Mobil Tyco Solar Energy Corporation

MASTER

AMORPHOUS-SILICON THIN-FILM
HETEROJUNCTION SOLAR CELLS

TECHNICAL REPORT FOR THE PERIOD
March 1, 1980 — December 1, 1980

Mary C. Cretella
James A. Gregory
Donald B. Sandstrom
and
Professor William Paul,
Harvard University

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January 1981

Work Performed:

SERI Contract: XJ-φ-9056-1
Under Prime Contract: No, EG-77-C-01-4042

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I. INTRODUCTION

The investigation of amorphous silicon materials at MTSEC has had two major thrusts: 1) to improve the amorphous material, i.e., obtain a low state density in the gap, improve the carrier collection depth and diminish non-radiative recombinations; 2) to attempt to understand and improve on the limitations of the junction devices while evaluating the amorphous silicon materials. In the first of these efforts, the investigation has continued to examine the modifications to the a-Si(H) network by alloying silicon with other group IVA elements, either in binary or ternary compositions, and/or by replacing the hydrogenation for defect compensation with a combination of hydrogenation and alkylation or hydrogenation and halogenation. For the second part, we have been pursuing the examination of the doped junction layers in an attempt to determine the limiting characteristics of the junctions in solar cell devices of these amorphous materials.

We have prepared amorphous alloys of Si-Ge, Si-C, Si-Sn as well as ternary compositions of Si-Ge-C and Si-Sn-C. In addition, we have added Na vapor to the gas feed to deposit a-Si(Na, H) films and to prepare Si-Sn we have added fluoride along with the tin by vapor additions of SnF_4 to the gas feed.

We have measured the optical properties of these materials and have obtained structural and compositional information from the IR vibrational spectra using the scanning electron microscope and from analyses using scanning Auger microscopy. Electrical measurements have included the dark conductivity and the photo conductivity under room fluorescent light and at AM1 conditions. Some measurements of photoluminescence and density of gap states by the capacitive voltage technique have been made for us by Prof. W. Paul's group at Harvard

on our standard a-Si(H) films.

With alloys that displayed promising photoconductive properties we have prepared n-i-p devices to assess the solar cell properties. Although this has been a broad program and not all measurements are yet complete on all films which have been synthesized, the promising alloy compositions which have emerged will be studied at least to the extent outlined above. Among these are the Si-Ge, Si-C, and Si-Sn compositions. Fabrication of these alloys allow the optical energy gap to be varied over a range from ~ 1 eV to ~ 3 eV. A solar cell device prepared from a-Si_{0.7}Ge_{0.3}(H) alloy film has shown promise with Si_{0.7}Ge_{0.3} solar cell parameters not drastically different from the a-Si(H) and having a broader spectral response into the short wave length regime.

The addition of Na has altered the structure as seen by IR vibrational spectra and produces an n-type material with resistivities as low as the order of 1 Ω -cm at AM1. The possibility of this and other elements as dopant alternatives to P and B are promising.

II. EXPERIMENTAL PROCEDURES

The apparatus which is used for the deposition is a capacitatively coupled glow discharge as described in earlier reports and is shown schematically in Figure 1. Briefly, gas flows are controlled and introduced from a Corso Gray gas handling apparatus, the pressure is monitored with a Baratron manometer and controlled with a variable orifice in the vacuum line. The total flow rate is held at 20 sccm at a total chamber pressure of 0.5 Torr. The power for the discharge is generated by a 13.6 MHz r.f. generator with appropriate shielding and capacitance matching control. The total input power is <10 Watts which yields an electrode watt density of < .1 Watt/cm². Deposition

rates are typically .3 to .6 nm/sec; substrate temperatures can be varied to 600°C but typically depositions are made on substrates held at 260 - 275°C. Deposition times are selected to give films of about 1 to 2 μm thickness.

When using hydrides of the reactant gases, the volume of flow for these is 25% of the total flow; the remainder being equal volumes of H₂ and Ar.

When using a solid source of reactant, the solid is loaded into an ampoule which is then inserted into a quartz tubing sleeve wound with a wire resistance heater. The cap for the quartz sleeve container is positioned so that its nozzle is directed between the electrodes. The vapor is carried by diverting the argon gas feed through the quartz sleeve enclosure. This arrangement, shown schematically in Fig. 2, was used for introducing vapor from solids such as Na and SnF₄.

The arrangement shown in Fig. 3 was used for introducing vapors of liquid sources, such as Sn(C₂H₅)₄ and Sn(CH₃)₄. External heating could be applied if necessary; at the reduced pressure of the system, however, the liquids boil and the gas evolved into the glow discharge is directly regulated by a needle valve in the line. The gas concentration can be monitored by determining the pressure differential with the valve in the opened and then the closed positions.

Consistent with our previous practice, in each run a variety of substrates are used to allow for various measurements and include: For optical and electrical measurements, 7059 glass and silica; for IR spectra, Si (EFG ribbon); for devices Mo, SS, ITO coated 7059 (5 Ω/□ and 80 Ω/□) and Mo, Ni, or Pt grids on 7059 glass. These measurements are reported in the following sections.

III. OPTICAL AND INFRARED MEASUREMENTS

Optical and infrared measurements were made on the various alloy films. The optical energy gaps were determined for each alloy from the plot of the optical absorption coefficient as $(\alpha h\nu)^{1/2}$ versus the photon energy, $h\nu$. The intercept of the extrapolation of the linear portion of each of these curves is taken as the optical energy gap.

The infrared vibrational spectra measurements of a-Si(H) films provide information on the structural and compositional character. The integrated absorption of the wag mode at 630 cm^{-1} frequency has been shown to correlate with the hydrogen concentration and various workers have shown the effects of chemical bonding on the frequency position of the Si-H stretch mode at $\sim 2000\text{ cm}^{-1}$ frequency. Contamination by oxygen of C_xH_y at significant levels can also be detected by the IR measurements.

A. Films containing Na

The curves of $(\alpha h\nu)^{1/2}$ versus $(h\nu)$ are shown in Fig. 4 for the doped films deposited at Na source temperatures of 200, 245, 260, 300 and 360°C . At temperatures of 245°C and above there is a small dependence of E_{og} on source temperature, as shown in the inset of Fig. 4. At 200°C , however, the concentration of Na vapor in the gas discharge appears to be too low and no effect is observed. This is consistent with the observation from hot probing of the samples that showed pronounced n-type for the films at $T > 245^\circ\text{C}$ and small to no deflection at the lower temperatures. Increasing the substrate temperature decreased the gap slightly, however this is more likely a result of the attendant decrease in hydrogen incorporation.

At the highest source temperature the films exhibited some instability due to stress, those films nearest the Na vapor source actually "coiling" away

from the substrate. Optically, the films which were partially "coiled" appeared to have some preferred directions; however, X-ray diffraction showed only the diffused halo usually found with a-Si(H) films.

Infrared absorption measurements of the films prepared at $T_{Na} < 300^{\circ}C$ showed no marked difference from those of the a-Si(H). At $T_{Na} > 300^{\circ}C$, however, a broadening of the vibrational mode for Si-H (2000 cm^{-1}) was observed as well as a small absorption at 1020 cm^{-1} frequency and a larger absorption at 430 cm^{-1} frequency (Fig. 5). These latter absorption peaks are not identified but may be due to Si-Si defect modes. Also, with the high temperature films, absorption peaks at $\sim 1000\text{ cm}^{-1}$ frequency indicate some oxygen contamination (probably from the quartz ampoule).

B. Films of doped a-Si_xC_{1-x}(H)

Our previous reports have described the optical and electrical properties of the high resistivity, large gap a-Si_xC_{1-x}(H) films. In Fig. 6 are shown the plots of $(\alpha h\nu)^{\frac{1}{2}}$ as $(h\nu)$ for a-Si_xC_{1-x}(H,Z) where Z is P, B or Na at concentrations of 1% and 10% for PH₃ or B₂H₆ in the SiH₄ gas feed and T_{Na} is $250^{\circ}C$. T_s is $\sim 280^{\circ}C$ in all cases. It is apparent that with the possible exception of the films with Na, the addition of a dopant increases the optical energy gap, unlike the behavior of dopant elements in a-Si(H).

The infrared vibrational spectra do not show the vibrational modes for either B-H or P-H which suggests that the B and P are incorporated into the a-Si_x-C_{1-x}(H) network. The spectra show the typical vibrational modes of a-Si_x-C_{1-x}(H) as shown in Fig. 7.

C. Films of ternary composition a-Si_xGe_yC_z(H)

Films were deposited from various gas compositions of SiH₄, GeH₄ and C₂H₄. The optical energy gap decreased as the concentration of C₂H₄

decreased (Fig. 8). E_{og} for a gas composition of 5 SiH_4 :4 GeH_4 :1 C_2H_4 was 1.5 eV.

The infrared vibrational structure is surprising in that the vibrational mode for Ge-H is observed in these spectra. Previously, we have reported that the hydrogen in hydrogenated Si-Ge compositions shows a marked preference for attachment to the Si. In the binary alloy the principal Si-H stretch mode occurs at $\sim 2000 \text{ cm}^{-1}$ frequency. In the ternaries, however, the Si-H shifts to the 2090 cm^{-1} frequency (typical of Si-C alloys) and the Ge-H stretch is observed at 1960 cm^{-1} frequency. Other differences include the appearance of a small absorption peak at $\sim 1015 \text{ cm}^{-1}$ and a change in the ratio of the 845 cm^{-1} to the 890 cm^{-1} modes. An absorption at 1015 cm^{-1} has been reported to be associated with Si-F vibrations⁽¹⁾, however, this band in our alloys occurs in the absence of F. As we have suggested earlier, it may be related to a Si-Si defect. The ratio of the 845 cm^{-1} to 890 cm^{-1} modes in a-Si(H) alloys is about 0.5 and occurs when there is a vibrational mode at $\sim 2090 \text{ cm}^{-1}$. With Si-C alloys, we have observed this ratio to be about unity. In the ternary composition the 845/890 ratio also decreases with decreasing C_2H_4 concentration in the gas feed. The reasons for this behavior are not understood. Typical IR spectra of these alloys are shown in Fig. 9.

D. Films containing Sn

As was reported previously, efforts to introduce tin via evaporation of the metal were unsuccessful. Instead we have used the liquids $\text{Sn}(\text{C}_2\text{H}_5)_4$ and $\text{Sn}(\text{CH}_3)_4$ and the solid SnF_4 as source materials by the modifications described above. Thus, we have obtained ternary compositions of Si-C-Sn(H) and binary compositions of Si-Sn(H,F). Deposition conditions for these alloys have not been optimized, however, the preliminary results are quite intriguing.

The optical data plotted in Figs 10 and 11 show marked differences between films deposited from the organo-tin and tin halide sources. The optical energy gap is about 1.65 eV for the tetramethyl tin source while for the SnF_4 source E_{og} is about 1.9 eV.

However, as can be seen in the figure, the slope of the plot of $(\alpha h\nu)^{1/2}$ vs. $h\nu$ for the organo-tin silicon film is quite different from other a-Si(H) and alloyed films. Additionally, when an organo-tin silicon film doped with 1% PH_3 in SiH_4 was deposited an unusual effect was observed. When first deposited the film was nearly opaque and gave an E_{og} of ~ 1.4 eV (Δ in Fig. 11). Gradually the film changed and became clear and colorless with an attendant change in the optical properties ($\circ$ in Fig. 11). There is no "cut-off" in transmission, at least to wavelengths of $\lambda = 350$ nm, merely a gradual tailing off. Before the "transition" the $(\alpha h\nu)^{1/2}$ vs. $h\nu$ plot showed a more shallow slope than we have usually observed for a-Si and its compounds.

The IR spectra for these films are shown in Fig. 12. In both systems the large absorption at the frequency $\sim 1000 \text{ cm}^{-1}$ suggest substantial oxygen contamination, not unlikely in the present set up. These results are still, of course, preliminary.

E. Doped a-Si(H)

To understand better the contribution of the junction layers in fabricating devices, we have looked at various doping levels, dopants and flow compositions in our system. The data on these films are still being acquired and will be reported later.

IV. COMPOSITIONAL ANALYSIS

Several of our alloy compositions have been analyzed by Photometrics, Inc. (Lexington, MA) using Scanning Auger Microscopy. The results do not

allow quantification of the composition, however, they are useful in gauging the homogeneity of the films and have moderate sensitivity for determining relative contamination levels of O and C as well as Ar. The results of these analyses are given with the resistivity data. The amount of Sn incorporated in the films is quite small. As expected O contamination with the fluoride source is substantial.

V. ELECTRICAL MEASUREMENTS

Incorporation of Na in the amorphous films can have substantial effects. The resistivity of one a-SiNa(H) sample was less than $10 \Omega\text{-cm}$ (see Table I). The resistivity of the Na doped samples decreased roughly as the ampoule temperature increased, presumably due to a higher level of incorporation of Na. Those films showing low resistivities ($< 10^3 \Omega\text{-cm}$ under AM1) vary widely in values of σ_0 , as seen in Table II, running from values corresponding to extended state conduction to hopping conduction; we cannot say, at this point, which mechanism predominates.

Hot probe measurements indicated the Na doped films with the lower resistivities were n-type.

The effect of Na on the resistivities of Group IV ternaries was minimal; the data was limited and may be subject to the variable level of incorporation noted for the a-SiNa(H) films.

Comparing the data points in Table I along with those in the first Annual Report, there appears to be little difference in the resistivity of a-Si(H) samples doped at the 1% and 10% levels of either PH_3 or B_2H_6 , unlike the difference in resistivity between 1% and .1% B_2H_6 . The resistance per square of p-n junctions also appears to be independent of doping level in this 1% to 10% range. This is in general agreement with the work of Spear et al. (2),

where the decrease in resistivity saturated at levels near 1% dopant in the gas phase.

The same conclusions appear to apply to a $\text{a-Si}_x\text{C}_{1-x}(\text{H})$ doped at the 10% levels; the resistivity is generally at the sensitivity limit of the apparatus.

The resistivity of the a-SiCGe(H) ternaries decreased as did E_{og} as the amount of C_2H_4 in the glow decreased from 33% to 10% of the hydride concentration. Measurements of $\log \sigma$ vs. $1/T$ showed that there was not a single activation energy for a given sample, and the values of σ_0 for three samples implied hopping conduction predominated. The values of σ_0 and ΔE shown in Table II are extrapolations of high temperature ($> 200^\circ\text{C}$) behavior.

The data on a-SiSnC(H) alloys imply that the films can be doped with the inclusion of P, but there appears to be little photoconductivity for these films where, judging by pressure changes following introduction of the organo-tin, the $\text{SiH}_4:\text{Sn}(\text{CH}_3)_4$ flow ratio was 10 or 20 to 1.

The limited data on a-SiSn(H,F) films indicate that incorporation of F from SnF_4 source also lowers the photoconductivity of the samples.

VI. DEVICE FABRICATION

Several devices have been fabricated on promising materials using a p-i-n configuration and the device structure described in previous reports. We find a serious shortfall in this area due to large contact resistance effects and interlayer states. The investigation of doping efficiency and the characterization of contacts are addressing these problems.

VII. ADDITIONAL MEASUREMENTS

Professor William Paul's group at Harvard has measured several of our a-Si(H) films (our baseline material) for gap density of states, using

the C(V) technique; for photoluminescent properties and for field effect. Their results which are presented here as a separate summary, do demonstrate that our bulk material has excellent characteristics, however the lack of field effect adds further evidence that our shortfall in solar cell fabrication lies with interface states and contact problems. These are being addressed as part of the continuing effort.

TABLE I

Sample	Reactant Composition (Diluent, H ₂ +Ar)	Resistivity (Ω-cm)		Comment
		Dark	AM1	
<u>a-Si(H)</u>				
Several*	SiH ₄	2.2 x 10 ⁹	1.5 x 10 ⁴	Undoped
B-32-1	SiH ₄	8.1 x 10 ³	2.0 x 10 ³	p-i-n (1% PH ₃ , B ₂ H ₆)
B-33-1	SiH ₄	3.5 x 10 ³	1.2 x 10 ³	p-i-n (1% PH ₃ , B ₂ H ₆)
B-41	SiH ₄	9.6 x 10 ²	8.6 x 10 ²	n ⁺⁺ (10% PH ₃)
B-44-1	SiH ₄	3.6 x 10 ⁶	6.2 x 10 ²	p ⁺⁺ (10% B ₂ H ₆)

* Oxygen is at detection level of SAM, < 1%.

<u>a-Si_xGe_{1-x}(H)</u>				
B-45-1	1SiH ₄ :1GeH ₄	6.1×10^3	2.6×10^3	n-i-p (1% PH ₃ , B ₂ H ₆)

<u>a-Si_xC_{1-x}(H)</u>				
B-2-3	1SiH ₄ :2C ₂ H ₄	-	5×10^{13}	p ⁺⁺ (10% B ₂ H ₆)
B-3-1	1SiH ₄ :2C ₂ H ₄	-	1×10^{14}	n ⁺⁺ (10% PH ₃)
B-3-3	1SiH ₄ :2C ₂ H ₄	-	3.7×10^{11}	n ⁺⁺ (10% PH ₃)

TABLE I (cont.)

Sample	Reactant Composition (Diluent, H ₂ +Ar)	Resistivity (Ω-cm)		Comment
		Dark	AM1	
<u>a-Si(Na,H)</u>				
B-8-3	SiH ₄ + T _{Na} = 360°C	1.7 x 10 ⁴	6.3	n-i-p(Na)-p (1% PH ₃ , B ₂ H ₆)
B-8-5	SiH ₄ + T _{Na} = 360°C	1.1 x 10 ³	2.2 x 10 ²	
B-12-3	SiH ₄ + T _{Na} = 340°C	5.2 x 10 ⁴	5.9 x 10 ²	
B-10-3	SiH ₄ + T _{Na} = 260°C	2.6 x 10 ³	5.3 x 10 ²	
B-11-5	SiH ₄ + T _{Na} = 245°C	6.5 x 10 ⁹	2.4 x 10 ⁴	
B-9-3	SiH ₄ + T _{Na} = 200°C	1.8 x 10 ¹⁰	1.6 x 10 ⁵	
B-19-1	SiH ₄ + T _{Na} = 250°C	9.3 x 10 ⁴	3.6 x 10 ⁴	
<u>a-Si_xC_{1-x}(Na,H)</u>				
B-20-1	1SiH ₄ :2C ₂ H ₄ , T _{Na} = 250°C	-	1 x 10 ¹⁴	
<u>a-Si_xGe_{1-x}(Na,H)</u>				
B-22-1	4SiH ₄ :1GeH ₄ , T _{Na} = 250°C	1.8 x 10 ¹⁰	1.1 x 10 ⁶	High oxygen and carbon contamination
B-23-1*	4SiH ₄ :1GeH ₄ , T _{Na} = 250°C	1.7 x 10 ¹⁰	1.1 x 10 ⁶	
B-23-6	4SiH ₄ :1GeH ₄ , T _{Na} = 250°C	4.9 x 10 ⁹	4.1 x 10 ⁵	
* Comp. (SAM) Si _{.56} Ge _{.14} C _{.13} O _{.17}				
<u>a-Si_xC_yGe_z(Na,H)</u>				
B-28-5*	5SiH ₄ :1C ₂ H ₄ :4GeH ₄ , T _{Na} = 245°C	-	10 ⁹	Low oxygen contamination
* Comp. (SAM) Si _{.53} C _{.03} Ge _{.41} O _{.03}				

TABLE I (cont.)

Sample	Reactant Composition (Diluent, H ₂ +Ar)	Resistivity (Ω-cm)		Comment
		Dark	AM1	
		<u>a-Si_xC_yGe_z (H)</u>		
B-24-1	1SiH ₄ :1C ₂ H ₄ :1GeH ₄	3.2 x 10 ¹⁰	1.0 x 10 ¹⁰	Moderate oxygen contamination.
B-25-5*	2SiH ₄ :1C ₂ H ₄ :1GeH ₄	8.6 x 10 ¹¹	2.9 x 10 ¹⁰	
B-26-6	5SiH ₄ :1C ₂ H ₄ :4GeH ₄	1.0 x 10 ¹⁰	3.0 x 10 ⁹	

* Comp. (SAM) Si_{.53}C_{.20}Ge_{.20}O_{.07}

		<u>a-Si_xSn_yC_z, oxygen level is high</u>		
B-37-1*	SiH ₄ + Sn(CH ₃) ₄	6.9 x 10 ¹⁰	1.7 x 10 ¹⁰	
B-38-1**	SiH ₄ + Sn(CH ₃) ₄	3.2 x 10 ⁸	2.1 x 10 ⁸	1% PH ₃ in SiH ₄
B-38-5	SiH ₄ + Sn(CH ₃) ₄		> 10 ¹⁰	1% PH ₃ in SiH ₄

* Comp. (SAM) Si_{.78}C_{.13}Sn_{.01}O_{.08}

** Comp. (SAM) Si_{.62}C_{.18}Sn_{.02}O_{.18}

		<u>a-Si_xSn_y (H,F)</u>		
B-36-1*	SiH ₄ + SnF ₄ (T=200°C)	1.6 x 10 ⁹	1.0 x 10 ⁶	
B-36-3	SiH ₄ + SnF ₄ (T=200°C)	8.6 x 10 ⁸	1.1 x 10 ⁹	
B-39-1**	SiH ₄ + SnF ₄ (T=420°C)	1.2 x 10 ¹⁰	2.8 x 10 ⁴	

* Comp. (SAM) Si_{.97}Sn_{.02}O_{.01}

** Comp. (SAM) Si_{.96}Sn_{.01}C_{.02}O_{.01}

TABLE II

	<u>$\sigma_0 (\Omega\text{-cm})^{-1} \Delta E (\text{eV})$</u>		
B-8-5	9.5×10^3	.38	a-SiNa
B-10-3	44	.39	a-SiNa
B-24-1	1×10^{-3}	.54	a-SiCGe, non-linear
B-25-9	1.2×10^{-4}	.64	a-SiCGe, non-linear
B-26-9	.4	.75	a-SiCGe, non-linear

TABLE III

SUMMARY OF HARVARD MEASUREMENTS ON
MOBIL TYCO SAMPLES* (Wm. Paul)

DOS, $C(\omega)$	$6 \times 10^{15} - 1.1 \times 10^{16}$
$(\mu\tau)_{\text{holes}}$	$2.9 \times 10^{-8} - 4.1 \times 10^{-8}$
(Spectral resp., Schottkies)	
Field Effect	Nil $\rightarrow$ X10
E^{04}	1.925
I.R. (Si-H, stretch)	Pure 2000 cm^{-1}
C_H (evolution)	15 at %
PL int (#104 H.U.)	0.5 - 0.85
PL width	.25 eV
E peak	1.34 eV
T_o (high T, exp. trap in: $1 \sim e^{T/T_o}$)	21K
T_o (Low intensity)	17K
Non geminate rec. @ 150K	X2
Non geminate rec. @ 77K	X1.8
E_α (exponential α -edge $\propto e^{E/E_\alpha}$)	"Close to smallest" - 44 meV
α (1.2 eV) (cm^{-1})	"Close to smallest" $\rightarrow$ 0.3
$\Delta\sigma$	2×10^6
E_{μ_α} (activation energy drift mobility)	0.12 eV

Low F.E. may relate to interface; contaminants/states. Everything else consistent with clean gap and short, low density band tails.

* Samples (7) from 1977 and 1980 a-Si(H) depositions.

FIGURE CAPTIONS

Figure No.

1. Schematic of glow discharge chamber.
2. Modification for introducing vapor from solid source resistant.
3. Modification for introducing vapor from liquid source reactant.
4. Optical energy gap from the extrapolation of $(\alpha h\nu)^{1/2}$ vs. $h\nu$ and the variation of E_{og} with Na temperature.
5. Effect of Na additions on the IR vibrational structure for a-SiH and a-Si_xGe_{1-x} compositions.
6. Optical energy gap from $(\alpha h\nu)^{1/2}$ vs. $h\nu$ showing the doping effects on a-Si_xC_{1-x}(H). Films were grown at gas compositions of 1SiH₄:2C₂H₄ with H₂ and Ar as diluent gases. PH₃ and B₂H₆ are each premixed at 1% and 10% in SiH₄.
7. IR vibrational spectrum typical of a-Si_xC_{1-x}(H) compositions: In this figure, 1SiH₄:2C₂H₄, no added dopant.
8. Optical energy gap from $(\alpha h\nu)^{1/2}$ vs. $h\nu$ for different SiH₄:C₂H₆:GeH₄ compositions in the gas feed.
9. IR spectra showing difference between Si-Ge- and Si-C-Ge vibrational structure. In latter case distinct modes at 1960 cm⁻¹ and 1020 cm⁻¹ are observed.
10. Optical energy gap data for Si-Sn-C films prepared with tetramethyltin source; for undoped and doped with 1% PH₃ in SiH₄.
11. Optical energy gap data for Si-Sn film prepared with SnF₄ source.
12. IR vibrational spectra for films also described in Figures 10 and 11. Note: Large oxygen contamination; also absorption bands centered at 1020 cm⁻¹ and 430 cm⁻¹.

TYPICAL OPERATING CONDITIONS

TOTAL GAS FLOW: 20 sccm
 TOTAL PRESSURE: 0.5 Torr
 T_s : 270°C
 DILUENT GASES: $H_2 + Ar$ (1:1)
 V_{pp} at 13 MHz: 100 volts

Fig. 1

SYSTEM FOR INTRODUCING VAPOR INTO GLOW DISCHARGE

Fig. 2

SYSTEM FOR INTRODUCING VAPOR INTO GLOW DISCHARGE

Fig. 3

Fig. 4

Fig. 5

A - Undoped

B - 1% B_2H_6 in SiH_4 (.6% B in total flow)

C - 1% PH_3 in SiH_4 (.3% P " " ")

D - Na @ $T_{\text{Na}} = 300^\circ\text{C}$

E - 10% B_2H_6 in SiH_4 (1.6% B in total flow)

F - 10% PH_3 in SiH_4 (0.8% P " " ")

Fig. 6

Fig. 7

a-Si_xC_yGe_z(H)
T_s = 260°C

	SiH ₄	:	C ₂ H ₄	:	GeH ₄
A	5	:	1	:	4
B	1	:	1	:	1
C	2	:	1	:	1

$(d\hbar\nu)^{\frac{1}{2}}, (\text{cm}^{-\frac{1}{2}}, \text{eV}^{\frac{1}{2}})$

Fig. 8

Fig. 9

Fig. 10

Fig. 11

Fig. 12