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# Low temperature (300$^{o}$C) growth of crystalline/non-crystalline thin Si films by a newly developed single shower dual injection system employing microwave excited high density hydrogen plasma and silicon radicals CVD process.

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## Introduction

Low temperature (300$^{0}$C) deposition of thin crystalline/non-crystalline silicon films by using newly developed single shower, dual injection, microwave excited high density plasma ($10^{11}$cm$^{-3}$)system, exhibiting low electron temperature (1.3eV), is described. A dual shower system was reported earlier [1]. *For the first time*, for this system, experimental results are presented correlating between the deposition and plasma parameters with the resulting Si films properties. Their consistent interdependence enables to pre-determine, in a wide range by design the deposited Si films properties.

## Experimental

In Fig.1, the top Radial Line Slot Antenna (RLSA) radiates uniform microwaves for plasma excitation. An Aluminum shower injects towards the RLSA and towards the substrate, separate, independently controlled, uniformly distributed Hydrogen and $SiH_4$ gases respectively. The microwaves excite uniform Hydrogen plasma which contains high temperature electrons and high energy ions. Its frequency (2.45GHz) results Hydrogen plasma region *confinement* to about 20mm-30mm (depending on the total gas pressure and microwave power) from the dielectric plate. Ions and electrons diffuse down from the plasma excitation region through the *grid shaped* shower, creating *plasma diffusion region* up to the electrically isolated substrate.

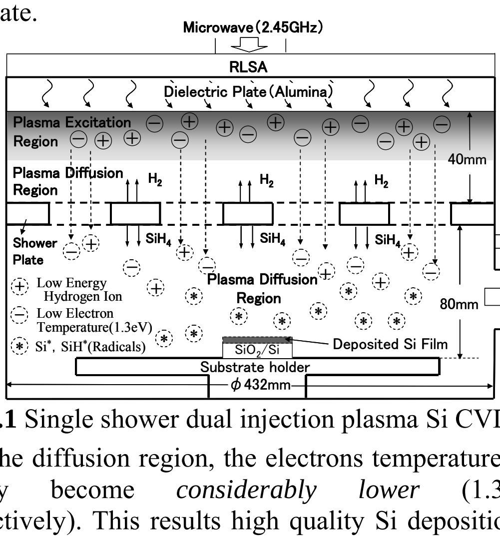


**Fig.1** Single shower dual injection plasma Si CVD system

In the diffusion region, the electrons temperature and the ion energy become *considerably lower* (1.3eVand10eV respectively). This results high quality Si deposition since: (a) their currents cancel each other in the plasma diffusion region, *preventing charge-up damage* in the deposited Si films, (b) metal sputtering from the chamber inner walls by the ions is prevented , (c) the shower is positioned in the plasma diffusion region; therefore its material sputtering by the ions is prevented, (d) the low ion bombardment energy results the *deposition of damage free Si films*,and (e) undesirable gas phase decomposition of the $SiH_4$ is prevented *ensuring Si film growth on the substrate by only surface reaction* which is a well controlled process. In this system, reaction of the plasma species with the $SiH_4$ takes place and *neutral radicals are efficiently produced of the $SiH_4$ molecules by the low temperature* (1.3eV) *electrons*. Accordingly, the Si deposition proceeds by the *high reactivity silicon neutral radicals (Si*)* even at low substrate temperatures (300$^{0}$C).

## Results and Discussions

Two sets of experimental results are presented. In the first (Fig. 2), the *total pressure* ($P_{total} = P_{H2}+P_{SiH4}$) was varied keeping the microwave power ($P_{mw}$) and gases flow rates (sccm) ratios ($R=H_2/ SiH_4$) constant. In the second (Fig. 3), the *microwave power* was varied keeping $P_{total}$ and R constant.

Fig. 2(a) presents the deposition rate (D.R) vs. $P_{total}$ for different gas flow rates, but identical R=100:1, all exhibiting a maximum at 100mTorr.Clearly, D.R attains higher values as the flow rates are increased. Re-plotting the curves of Fig. 2(a) for $P_{total}$> 100mTorr, results *straight lines* on a semi-log plane (Fig. 2(b)), all exhibiting a *similar slope* of $5x10^{-3}$ Torr$^{-1}$. This implies that an *ordered physical mechanism governs the deposition process*. The OES intensity (Fig. 2(c)) exhibit similar trends to those of the D.R in Fig. 2(a), indicating that a one to one relation exists between the radical content and film growth process. The data in each radical group (Si*, total Si*, Hα ) of Fig. 2(c) indicate that the OES for a given group is practically independent of R. The XRD data in Fig.2(d) shows that the degree of (111) preferred orientation deteriorate with increasing $P_{total}$. The refractive index (n) in Fig. 2(e) exhibits a minimum at 100 mTorr obtained at maximum D.R.

Fig.3(a) shows D.R vs. $P_{mw}$ for R= 20:1under different flow rates. D.R increases exhibiting longer linear regions as the individual gases flow rates are increased. The OES intensity in Fig.3(b) exhibit similar trends to the D.R curves in Fig.3(a) as is the case in Fig. 2. Fig. 3(c)shows the affect of Si* on D.R. Fig. 3(d) shows that the Si films (111) preferred orientation increases with $P_{mw}$ up to a maximum point which is dependent on the individual flow rates. The preferred orientation is higher for the lower flow rates. The refractive index in Fig. 3(e) exhibits minimum which attain higher values and at the same time are shifted to higher $P_{mw}$ values, as the individual flow rates are increased.

## Acknowledgement

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[1] T.Ohmi, M.Hirayama and A.Teramoto,
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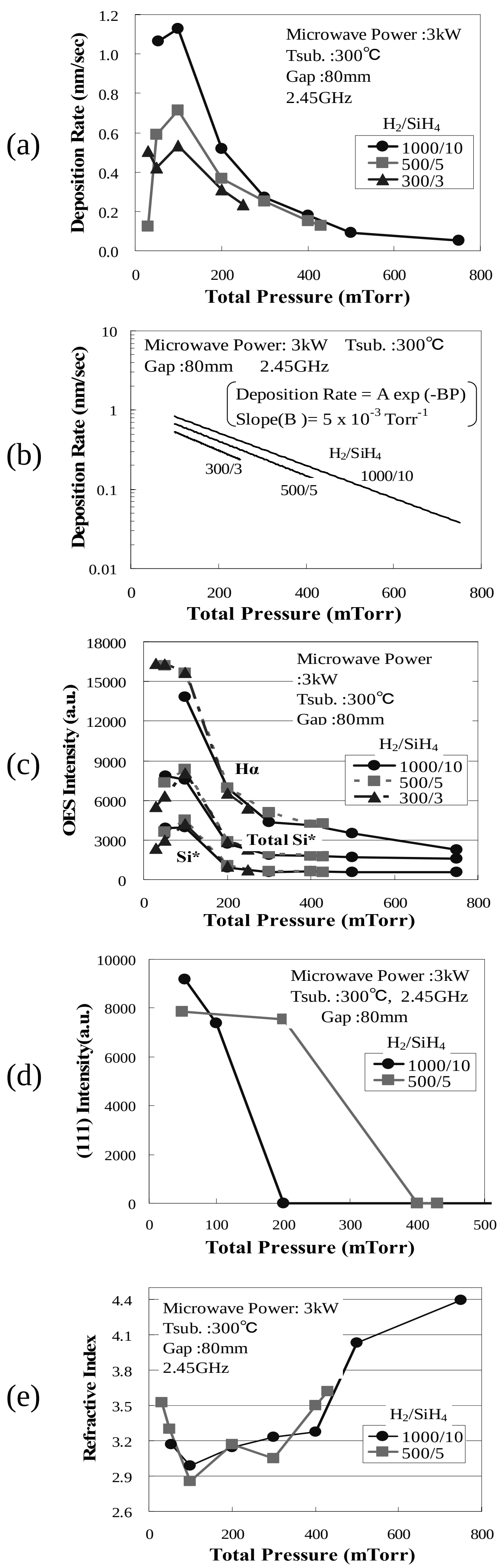


Fig.2 Si films properties as a function of total $H_2$+SiH4 pressure

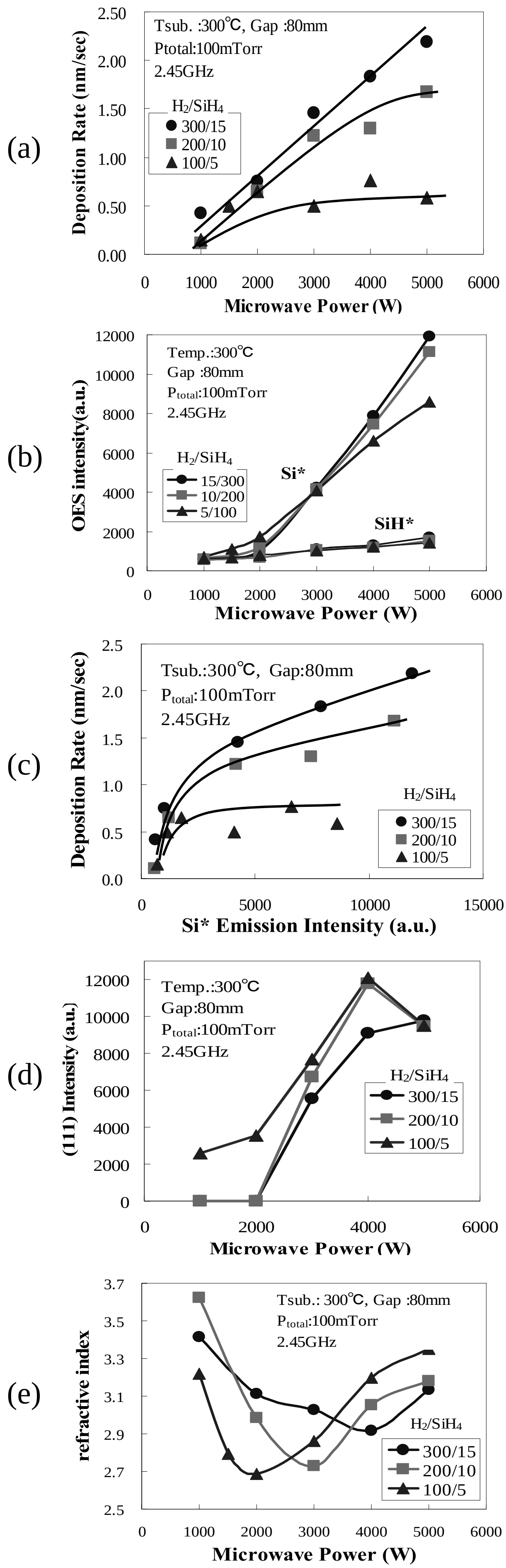


Fig.3 Si films properties as a function of microwave power (2.45GHz)