for single crystal silicon. The two principal factors that cause the oxidation kinetics of polysilicon thin films to be different are the presence of grain boundaries and the finite thickness of the film. Because of these two factors, several other mechanisms (such as dopant segregation to the grain boundaries and rapid diffusion of the dopant along the grain boundary) influence the oxidation kinetics significantly. To accurately model the oxidation of polycrystalline silicon, these factors must be taken into account.

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# Properties of Plasma-Enhanced CVD Silicon Films

## I: Undoped Films Deposited from 525° to 725°C

**T. I. Kamins* and K. L. Chiang**

*Hewlett-Packard Laboratories, Palo Alto, California 94304*

## ABSTRACT

Undoped silicon films deposited by plasma-enhanced CVD from dichlorosilane in argon over the temperature range 525°-725°C have been studied, and their properties have been compared with those of LPCVD silicon films deposited from silane. Significant compressive stresses of $6 \times 10^9$ dynes/cm$^2$ are seen in PECVD films. X-ray, TEM, and reflectance measurements show that the films deposited at 600°C and below are amorphous, while those deposited at 625°C are polycrystalline with a poorly defined structure. A better developed polycrystalline structure is obtained at higher deposition temperatures, although the dominant {110} texture does not develop as readily as in LPCVD films. A polycrystalline structure begins to form at temperatures about 25°-35°C higher in the PECVD films than in LPCVD films. After annealing at 1000°C, all PECVD films are polycrystalline. The resistivities of films doped with phosphorus by ion implantation or from a gaseous $POCl_3$ source are lower for the initially polycrystalline films than for the initially amorphous films. PECVD films deposited at 625°C have higher resistivities than do LPCVD films deposited at the same temperature.

For the last few years, most polycrystalline-silicon films used for MOS integrated-circuit gate electrodes have been deposited by thermal decomposition of silane in low pressure CVD (LPCVD) reactors near 625°C (1). However, the pyrolysis reaction is very temperature sensitive so that undesired temperature variations in the reactor can cause significant thickness variations. In addition, the deposition rate cannot be readily increased, and large quantities of dopant atoms cannot easily be incorporated into the LPCVD films during their deposition. The gate-electrode dopant atoms are usually added after deposition, possibly complicating the process sequence.

For these reasons, the plasma-enhanced CVD (PECVD) reactors developed to deposit dielectric films (2) are being studied for the deposition of polycrystalline silicon. Significant quantities of dopant atoms can be incorporated during the deposition, and the process is less sensitive to temperature variations. However, little is known about the properties of the resulting silicon films. For example, the presence of argon in the plasma may cause some unwanted argon inclusion in the films, changing their properties. The plasma may also provide momentum to the migrating species adsorbed on the wafer surface, in addition to providing the energy for the decomposition, so that the microstructure may be altered.

To learn more about the suitability of the PECVD silicon films for use in integrated circuits, their properties were evaluated in this study. The films were deposited by ASM/America, Phoenix, Arizona, in a slightly modified version of a reactor described previously (2). Both undoped films deposited over the temperature range 525°-725°C and doped films de-

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* Electrochemical Society Active Member.

Key words: CVD, crystallography, doping, reflectance.

posited at a constant temperature of 628°C were studied. The PECVD films were compared to LPCVD films whenever possible. In particular, the properties of the undoped PECVD films were compared to those found in a similar investigation conducted while the low pressure CVD process was being developed (3).

This paper describes the properties of undoped silicon films deposited by PECVD at temperatures from 525° to 725°C in 25°C increments. A following paper (4) discusses the properties of films doped during deposition at a temperature of 628°C and subsequently annealed at varying temperatures.

## Film Deposition

In the PECVD reactor used (2), the wafers are held adjacent to closely spaced vertical electrodes, with adjacent electrodes connected to opposite terminals of an rf generator (Fig. 1). The entire electrode assembly is contained in an evacuated chamber within a resistance-heated furnace. In this way, approximately 100 wafers can be processed simultaneously while retaining the desired parallel-plate electrode geometry.

The gas flows of dichlorosilane and argon were 279 and 840 $cm^3$/min, respectively, and the target film thickness was 500 nm. An attempt was made to adjust the deposition times to produce the desired thickness at the different temperatures. The deposition rates calculated from the film thicknesses and deposition times varied by less than 25% between 525° and 725°C, with the maximum rate near 650°C. This slow variation with temperature can be contrasted to the rapid changes in deposition rate with temperature in an LPCVD reactor, where the thickness almost doubles when the temperature is changed by 25°C.

The eight wafers included in each deposition were placed in one row, which was located slightly more than halfway back from the gas inlet (row E in Fig. 1a). These eight wafers included five wafers covered with approximately 100 nm of thermally grown silicon dioxide (two <111> CZ and three <100> CZ) and three unoxidized wafers (one <111> CZ, one <100> CZ, and one <100> FZ). The differently oriented, oxidized wafers allowed elimination of substrate effects during x-ray measurements. The unoxidized CZ wafers permitted the influence of the underlying substrate on the crystal development to be studied. The FZ wafer was used for infrared absorption measurements to detect large quantities of hydrogen or oxygen in the deposited films.

## Crystal Structure

To learn more about the structure of the PECVD silicon films and to compare them with LPCVD films, their preferred orientation or texture was determined by x-ray diffraction. One set of films was measured after deposition, while another set was annealed at 1000°C in nitrogen before the x-ray analysis to investigate the stability of the structure. Standard LPCVD silicon films deposited at 625°C were included for comparison.

A General Electric x-ray diffractometer was used, with experimental conditions similar to those in a previous investigation of LPCVD silicon films (3). The peak heights were normalized to indicate the proportion of {111}, {110}, {311}, {100}, {331}, and {211} oriented crystallites in the films. Film-thickness corrections, as well as the standard powder-pattern intensities, were used to normalize the data. Most of the films examined were deposited on thermally oxidized, <100>-oriented silicon wafers, but some films deposited on <111>-oriented substrates allowed more detailed observation of possible {100} texture.

The preferred orientation of the PECVD films is shown in Fig. 2 as a function of the deposition temperature. No crystalline peaks are observed in films deposited at 600°C or below, indicating that these films are amorphous. Above 600°C the {110} texture dominates, with only small amounts of {111}, {311}, and {331} orientations present in some films. The maximum in the {110} texture occurs at 700°C and measurable {111} texture appears only above 700°C. For comparison, {110}, {311}, and {111} texture is seen in an LPCVD polysilicon film recently deposited near 625°C.

These results may be compared with those previously obtained on LPCVD silicon films deposited over the same temperature range (Fig. 3) (3). As in the PECVD films, significant texture begins appearing in the LPCVD films above 600°C. However, the dominant {110} texture in the LPCVD films reaches a maximum at 625°C and then decreases, while the maximum in the PECVD films does not occur until 700°C. In both cases, the {111} texture begins increasing only at temperatures above this {110} maximum. No {100} texture is seen in the PECVD films, consistent with the absence of a minimum in the {110} texture. Such a minimum may occur at higher temperatures than those investigated, possibly with a corresponding increase in the {100} texture.

Figure 4 shows the preferred orientation of the PECVD films after an 80 min, nitrogen anneal at 1000°C. Significant texture is seen in the initially

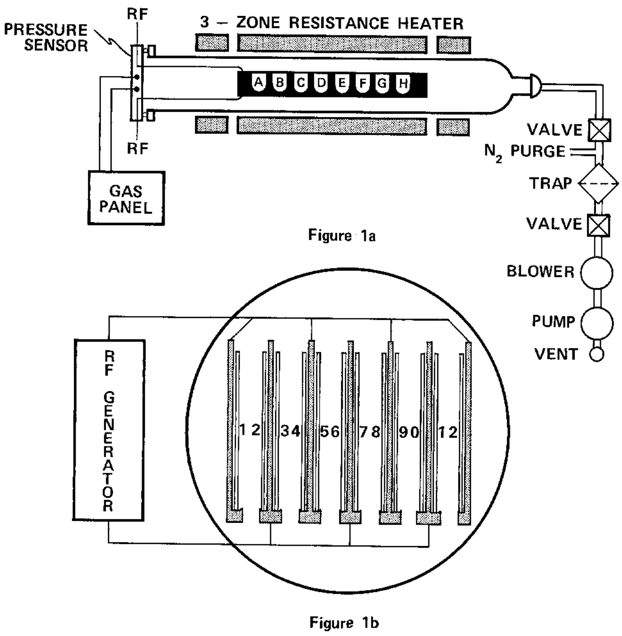

Figure 1a

Figure 1b

Fig. 1. (a) Schematic diagram of PECVD reactor indicating 8 rows of wafers. (b) Position of wafers within one row (2).

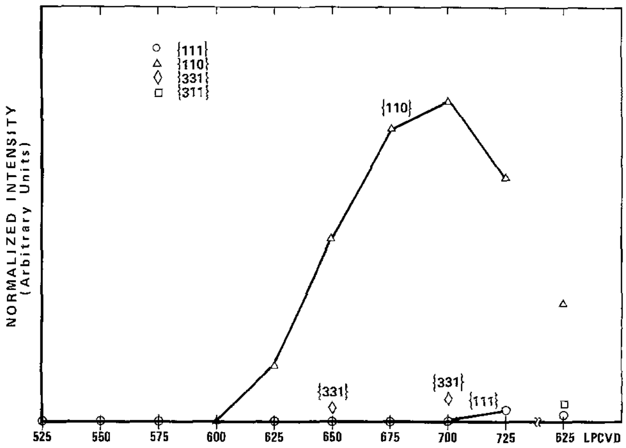

Fig. 2. X-ray texture of PECVD films as a function of deposition temperature before additional heat-treatment.

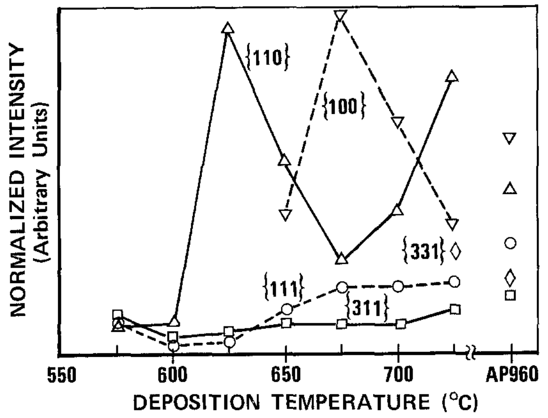

Fig. 3. X-ray texture of LPCVD films as a function of deposition temperature.

amorphous films deposited below 625°C. However, the degree of crystallinity in these films is, perhaps, less than expected since initially amorphous LPCVD films readily crystallize on annealing to give fairly large grain silicon films with a dominant {311} orientation (5). The amount of minor orientations in the initially polycrystalline PECVD films deposited at higher temperatures increases somewhat on annealing, but the dominant {110} texture does not change greatly, consistent with previous studies of LPCVD films (5).

These x-ray measurements suggest that the structure of the PECVD silicon films does not develop as readily as does that in LPCVD films deposited at the same temperature and that the PECVD films change less than do the LPCVD films with further heat-treatment, observations consistent with the other film properties discussed below.

Transmission electron microscopy shows that the films deposited at 600°C and below are amorphous with some small crystalline inclusions ($\lesssim 1\%$), while those deposited at 625°C are polycrystalline with a poorly developed structure and small grains (~30 nm). The grain structure in films deposited at 650°C is much better defined, and the grain size approaches 100 nm. For comparison, LPCVD films deposited at 575°C and below are amorphous, while films deposited at 600°C are fine grain polycrystalline (~55 nm) and those deposited at 625°C and above are polycrystalline with well-defined grains about 70-80 nm across (3).

All PECVD films are polycrystalline after annealing, but the grain size in the initially amorphous films (~30 nm) remains much smaller than that in the initially polycrystalline films. This behavior is different from that of amorphous LPCVD films, which readily crystallize into large grain material on annealing (5). The grain size in the initially polycrystalline films increases only slightly on annealing; the major effect is an increase in the perfection of the individual crystallites.

## Optical Properties

To obtain additional information about the film structure and its change on annealing, the optical reflectance of undoped films deposited at each temperature was measured as a function of wavelength both before and after annealing. These measurements allow a rapid assessment of the film structure once a correlation has been made with the microstructure determined by transmission electron microscopy. The value of this technique in evaluating the film structure during processing will become apparent in the following discussion. An HP8540 U.V.-Visible spectrophotometer, which samples all wavelengths simultaneously, was used with a single crystal silicon wafer as the reference sample. Reflectance measurements were made in both the 200-400 and 400-800 nm wavelength ranges.

*After deposition.*—In the 400-800 nm wavelength range (Fig. 5), PECVD films deposited at 600°C and below and not further heat-treated exhibit markedly different behavior from films deposited at 625°C and above. The initially amorphous, low temperature films are strongly absorbing below 570 nm, so that optical interference of light reflected from the top and bottom of the film is not visible. A limited number of interference peaks are seen at higher wavelengths. The film deposited at 625°C is strongly absorbing below 480 nm, while the absorption edge decreases to about 450 nm in films deposited at 725°C. The absorption edge decreases significantly between films deposited at 625° and 650°C and more slowly above 650°C, consistent with the poorly developed polycrystalline structure at 625°C determined by the x-ray and TEM measurements. The absorption edge decreases at deposition temperatures about 25°-35°C lower in the LPCVD films than in the PECVD films, consistent with the x-ray and TEM observations of a better developed structure in the LPCVD films at a given deposition temperature.

Reflectance measurements in the 200-400 nm wavelength range on amorphous PECVD films deposited at 600°C and below and not further heat-treated show minima at 275 and 370 nm superposed on a uniform background (Fig. 6). [These minima indicate the absence in the PECVD films of energy-band structure that is present in the single crystal reference wafer (6)]. At the shortest wavelengths the initially polycrystalline films have a much reduced reflectance ($R \approx 20\% R_{\rm Si}$), which increases more or less monotonically

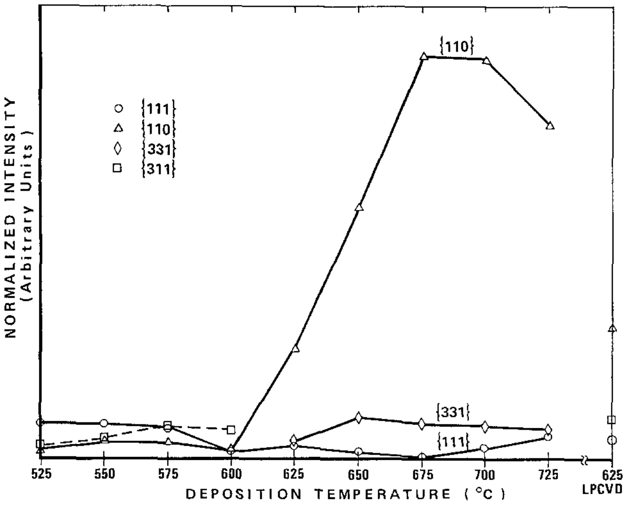

Fig. 4. X-ray texture of PECVD films as a function of deposition temperature after annealing at 1000°C in nitrogen.

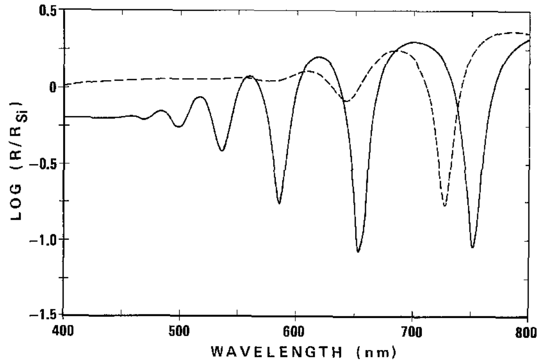

Fig. 5. Reflectance of PECVD silicon films as a function of wavelength from 400 to 800 nm for amorphous film deposited at 600°C (dashed curve) and polycrystalline film deposited at 650°C (solid curve).

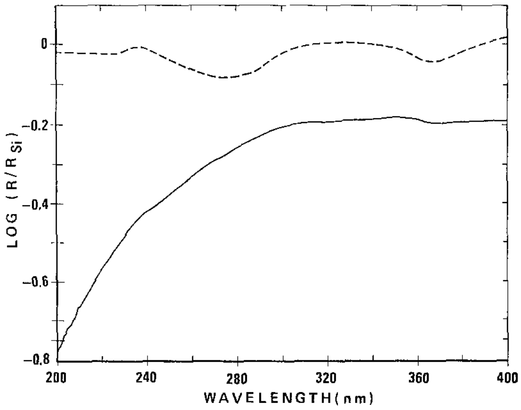

Fig. 6. Reflectance of PECVD silicon films as a function of wavelength from 200 to 400 nm for amorphous film deposited at 600°C (dashed curve) and polycrystalline film deposited at 650°C (solid curve).

with increasing wavelength, indicating significant surface roughness. Above 300 nm the reflectance remains relatively constant with only small minima, consistent with the better developed crystalline structure. However, the magnitude of the reflectance remains lower than for the films deposited at lower temperatures, suggesting a lower index of refraction in the polycrystalline films.

In the LPCVD films, the minima at 275 and 370 nm are visible in amorphous films, but are almost unnoticeable in films deposited at the higher temperature. In the PECVD films, minima are always visible (although they are less pronounced in the films deposited at 650°C and above), showing that the energy-band structure of the LPCVD films is closer to that of crystalline silicon than is that of the PECVD films. The x-ray and TEM measurements also indicate that the structure in the PECVD films does not develop as readily as in the LPCVD films.

Although a higher temperature is needed to obtain the same structure in the PECVD films as in the LPCVD films, the pressure during the PECVD depositions was 2 Torr, about 10 times as great as that used for LPCVD deposition of silicon at 625°C. A greater number of adsorbed species at this higher pressure might impede surface migration of the depositing atoms or molecules and thus reduce the hypothesized, beneficial effects of the plasma in aiding surface migration (7, 8). A subsidiary experiment in the LPCVD reactor with the silane diluted by nitrogen to produce a total deposition pressure of 2 Torr showed that the structural differences are not related to the higher pressure. Other differences in deposition conditions that may have changed the surface migration, and hence the structural development, are the presence of a chlorine by-product and a deposition rate twice as high in the PECVD system as in the LPCVD reactor.

*After annealing.*—After annealing the PECVD films at 1000°C in dry nitrogen for 80 min, the general shape of the reflectance curves in the 400-800 nm range changes markedly. Significant interference is seen above 440 nm for all films, indicating the development of a polycrystalline structure, as seen in the x-ray and TEM measurements. Even for the initially polycrystalline films, the interference is greater after annealing than before annealing, suggesting an improvement in the crystal structure.

In the 200-400 nm wavelength range, however, no significant reflectance changes occur on annealing. The uniform background of the low temperature films is still observed, although the magnitudes of the minima diminish. The absence of significant change in the 200-400 nm spectrum, while marked changes occur in the 400-800 nm range, may be related to the different depths of the film sampled in each wavelength range. The shorter wavelengths sample only the top atomic layers in the film while the longer wavelengths penetrate the entire thickness. This reasoning suggests that the surface of a film may not be able to change on annealing, even though the bulk of the film is converted from an amorphous to a polycrystalline structure. It is likely that a thin oxidized layer on the surface or some oxygen penetration into the surface layers stabilizes the surface topology or the crystal structure near the surface.

Comparison of the wavelengths of the interference extrema before and after annealing indicates that neither the index of refraction nor the thickness of films deposited above 625°C changes on annealing (within 2%). A decrease of about 4% is observed in films deposited at 625°C, consistent with the behavior of PECVD films doped during deposition (4). The large decrease seen in the index of refraction of the initially amorphous films on annealing is expected from similar experiments with LPCVD silicon films (3).

## Stress

Measurements of the wafer flatness after deposition indicate the stress in the films. A Canon Model LSF-500 laser-scanning flatness tester was used to determine the sense and maximum deflection of the wafer surface compared to positions 3 mm from the edges. In all cases the wafer is concave downward, indicating compressive stress in the films. The curvature appears to have its maximum value of approximately 20 $\mu$m at deposition temperatures of 625°-650°C and to decrease for both higher and lower deposition temperatures, although considerable scatter appears in the data. The corresponding stress is in these 3 in. diameter wafers $6 \times 10^9$ dynes/cm$^2$.

## Resistivity

To learn more about the structure and usefulness of PECVD silicon films, the films deposited at varying temperatures were doped with phosphorus by ion implantation or from a gaseous $POCl_3$ source. The experimental conditions chosen allowed comparison with experiments performed on LPCVD silicon films deposited over the same temperature range (3). The dopant concentrations were selected to accentuate differences between the films, rather than to be optimum for silicon-gate, MOS IC applications, and consequently may overstate the differences expected in practical applications.

*$POCl_3$ doping.*—A temperature of 900°C was used, along with a low concentration of $POCl_3$ in order to limit the amount of phosphorus entering the silicon and to introduce approximately the same amount into each film. The gas flow consisted of 3800 cm$^3$/min nitrogen, 1000 cm$^3$/min oxygen, and 200 cm$^3$/min of source (nitrogen bubbled through liquid $POCl_3$ at 20°C). After the phosphorus glass was removed with dilute HF, the sheet resistance was measured with a four-point probe. The resistivity depends strongly on the deposition temperature of the silicon film (Fig. 7). It increases slightly with increasing deposition temperature from 525° to 575°C and then abruptly increases at 600°C. The resistivity is markedly lower at 625°C and then decreases to a constant value for films deposited in the 650°-725°C temperature range. The abrupt decrease between 600° and 625°C corresponds to the temperature at which significant crystallinity appears in the as-deposited films.

The PECVD films were subsequently annealed at 1000°C for 80 min in dry nitrogen. Since the film surfaces were not covered during annealing, some phosphorus may have escaped, but this loss is expected to be small. As Fig. 7 shows, the resistivities of the initially amorphous films remain higher than those of the initially polycrystalline films. The resistivities of

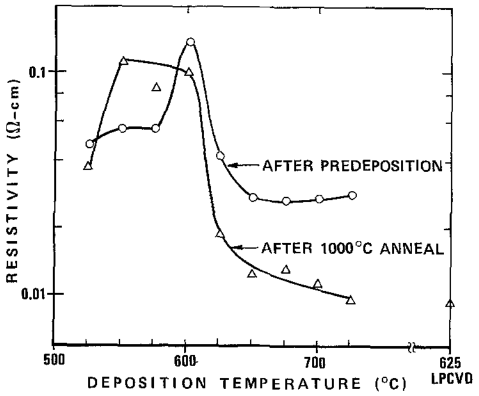

**Fig. 7. Resistivity as a function of deposition temperature after doping from a gaseous source and after a subsequent 1000°C, nitrogen anneal.**

films deposited between 650° and 725°C decrease by more than a factor of two on annealing. In this range, the resistivity appears to decrease slightly as the deposition temperature increases, with the resistivity of the 725°C sample about the same as that of a 625°C LPCVD film included in this experiment for comparison. The higher resistivity of the 625°C PECVD film compared to that of the LPCVD film deposited at the same temperature is consistent with the less well-developed structure in the PECVD material.

The resistivity of LPCVD films deposited over a similar temperature range is also maximum near 600°C after annealing (3). However, the resistivity of initially amorphous LPCVD films approaches that of films deposited at high temperatures. In contrast, the resistivity of the initially amorphous PECVD films remains much higher than that of high temperature PECVD films, again showing that the amorphous PECVD films do not crystallize as easily as do LPCVD films.

Reflectance measurements of the PECVD films in the 400-800 nm wavelength range after the 900°C $POCl_3$ doping indicate that all films are polycrystalline. The magnitude of the optical interference in the initially polycrystalline films increases somewhat after doping at 900°C and again after annealing at 1000°C, especially in films deposited just above the amorphous-to-polycrystalline transition temperature, indicating an increase in structural order.

*Phosphorus implantation.*—Other samples were implanted with $5 \times 10^{15}$ cm$^{-2}$, 50 keV phosphorus ions and subsequently annealed in dry nitrogen, first at 550°C and then at 1000°C. After the 550°C anneal (Fig. 8), the resistivity is too high to measure readily in the initially amorphous films deposited below 625°C (resistivity >> 100 Ω-cm). It is 16 Ω-cm in the film deposited at 625°C and is nearly constant with values of 0.14-0.17 Ω-cm for higher deposition temperatures. The resistivity in a 470 nm thick LPCVD film deposited at 625°C and doped and annealed with the PECVD films is 0.012 Ω-cm after the 550°C anneal.

The films were then covered with 600 nm of PECVD oxide at 380°C to protect the surface and annealed at 1000°C in dry nitrogen. After removing the oxide, the resistivity of the lower temperature films averages 0.015 Ω-cm, while that of the higher temperature films is about 0.0068 Ω-cm. As in the case of $POCl_3$ doping, the resistivity of the PECVD film deposited at 625°C is intermediate, with a value of 0.0077 Ω-cm. The resistivity of the 625°C LPCVD film is 0.0039 Ω-cm.

The markedly lower resistivity in the 625°C LPCVD film than in any of the PECVD films after the 550°C anneal is again consistent with a better developed structure in the LPCVD film. The difference in resistivity decreases markedly after annealing at 1000°C, indicating that the structure is dominated by grain growth occurring during the high temperature anneal of these highly doped films.

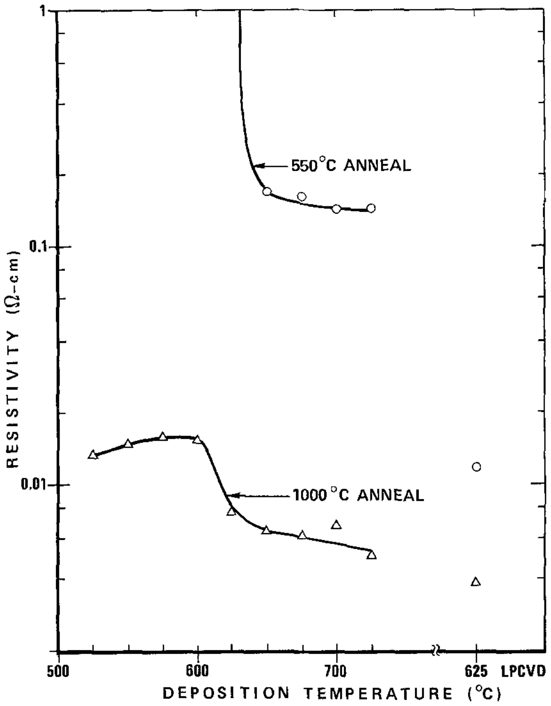

**Fig. 8. Resistivity as a function of deposition temperature after ion implantation of $5 \times 10^{15}$ cm$^{-2}$, 50 keV phosphorus ions, and annealing at 550° and 1000°C.**

Reflectance measurements from 400 to 800 nm indicate an initially polycrystalline structure in the PECVD films deposited at 625°C and above, a change to a less well-developed structure after implantation and the 550°C anneal, and a return to a polycrystalline structure after the subsequent 1000°C anneal. The initially amorphous films deposited at lower temperatures remain amorphous after the implantation and 550°C anneal and become polycrystalline after the 1000°C anneal.

## Summary

Undoped silicon films deposited from dichlorosilane in argon by plasma-enhanced CVD over the temperature range 525°-725°C have been studied, and their properties have been compared with those of LPCVD films deposited from silane.

Significant compressive stresses of $6 \times 10^9$ dynes/cm$^2$ were observed. X-ray, TEM, and reflectance measurements indicate that the films deposited at 600°C and below were amorphous, while those deposited at 625°C were polycrystalline with a poorly defined structure. A better developed polycrystalline structure was obtained at higher deposition temperatures, although the dominant {110} texture did not develop as readily in the PECVD films as in LPCVD films. The polycrystalline structure began to form at temperatures about 25°-35°C higher in the PECVD films than in LPCVD films. After annealing at 1000°C, all PECVD films were polycrystalline.

The resistivities of films doped with phosphorus by ion implantation or from a gaseous $POCl_3$ source were lower for the initially polycrystalline films deposited above 625°C than for the initially amorphous films PECVD films deposited at 625°C had higher resistivities than did LPCVD films deposited at the same temperature. The resistivities of all PECVD films decreased on further annealing.

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# Properties of Plasma-Enhanced CVD Silicon Films

## II. Films Doped During Deposition

**T. I. Kamins* and K. L. Chiang**

*Hewlett-Packard Laboratories, Palo Alto, California 94304*

ABSTRACT

Doped polycrystalline silicon films were deposited by plasma-enhanced CVD from a mixture of dichlorosilane and phosphine in argon at 628°C and a pressure of approximately 2 Torr. The films were annealed at temperatures varying from 450° to 1050°C, and their properties were compared to those of conventional LPCVD polysilicon films deposited from silane at 0.2 Torr. The doped PECVD films are polycrystalline as deposited, with a less well-developed structure than that of undoped LPCVD films. The phosphorus concentration in the PECVD films is approximately (4-5) × $10^{20}$ $\text{cm}^{-3}$. The chlorine concentration of about $3 \times 10^{20}$ $\text{cm}^{-3}$ seen after deposition decreases near the film surface after annealing at high temperatures. The films have a fine-grain, polycrystalline structure after deposition; the grain size increases from about 10 nm to about 500 nm on annealing. A small amount of {111} preferred orientation is observed after deposition, but strong {100} texture develops after annealing above 750°C. The other properties of the films also improve when the films are annealed above 750°C. The optical properties become more like those of crystalline silicon, and the compressive stress decreases from its initial value of about $10^{10}$ dynes/$\text{cm}^2$. The sheet resistance decreases from about 1500 to about 13 Ω/sq on annealing, although more phosphorus is needed in the PECVD films to obtain this sheet resistance than is needed in LPCVD films. The flatband voltage of MOS capacitors fabricated using PECVD silicon films for the gate electrodes decreases in magnitude on annealing above 750°C, approaching that of capacitors with LPCVD polysilicon. The fixed charge density also decreases on annealing. The properties of the PECVD films are suitable for use in MOS integrated circuits after annealing at temperatures above 750°C.

A previous paper (1) has discussed the properties of undoped, polycrystalline-silicon films formed by plasma-enhanced CVD (PECVD). Often, however, the deposition of heavily doped films is desired for use as gate electrodes or interconnections in integrated circuits' (2) or as dopant sources for the formation of shallow junctions in the underlying single crystal silicon (3). In CVD systems where the energy is supplied only thermally, the addition of large quantities of n-type dopant during the deposition greatly decreases the deposition rate (4). In addition, differences in the decomposition rates of the silicon-containing gas and the dopant gas make uniformity control difficult (5).

Using a plasma to aid the decomposition of the reactant gases removes many of the limitations previously encountered. However, the dopant atoms may not reach substitutional sites in a well-developed polycrystalline structure during the low temperature deposition. In addition, the presence of the dopant gas may change the structure of the deposited film. These uncertainties suggested a study of the properties of PECVD films doped during deposition and an investigation of the effect of subseqent heat-treatment on the properties. This paper summarizes the results of this study and, especially, shows that the properties improve greatly after annealing at temperatures above 750°C.

### Experimental Procedure

In this experiment, dopant was added during the deposition of polycrystalline silicon films in the same large-capacity reactor described in Ref. (1) and (5). The films were deposited at 628°C by the decomposition of a mixture of dichlorosilane and phosphine, with argon as a diluent. During the 19 min deposition, the gas flows were 279 $\text{cm}^3$/min of dichlorosilane, 89 $\text{cm}^3$/min of 1% phosphine in argon, and 240 $\text{cm}^3$/min of argon; the total pressure was 2 Torr. The target thickness of the films was 0.5 μm. The 23 3-in. wafers were located in the first two rows near the gas-inlet end of the reactor [rows A and B in Fig. 1 of Ref. (1)]. Twenty of the wafers were covered with 100 nm of thermally grown silicon dioxide, and three were bare, <100>-oriented, float-zone wafers. The latter were to be used for infrared absorption measurements, which would allow observation of large quantities of hydrogen or oxygen in the films.

After the films were initially characterized, they were annealed in dry nitrogen for 80 min at temperatures varying from 450° to 1050°C in 100°C increments. Different wafers were used at each annealing temperature. The wafer surfaces were not protected during the heat cycles.

For comparison, standard LPCVD polysilicon films were processed and measured along with the PECVD films whenever practical. The LPCVD films were deposited from 100% silane at the typically used deposition temperature of 628°-633°C and a total deposition pressure of approximately 0.2 Torr.

### Film Composition

Auger analysis, Rutherford backscattering spectroscopy (RBS), and secondary ion mass spectroscopy

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* Electrochemical Society Active Member.

Key words: CVD, resistivity, stress-strain, integrated circuits.