to that the time required for electrons to escape plasma relative to the field time reversals decreases. In fact, as electrode gap increases electrons are trapped in the low field bulk and can either contribute to electron-molecule elastic collisions or accelerated during one half of the cycle and then decelerated and give the kinetic energy back to the field when it reverse direction in the next half cycle. In the first case of elastic collisions, power dissipation will be rather low while in the second case of inductive motion, electrons will be unable to impart any of the energy that have gained from the field to the gas, explaining thus the almost constant power dissipation.

The fact that the discharge structure remains almost unaffected with the variation of electrode gap at 50MHz is also reflected on the measured values of V_{dc}. In contrast to the 30MHz case the values of self-bias voltage remains almost constant as electrode gap increases, while also takes quite lower values (~ -13Volt) compared to the 30MHz excitation.

The dependence of the power dissipation on the variations of electrode gap is also reflected on the spatial distribution of radicals produced by electron-molecule collisions. In fig. 2(a) is presented the spatial distribution of $\dot{S}iH$ ($A^2\Delta$) radical, result from silane dissociative excitation at both 30MHz and 50MHz and the higher electrode distance of 2.5cm that has been used in this study. As frequency increases emission intensity drops and the maximum of excited radical production is displaced towards the RF electrode. At 50MHz and for distance above 1.2cm from the RF electrode, excitation rate is almost neglible. This behavior reveals that bulk ohmic and grounded sheath electron heating mechanisms are

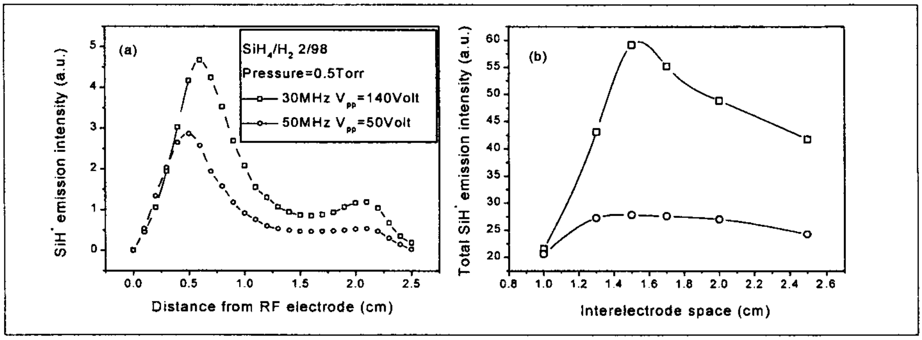

Figure 2: (a) Spatial distribution of SiH^* emission intensity at 30MHz and 50MHz and electrode gap of 2.5cm. (b) Total emission intensity as a function of interelectrode space for 30MHz and 50MHz

unable to produce electrons with energy higher than 10.4eV (process threshold).

Concerning total SiH^* emission intensity as calculated by integrating emission profiles and is shown in fig. 2(b), is higher at 30MHz compared to 50MHz for all electrode distances, except of the 1cm case, where the quite low power dissipation at 30MHz (fig.1) leads to almost the same intensity. At both frequencies total SiH^* production presents a maximum that is placed at 1.5cm and 1.3cm, for the 30MHz and 50MHz discharges respectively. The existence of a maximum in excited radical production is the result of an optimum in electron density and energy [4]. This optimum is more intense at 30MHz indicating that at lower frequencies electron properties is more sensitive in changes on the interelectrode space.

The fact that the discharge efficiency in producing radicals varies with interelectrode space is reflected on the deposition rate that as can be observed from fig. 3, presents an optimum at both 30MHz and 50MHz. As in the case of the power dissipation and the excitation rate the effect of interelectrode space on the deposition rate is more pronounced at 30MHz. It is of a great importance that the optimum in the deposition rate coincide with SiH^* maximum production, being 1.5cm and 1.3cm for 30MHz and 50MHz respectively. In the case of μc-Si:H and a-Si:H deposition from highly diluted SiH_4 in H_2 discharges, neutral radicals produced from electron induced dissociation of silane will be responsible for the film growth. The contribution of ions to the film growth rate can be neglected as their concentration in the gas phase and their flux towards the growing surface is expected to be

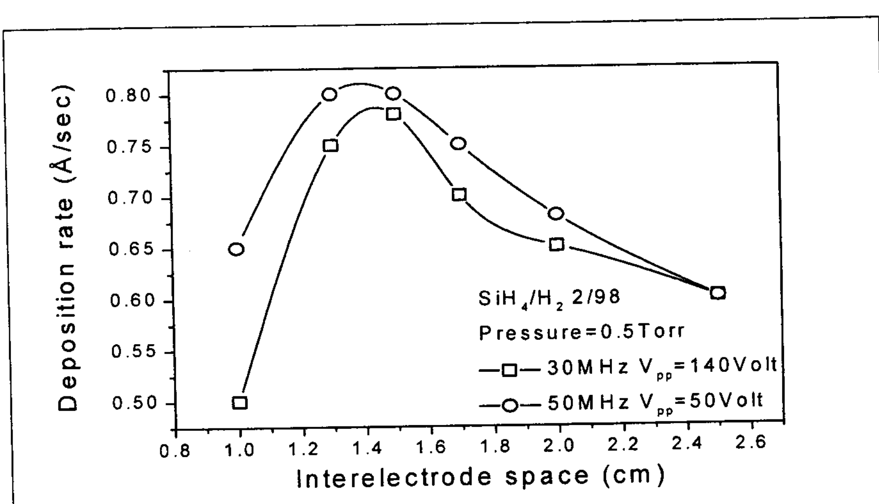

Figure 3: Variation of the deposition rate as a function of electrode gap for 30MHz and 50MHz 2% SiH_4 in H_2 discharges

about two orders of magnitude less than these of neutral radicals [8]. The fact that a simple relation between the deposition rate and the radical production in the gas phase has been observed can provide information concerning the radicals that are the main film precursors. Taking into account that the gas phase and surface reactivity and the mass transport of neutral radicals to the growing surface will determine their relative contribution to the film growth, the fact that such relation between a primary electron induced process and deposition rate exist, clearly indicates that film growth rate is determined by radicals (SiH_2, Si_2H_4) that their reaction in the gas phase dominates diffusion and they also direct incorporate into film growth.

4. Conclusions

The combined effect, of the variation of the interelectrode space and the increase of the excitation frequency, on properties of highly diluted SiH_4 in H_2 discharges lead to deposition of μc-Si:H has been presented. Power dissipated in the discharge at constant peak-to-peak voltage has been found to continuously increase with the increase of interelectrode space at 30MHz while at 50MHz remains almost unaffected. At the same conditions, production of excited species presents an optimum at both frequencies and lies at lower electrode gaps at the higher frequency.

Deposition rate have been found to depend on the variations of the interelectrode space with this dependence being more pronounced at 30MHz. For both frequencies, optimum of film growth rate coincides to the maximum of excited radical production revealing that μc-Si:H growth rate is determined by highly reactive-highly sticking radicals.

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