

# GRAIN SIZE INFLUENCE ON SHEET RESISTANCE OF P- AND As-IMPLANTED POLYCRYSTALLINE SILICON DEPOSITED BY VERTICAL CVD REACTOR

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## Abstract

*We have investigated the influence of grain size on sheet resistance ( $R_s$ ) of doped polycrystalline Silicon films (poly-Si). Poly-Si samples were prepared in a vertical type CVD reactor in a wide range of deposition conditions, and implanted with P at doses of  $1 \times 10^{16}$  and  $2 \times 10^{16} \text{ cm}^{-2}$ , or with As at  $1 \times 10^{16} \text{ cm}^{-2}$ . The sheet resistance depends on the implanted species and it is closely related to the texture, mainly the grain size, of the obtained poly-Si layer.  $R_s$  depends inversely on grain size and P-doped films exhibit lower  $R_s$  values than As-doped films. This behavior can be due to different segregation of the dopant atoms at the grain boundaries.*

## 1. Introduction

Doped polycrystalline Silicon (poly-Si) is largely used in VLSI technology as gate electrode in MOS (Metal-Oxide-Semiconductor) structure and interconnections [1]. Its electrical properties are closely related to the crystalline structure of the deposited film, once amorphous phase does not become electrically active by doping/annealing [1]. Grain size and preferential orientation (PO), or texture, of deposited films can affect the electrical properties of doped samples [2]. The smaller the grain size the higher the percentage of amorphous phase at the grain boundaries, thus leading to an increase in  $R_s$  [1-3]. Both PO and grain size are strongly influenced by conditions used in deposition process of poly-Si thin films, particularly by temperature and total pressure, and annealing techniques employed. In this work we study the texture of the P- and As-implanted poly-Si thin films deposited at different process conditions and analyzed the dependence of the sheet resistance ( $R_s$ ) with the grain size. The analyses show that for both P- and As-implanted poly-Si samples, grain size affects inversely on sheet resistance. P-doped samples exhibit  $R_s$  values in the order of 20 - 50  $\Omega/\text{sq}$  adequate for applications in electronic devices, while As-doped samples exhibit values 2 or 3 orders of magnitude higher.

## 2. Experimental

1.5  $\mu\text{m}$  thick poly-Si films were deposited in a Vertical CVD Epitaxial Reactor at the Center for Semiconductors Components of State University of Campinas (CCS-UNICAMP) using Hydrogen diluted  $\text{SiH}_4$ . The experimental arrangement is schematically shown in figure (1).

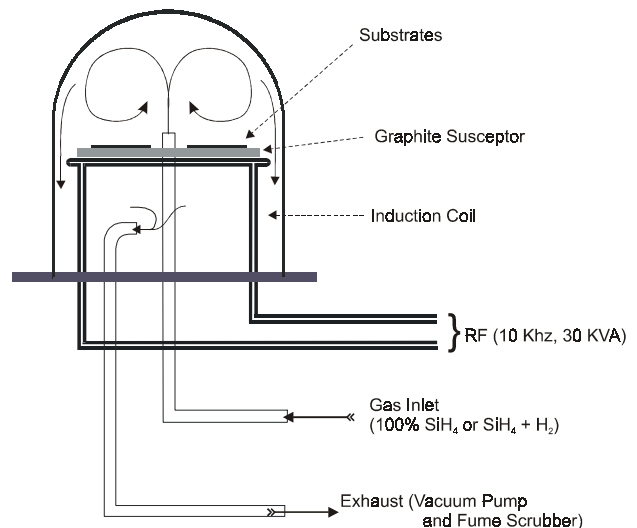


Figure 1: Schematic of the Experimental Assembly used for poly-Si deposition.

The reaction chamber is constituted by a quartz bell jar, and a graphite susceptor, where samples lay for deposition. A RF (10 kHz, 30 KVA) induction coil located just below the graphite susceptor heats the substrate to the required deposition temperature. The susceptor is also provided with a rotating mechanism to ensure a uniform gas and temperature distribution over the samples. Gases used in the process are introduced into the reactor in an ascending flow from a 3/8 in. diameter quartz tube located in the middle of the susceptor.

The substrates used for poly-Si deposition were a 2-in. <100> oriented p-type silicon wafer covered with a 0.6  $\mu\text{m}$  thermal oxide layer. The deposition temperature was monitored by an infrared optical pyrometer and rate flows of reagent gases were controlled by a Mass Flow Meter ( $\text{QSiH}_4$ ) and rotameter type flow meter ( $\text{QH}_2$ ). The conditions used for the depositions are presented in Table (1):

Pressure	5 – 100 Torr
Temperature	620 – 1,000 °C
$\text{QSiH}_4$	10 – 60 sccm
$\text{QH}_2$	980 – 36,100 sccm

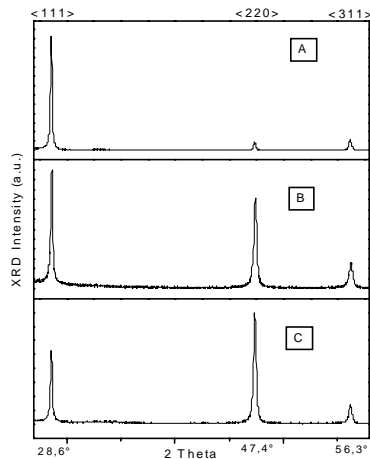
**Table 1: Conditions used for deposition of poly-Si films**

The doping of poly-Si samples was achieved by implanting P at doses of  $1 \times 10^{16} \text{ cm}^{-2}$  and  $2 \times 10^{16} \text{ cm}^{-2}$  or As at dose of  $1 \times 10^{16} \text{ cm}^{-2}$ , all with 150 keV. The post implantation annealing was performed after RCA cleaning in RTA process at 960 °C temperature during 40 sec in  $\text{N}_2$  atmosphere, to activate implanted species and to recover the crystalline damage (the high implantation doses used in this work can completely amorphize the implanted region [4]).

X-Ray Diffraction (XRD) was used to characterize the dominant crystal orientation (texture) and grain size (D) of the annealed films. Electrical properties (sheet resistance) were measured by four-point probe technique and the data correlated with XRD grain size calculated by Scherrer formula [5].

### 3. Results and Discussion

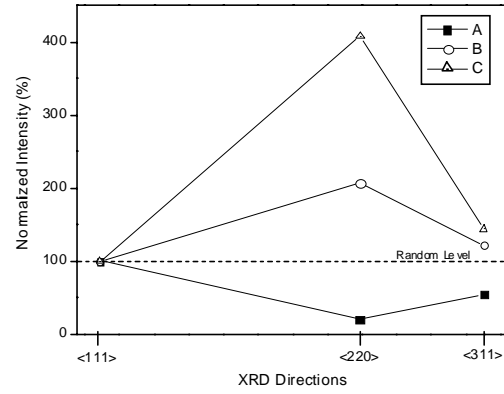
Figure (2) shows XRD spectra of poly-Si samples deposited in three different process conditions in the Vertical Reactor. One can easily see from figure (1), by comparing B with A and C with A, that changing the temperature and/or pressure will change the structure of the deposited film.



**Figure 2: XRD spectra showing the texture of the poly-Si films deposited at various process conditions.**

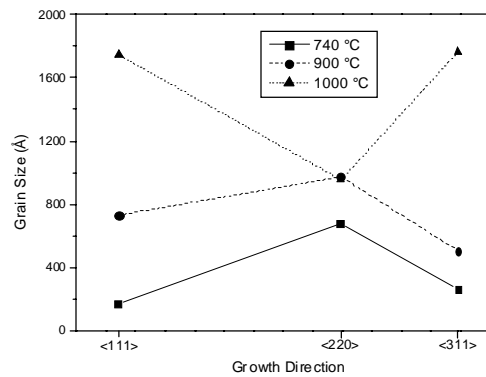
A: P=10 Torr, T=850°C,  $\text{QSiH}_4$ =40 sccm,  $\text{QH}_2$ =4800 sccm;  
B: P=10 Torr, T=800°C,  $\text{QSiH}_4$ =40 sccm,  $\text{QH}_2$ =4800 sccm;  
C: P=5 Torr, T=850°C,  $\text{QSiH}_4$ =40 sccm,  $\text{QH}_2$ =4800 sccm.

The difference in the growth kinetics can be more clearly observed verifying the dominant growth orientation or preferential orientation (PO). PO is determined by normalizing the measured XRD intensities to a completely random sample (powder) [1]. The normalized intensities of the spectra of the samples disposed in Fig (2) are shown in Fig (3).



**Figure 3: normalized intensities of the XRD spectra showed in figure (2)**

Higher temperature leads to a more prominent intensity in <111> direction which can be seen comparing B (850°C) and A (800°C) XRD profiles in fig. (2), while at low pressures <220> direction is enhanced, which can be seen comparing C (5 Torr) and A (10 Torr) XRD profiles in the same figure. One can notice that the grain structure is more sensitive to the temperature than to the pressure variation. A temperature variation of less than 10% causes an expressive increase in the relative intensity of <200> and <311> orientations when compared to a 100% pressure variation. The same trend is observed in grain size (D). Fig. (4) shows temperature influence on D for samples deposited at 100 Torr.



**Figure 4: Variation of the grain size (D) calculated by Scherrer Formula [5] as a function of temperature of the films deposited at P = 100 Torr,  $\text{QSiH}_4$  = 40 sccm,  $\text{QH}_2$  = 36100 sccm**

Although other parameters (P,  $\text{QSiH}_4$ , and  $\text{QH}_2$ ) also influence D values [1], the grain size is more sensitive to

the temperature variation. D variance with temperature is directly proportional. In fig (4) one can see that a 35% variation in temperature increases grain size up to 1 order of magnitude in the <111> and <311> directions. <220> oriented grains are also bigger at higher temperatures. The film thickness also affects the grain size, but since all samples have the same thickness (1.5  $\mu\text{m}$ ), its influence wasn't taken into account in the analysis.

The variation in the intensities of the <111>, <220> and <311> peaks and in the grain sizes observed in fig. (2) – (4) indicates that different deposition conditions affects the surface diffusion of adsorbed species and growth kinetics. So that one or another crystalline growth direction is benefited for the set of employed conditions. The higher the temperature, the larger the surface diffusion length (L) will be thus, adsorbed atoms can diffuse to a longer distance until they find a crystalline nucleus to aggregate to [1]. This process leads to a lower nucleus density in the initial growth stage, which implies in larger grains as deposition proceeds.

The mixture of amorphous and crystalline phases in poly-Si films leads to  $R_s$  values significantly higher in comparison to the single crystalline films. Tables (2) and (3) present the Sheet Resistance values ( $R_s$ ) measured on P- and As-implanted poly-Si by four-point probe technique, respectively. Used implantation energy was 150 keV in all samples.

Dose (cm <sup>-2</sup> )	Press (Torr)	Temp (°C)	QSiH <sub>4</sub> (sccm)	QH <sub>2</sub> (sccm)	D ave (Å)	$R_s$ (Ω/sq)
2x10 <sup>16</sup>	10	850	40	4800	676	23,74
	90	740	50	25300	657	23,56
1x10 <sup>16</sup>	100	740	40	36000	372	138,62
	100	900	40	36000	736	40,54
	100	1000	40	36000	1497	14,36
[6] POCl <sub>3</sub> diff. doped (900°C; 25 min)					1500 – 300	100-500
[7] POCl <sub>3</sub> diff. doped		950°C; up to 60 min			3500	42 - 190
		630 °C; up to 180 sec			1000	75 - 190

**Table 2: Sheet resistance  $R_s$  of P-doped poly-Si samples**

Dose (cm <sup>-2</sup> )	Press (Torr)	Temp (°C)	QSiH <sub>4</sub> (sccm)	QH <sub>2</sub> (sccm)	D ave (Å)	$R_s$ (Ω/sq)
1x10 <sup>16</sup>	5	850	40	4800	493	401,36
	10	850	40	4800	418	781,43
	5	800	40	4800	239	1594,56
1x10 <sup>16</sup>	[8] I.I. 70 keV		Oxide cover		1500 - 100	20 – 350
1x10 <sup>16</sup>	[9] I.I. 90 keV		Oxide cover			10-10k
			No cover			100-10M

**Table 3: Sheet Resistance  $R_s$  of As-doped poly-Si samples**

P-implanted samples have  $R_s$  values in the range of 14 – 138  $\Omega/\text{sq}$  for both 1x10<sup>16</sup> and 2x10<sup>16</sup> cm<sup>-2</sup> implantation doses and most samples have  $R_s$  less than 50  $\Omega/\text{sq}$ , adequate for microelectronic applications.

As-implanted samples have  $R_s$  values considerably higher, in the range of 400 – 1600  $\Omega/\text{sq}$  for implantation doses of 1x10<sup>16</sup> cm<sup>-2</sup>. In spite of the absolute values, one can see that  $R_s$  varies inversely on average grain size for both P- and As-implanted samples, independent of the deposition conditions. Samples deposited at quite different conditions can produce P-doped films with the same grain size, thus with the same  $R_s$ . Keeping constant all other parameters and increasing temperature, increases D values and this implies in a decrease in  $R_s$  values for both P- and As-implanted samples.

Band model proposed by Seto [2] can be used to explain the obtained results. According to this model, a large number of defects due to incomplete atomic bonding exists in the grain boundaries, which forms trapping states. This reduces the number of free carriers available for electrical conduction. After trapping the mobile carriers, the traps become electrically charged and they create a potential barrier, which impedes the motion of carriers from one grain to another. The amorphous phase is also an insulating region, which implies in another potential barrier. The bigger the grain size, the smaller the amorphous portion will be, so that, less trapping states will exist in poly-Si films with big crystalline grains. This leads to a higher free carrier concentration, that reduces the resistivity of the poly-Si film, as observed.

Differences in  $R_s$  values for P- and As-implanted samples can be due to different diffusion mechanisms for these impurities. P-diffusion is approximately isotropic in poly-Si so that there is no net flux from or to grain boundaries. As-diffusion has a more expressive diffusion coefficient in the amorphous phase than in the crystalline phase. Thus, there is a net flux of As-atoms from crystal grain to grain boundaries. Since impurities are not electrically active in the grain boundaries [1-3], this causes the  $R_s$  values in the As-doped samples to be higher than in P-doped samples. The vertical arrangement of the grain boundaries (crystal grains have a columnar structure in poly-Si layers) leads As to diffuse deeper in the poly-Si layer. Besides, As also diffuses to the atmosphere during annealing (outdiffusion) if no protection is used over the implanted layer [1, 9-10]. This is the case of our samples. Even though,  $R_s$  values for our As-doped samples are consistent with the results found in the literature [9-10].

#### 4. Conclusion

In this study we have observed that temperature is of great importance on the grain size of deposited poly-Si layers and that sheet resistance depends inversely on grain size, independent of using P or As as dopant impurity. P-implanted samples achieved  $R_s$  values adequate for applications in microelectronic devices, while differences on the diffusion process lead As-implanted samples to  $R_s$  values 2 or 3 orders of magnitude higher.

## 5. Acknowledgments

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