"Everything You Ever Wanted To Know About Hot Wire Chemical Vapor Deposition, But Were Afraid To Ask"

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Mentor: Professor Stacey Bent; Department of Chemical Engineering, Stanford University
IISME Category: Science Curriculum (Chemistry) Development for High School

DESCRIPTION OF LESSON AND INTENDED STUDENT BODY

The hot-wire chemical vapor deposition unit is written with the intention that it can be taught within one to two weeks using a 90 minute block schedule where students attend their chemistry class everyday. I recommend using this unit as an end of semester project/lesson to evaluate students' knowledge and understanding of chemical nomenclature, the periodic table, chemical bonding, the mole, gas laws, stoichiometry and their relationship to some basic concepts of hot wire chemical vapor deposition.

I believe this unit can be taught to currently enrolled high school chemistry students in the 10^{th} through 12^{th} grades who have completed courses in the physical sciences and biology. In addition, they should have completed algebra and their computer literacy skills should be at a level where they can complete Internet searches and download information from the World Wide Web. They should also be familiar with developing and giving presentations using the PowerPoint software program.

EDUCATIONAL TRANSFER PLAN RUBRIC:

:omes	**onal Standard – Standard VIII:** throughout this lesson I have incorporated the epts, ideas and evaluation strategies discussed in national standard VIII: *omplished science teachers use a variety of instructional strategies to expand students' rstandings of the major ideas of science."* By creating a competitive team ronment while learning about HWCVD, I wanted to accomplish two goals. First, ucate students about this unique chemical methodology, and second have them chemistry that reflects the state standards. By trying this approach, I believe it esents the spirit of the text in the national standard when it states, "*…teachers late difficult content into terms more available to their students. They know the best gies and demonstrations to use in presenting difficult science concepts and are antly expanding their repertoire of these verbal and visual aids."* The objectives for team are listed in the table on page 11. The table lists the questions/activities student team will complete to demonstrate their understanding of the scientific epts and their relevancy to the California State Teaching Standards in Science mistry).
ssment Procedure	method of evaluation of this lesson plan will be measured in three ways. First, team will make a poster or PowerPoint presentation representing their rstanding and knowledge of the questions and activities listed in the table on 11 worth 100 points. Each group will receive a single letter grade for their product using a presentation grade rubric, which the students and the uctor will design together in class. Second, each student will also take a unit test h 100 points and receive an individual grade for that test. The test format esents a combination of questions and activities for multiple methods of uation of students' skills and abilities regarding their knowledge of HWCVD as ined in this paper. I have included an example of a unit test with a key written is format. Third, each team will have a lab practical requiring them to build and e molecular models and draw Lewis dot structures about silane and its derived als. The lab practical will be worth 50 points and will be graded using a rubric gned by students and the instructor. A student's total grade will consist of ng all the points earned from the presentation, the individual test and the lab ical. Other instructors may find alternative weightings work better for their ing style and classroom environment.
ity to Replicate	student handout, test and test answer sheet can be copied and distributed. This ld allow teachers to lead a discussion group, assign questions and activities and check for understanding with little difficulty.
tification of Resources	ew resources needed are copy paper, molecular model building kits, a computer PowerPoint software and Internet access.

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News Flash! World-renowned high school student research team gets go ahead to enter HWCVD competition! Details to follow on 11:00 o'clock news!

INTRODUCTION:

You just found out that your research team has been given the green light by your department chair to enter into an international competition with other highly respected chemical engineering students from around the world. Your team has been doing cutting edge scientific research the past two years in an area known as hot wire chemical vapor deposition (HWCVD) on a compound called silane, SiH_4. And although the individual members of your team have enjoyed professional and personal success along the way, they have never won as a group a major scientific award. You and they, feel now is the time to strike while the iron is hot.

Why is this important?

HWCVD can lead to development of better thin film materials. These thin films can be used in various applications such as inexpensive or high-powered solar cells, thin film transistor arrays used for liquid crystal displays, and gas sensors.[1]

BACKGROUND:

How did you get yourself into this?

One only has to think back a few years ago to understand how you arrived at this point in your high school science career. It was in 7th grade on that hot June day, when your Biology teacher, Mr. Prokaryote, had a substitute cover his class because he was ill with "studentitus." Anyway, you were sitting in back of the class thumbing through your physical science textbook and came across an article about "Making Diamonds at Low Pressures," by a process known as chemical vapor deposition. This intrigued you to read about the research done by Robert H. Wentorf, Jr., in 1955, in which he took peanut butter and other carbon containing compounds and turned them into industrial grade diamonds. He was able to do this with a process involving high temperatures ($\approx 2000°C$) and high pressures ($\approx 10^5$ atm).[2]

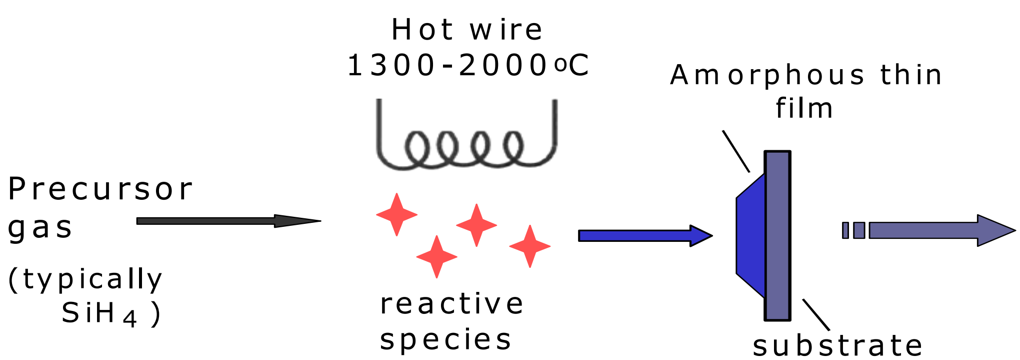
Then, during your freshman year, you and your newly formed team focused on an exciting, but little understood area of HWCVD involving a compound called silane, SiH_4, in its gas phase. This compound was placed inside an evacuated reaction chamber, decomposed, and its radicals (we'll discuss those in more detail below) were studied for their initial role in growing thin film materials. Your research left you begging the question of exactly how does the silane break up into radicals?

The actual decomposition of silane into its constituent radicals occurs by using a hot wire filament inside the chamber, similar to what you find in a household light bulb. The high temperature of the filament breaks silane's chemical bonds into different forms of a reactive species.[3] Once the bonds are broken, the fragments are now called radicals (they have unpaired electrons which make them highly reactive) zipping around in a reaction chamber without any charge.

Biological note, (yes, you did learn something in Mr. Prokaryote's class) the common radical that you may have heard of is oxygen's effect on large molecules in our cell membranes. If oxygen extracts an electron from a large molecule that makes up a cell membrane, it makes the molecule very reactive. These reactive molecules can join and change the properties of the cell membrane, so that the body views it as an outside enemy and its immune system begins to attack it. This process can be harmful to the organism especially when we're talking about nerve cells, which rarely regenerate in an adult. So this oxidation process caused by radicals can lead to aging.[3]

Back to HWCVD, the silane-derived radicals that are produced in the evacuated reaction chamber are H, Si, SiH, SiH_2, and SiH_3. What happens to some of those radicals? Well, some of them will stick to the walls of the chamber, and some of them will stick to the silicon substrate that has been placed inside the chamber and contribute to thin film growth (see diagram 1 below). Unfortunately, very few of them actually land directly on the substrate in the chamber, because they have short lifetimes and very low concentrations. One of the problems your team has been wrestling with is detecting exactly what radicals are impinging on (contacting) the silicon substrate. Is it simply Si? Is it SiH? Is it SiH_2 or SiH_3? Or a varied combination of all of the above?

Diagram 1: *Silane gas is decomposed into its reactive species and deposited onto a silicon substrate.*



Then it dawned on you. You remember reading in your physical science class about a process called infrared spectroscopy or IR for short. This detection technique uses light with wavelengths in the infrared portion of the electromagnetic spectrum to excite compounds. Oddly enough, the bonds between atoms in a compound can be thought of as behaving like a spring, and when this spring is exposed to IR radiation it will expand and contract, or vibrate. The vibrational motion can be detected as vibrational energy.[4] Because each compound has distinct vibrational energies, this powerful technique has the ability to detect and identify specific compounds just like a fingerprint or retinal scan does.

Next, your team set up the IR beam in a position so that it would shine through the bottom of the silicon substrate. You reasoned that if you knew the intensity of light entering the substrate, and the intensity of the light emitted, then you could calculate the energy difference. That difference occurs because discrete energy units of light, called photons, are emitted in smaller numbers than were in the incident beam. What's so fascinating about this is, even though the emitted beam has fewer photons, all of them are at the same energy level.

So, the difference in energy that we detect using IR represents those surface-bound radicals absorbing some of the photons and making the emitted IR beam less intense (see diagram 2 below).

I think a good analogy would be to imagine shining a flashlight through a translucent window. You know that the intensity of the incident light beam is going to be brighter than the intensity of the emitted light beam, because some of the energy (photons) is absorbed into the material.[5] In our case the absorbed light has gone into making the bonds in our sample vibrate. This detection process is an example of how we can confirm the Law of Conservation of Energy; the total energy of the system is constant.

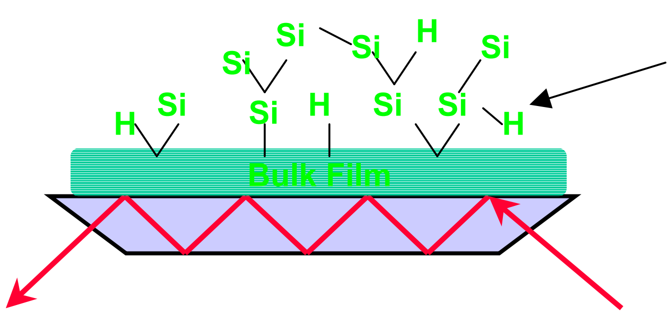


Diagram 2: *Incident IR beam enters from the right at a higher intensity and is emitted at a lower intensity.*

SUMMARY:

So, where does that leave your team?

You know the following: the gaseous phase of silane is introduced into a vacuum chamber, a small amount of the compound is decomposed by a hot wire filament, if they decompose and they have unpaired electrons, we then call them radicals. A few of the radicals deposit themselves onto a silicon substrate and contribute to the growth of an amorphous silicon thin film. The method by which your team can detect the particular species (radicals) that stick to the substrate is by IR spectroscopy.

COMPETITION RULES:

Your team's mission is to perform the following tasks in a timely manner and as complete as possible to be considered a world leader in the area of HWCVD.

1. Your team has to decide on a country of origin, a name and a research design logo (name and logo have to be approved by the instructor). Only one team per country of origin. Any documents handed into the teacher or presentations made must include this team information.

2. Each member of each team will have a specific title, which will be decided by the team members. The instructor has final say on all team combinations. Each team is to have a principle investigator (team leader), a postdoctoral student (this person will keep all the relevant papers in order) and two graduate students. The graduate students will coordinate the research to answer all questions and activities with equal contributions from the other two members.

3. Each team is to answer all questions and perform all activities listed on the following page to the best of their ability. Then, each team will prepare a poster or PowerPoint presentation which will be presented to the class on a date set by the teacher which is worth 100 points. The first team to present to the teacher that they have answered all the questions correctly and have a complete working presentation ready to go will earn 20 extra credit points.

4. Evaluation of the presentation will follow the HWCVD Presentation Grade Rubric developed by the students and the instructor. Each group will receive one letter grade by the teacher and that grade will be the same for each member within that group. If a team presents a late report, 50% of their total points will be deducted as a late penalty.

5. In addition to the presentation, each individual will take a HWCVD written test, which will be worth 100 points. This score will not be added into the team competition.

6. Each member from each team will demonstrate their knowledge of building molecular models and drawing Lewis dot structures for the lab practical portion of the test. The points earned from the lab practical portion will be included in the team competition.

7. The team with the most total points accrued from the presentation and the lab practical will win the competition. In the event of a tie, the teacher will assign those teams a tie breaking question set.

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QUESTIONS & ACTIVITIES FOR STUDENT TEAMS:

1. Build molecular models of SiH, SiH_2, SiH_3, and SiH_4.	No current state standard
2. Determine whether the bonds of SiH, SiH_2, SiH_3, and SiH_4 are ionic, covalent or metallic in nature.	Chemical Bonds: 2.a,b.
3. Draw a diagram of the electromagnetic radiation spectrum. Label it from Gamma rays to Radio waves and write the corresponding wavelengths in meters. Mark on the diagram where the Infrared portion of the spectrum is.	Physics Standard, Waves: 4. e.
4. Write a definition for IR spectroscopy. How can it be used in HWCVD as an effective tool to determine what radicals are deposited on the silicon surface?	Investigation and Experimentation: 1. a.
5. Write a definition for amorphous silicon. How does it differ from an ionic crystal, such as NaCl?	Chemical Bonds: 2. c.
6. Write electron configurations for Si, H, and C.	Atomic and Molecular Structure: 1. g.
7. If the reaction chamber has n moles of SiH_4, K – temp, and L – volume, calculate the pressure in Torr? (R – 0.08206 L • atm/K • mol).	Gases and their Properties: 4. c, h
8. Calculate the molar masses of SiH, and SiH_4. Given x grams of silane, calculate moles, number of particles, or volume of gas at standard temperature and pressure.	Conservation of Matter and Stoichiometry: 3. d.
9. Draw Lewis Dot Structures for SiH, SiH_2, SiH_3, and SiH_4.	Chemical Bonds: 2. e.
10. Locate on the internet the material safety data sheet (MSDS) for silane. Indicate the web address where you found it. Print out the MSDS for silane, and answer the following questions. How toxic is silane? How flammable is it? Is it reactive with air and to what degree? Is it volatile? What is its boiling point? What is its vapor pressure? If we cooled our reaction chamber to –50 ° C, would silane still be a gas?	Investigation and Experimentation: 1. a.
11. Locate and printout, including web address, the following models for silane: a ball and stick model, a space-filling model, and the Lewis dot structure.	Chemical Bonds: 2. e.

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PRESENTATION GRADE RUBRIC: Students and instructor will create grade specific categories for the rubric below at the beginning of the project.

Category	Excellent 90-100%	Good 80-89%	Satisfactory 70-79%	Needs Improvement 60-69%
Preparedness				
Content				
Posture and Eye Contact				
Time-Limit				
Accurate Information				
Speaks Clearly				

LAB PRACTICAL GRADE RUBRIC: Students and instructor will create grade specific categories for the rubric below at the beginning of the project.

Category	Excellent 90-100%	Good 80-89%	Satisfactory 70-79%	Needs Improvement 60-69%
Correct Models & Illustrations				
Accurate Information				
Explains Information Clearly				
Thoroughness in Answering Teacher Posed Questions				

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HWCVD TEST

Name (Print)____

Date:_____________________

Instructions:

1. Print your name and date on the space provided above these instructions. You will place all your answers on a separate answer sheet provided.

2. This unit test consists of VI sections (I through VI) distributed over 4 pages. Check your exam now to insure it is complete. If your test is incomplete please raise your hand immediately and I will speak to you before starting the test.

3. You will have the entire period to complete the test. When you are finished with your test, please bring it and your answer sheet to me. After I confirm that your name is on the test and your answer sheet, you will be allowed to work quietly on your homework or class work. There will be no bathroom privileges allowed unless an emergency arises. No notes, handouts or textbooks are allowed during the test.
Do the best you can without assistance. **This test is worth 100 points**. Good luck.

Section I: True – False. On the answer sheet, **print** T if the statement is true, F if the statement is false. 2 points each.

1. Robert H. Wentorf, Jr., used hot wire chemical vapor deposition to create industrial grade diamonds.

2. All of the silane derived radicals stick (bond) to the silicon substrate.

3. When the reaction chamber is filled with silane during HWCVD, the filament temperature can range between 1300 – 2000 ° C.

4. A radical is simply an ionized atom.

5. IR spectroscopy excites chemical bonds so that the vibrational motion can be detected as vibrational energy, which is unique to each chemical species.

6. The Lewis dot structure for silane has one unpaired electron.

7. The electron configuration for Si is $1s^22s^22p^63s^23p^4$.

8. An ionic crystal such as NaCl has a crystal lattice structure.

9. Infrared light has a longer wavelength and lower frequency than visible light.

10. The electron configuration for Carbon is $1s^22s^22p^5$.

Section II: Definitions. On the answer sheet, write definitions for the following statements. 3 points each.

1. Define the term infrared spectroscopy.

2. Define the term radical.

3. Define the term amorphous silicon.

4. Define the term photon.

5. Define the term electromagnetic spectrum.

Section III: Calculations. On the answer sheet, calculate the answers to the following three problems. Please show all your work with proper units. 4 points each.

1. Using the ideal gas equation, calculate the pressure in atmospheres inside an evacuated reaction chamber if the chamber has 5.0×10^{-5} moles of silane, Temperature of 25 °C, volume is 5.0 liters. (R = 0.08205746L-atm/mol-K) Write the formula and show how you algebraically manipulate it to find the unknown.

2. Convert the pressure you found in problem #1 into Torr.

3. Using the energy equation E=hv, calculate the energy in joules of a photon in the infrared portion of the spectrum if it has v (frequency) = 1×10^{13} s^{-1}. (h = $6.62606876 \times 10^{-34}$ J-s)

4. Calculate the molar masses for SiH and SiH_4. Write the masses to the hundredth of a gram.

5. Calculate how many molecules are in 3.00×10^{-2} kg of SiH_2.

Section IV: Sentence completion. On the answer sheet, print the word, or words that best completes the following sentences. 3 points each.

1. ______________ have at least one unpaired electron which make them highly reactive.

2. To detect silane derived radicals on the silicon substrate we can use a process

   called __________ _______________________.

3. The molecular model of silane has ____________ single bonds.

4. The Lewis dot structure of SiH_3 has ______________has unpaired electrons.

5. The electron configuration of $1s^22s^22p^2$ represents the element ____________.

Section V: Multiple Choice. On the answer sheet, circle the letter corresponds to the best answer. Only one answer is correct. 2 points each.

1. The electromagnetic spectrum represents
   A. electromagnetic radiation.
   B. nuclear radiation.
   C. chemical vapor deposition.
   D. vibrational energy.
   E. none of the above.

2. Hot wire chemical vapor deposition is a technique used to
   A. grow industrial grade diamonds.
   B. observe ions in a reaction chamber.
   C. grow amorphous silicon thin films.
   D. mass silane derived radicals.
   E. both and A and C.

3. The name of the document where a scientist can find safety information regarding a particular chemical is called
   A. The Journal of Chemical Engineering.
   B. The Merck Index.
   C. The Chemistry Handbook.
   D. The Material Safety Data Sheet.
   E. The Physics Handbook.

4. When Silane gas decomposes it can contribute to
   A. the precursor gas.
   B. a time of flight laser.
   C. the hot wire filament.
   D. the super conducting super collider.
   E. none of the above.

5. HWCVD can lead to the development of
   A. infrared spectroscopy.
   B. precursor gases.
   C. high powered solar cells, thin film transistor arrays and gas sensors.
   D. studentitus.
   E. single photon ionization (spi).

Section VI**: Matching.** On the answer sheet, indicate the word, or words from column A that match with the word, words or the equations from column B. **<u>Print</u>** the letter from column B that best matches the word in column A and place it next to its number. Each of the two questions below has at least one match, but no more than two. 2 points each.

1.

Column A	Column B
i. _____infrared spectroscopy	A. SiH_4.
ii._____silane derived radical	B. SiH.
iii.____ precursor gas	C. a unit of light energy.
iv.____ photon	D. a detection technique.
v._____ substrate deposition	E. an amorphous thin film.

2.

Column A	Column B
i. ____ hot wire filament	A. is used to decompose silane.
ii.____ oxidation by radicals	B. can behave like springs and vibrate.
iii.____ silicon substrate	C. the Material Safety Data Sheet.
iv.____ bonds between atoms in a compound	D. a deposition site for silane derived radicals.
v. _____ MSDS	E. can lead to aging.

HWCVD TEST ANSWER SHEET

Name (Print)____

Date: ________________________

Section I: True-False. **Print** T if the statement is true, F if the statement is false.

1. ____ 6. ____

2. ____ 7. ____

3. ____ 8. ____

4. ____ 9. ____

5. ____ 10. ____

Section II: Definitions.

1.

2.

3.

4.

5.

Section III: Calculations. Please show all your work and include correct units for full credit.

1.

2.

3.

4.

5.

Section IV: Sentence completion. Write the word or words that best completes the sentence.

1. ____________________

2. _____________ ___________________________

3. _____________________

4. _____________________

5. _____________________

Section V: Multiple Choice. Circle the letter that corresponds to the best answer.

1. A.	2. A.	3. A.	4. A.	5. A.
B.	B.	B.	B.	B.
C.	C.	C.	C.	C.
D.	D.	D.	D.	D.
E.	E.	E.	E.	E.

Section VI: Matching. Indicate the word, or words from column B that best match those in column A from the test by **printing** the letter in the space next to each number.

1.

Column A

i. _____infrared spectroscopy
ii._____silane derived radical
iii.____ precursor gas
iv.____ photon
v._____ substrate deposition

2.

Column A

i. ____ hot wire filament
ii.____ oxidation by radicals
iii.____ silicon substrate
iv.____ bonds between atoms in a compound
v. _____ MSDS

HWCVD TEST - ANSWER KEY

Section I: True – False. On the answer sheet, **print** T if the statement is true, F if the statement is false. 2 points each.

1. Robert H. Wentorf, Jr., used hot wire chemical vapor deposition to create industrial grade diamonds. False

2. All of the silane derived radicals when decomposed inside the chamber stick (bond) to the silicon substrate. False

3. When the reaction chamber is filled with silane during HWCVD, the filament temperature can range between 1300 – 2000 ° C. True

4. A radical is simply an ionized atom. False

5. IR spectroscopy excites chemical bonds so that the vibrational motion can be detected as vibrational energy, which is unique to each chemical species. True

6. The Lewis dot structure for silane has one unpaired electron. False

7. The electron configuration for Si is $1s^2 2s^2 2p^6 3s^2 3p^4$. False

8. An ionic crystal such as NaCl has a crystal lattice structure. True

9. Infrared light has a longer wavelength and lower frequency than visible light. True

10. The electron configuration for Carbon is $1s^2 2s^2 2p^5$. False

Section II: Definitions. On the answer sheet, write definitions for the following statements. 3 points each.

1. Define the term infrared spectroscopy.
   Infrared spectroscopy is a technique used to study the interaction (absorption or emission) of the infrared portion of the electromagnetic spectrum with chemical bonds.

2. Define the term radical.
   A particle that has one or more unpaired electrons making it chemically reactive.

3. Define the term amorphous silicon.
   Amorphous silicon is a noncrystalline solid whose molecules are randomly arranged and have no ordered long range structure. It softens over a wide temperature range rather than having a sharp melting point.

4. Define the term photon.
   Electromagnetic radiation is quantized into "particles" called photons whose energy is given by the formula E = hv.

5. Define the term electromagnetic radiation.
   Radiant energy that exhibits wavelike or particle like behavior and travels through space at the speed of light in a vacuum.

Section III: Calculations. On the answer sheet, calculate the answers to the following three problems. Please show all your work with proper units.

1. Using the ideal gas equation, calculate the pressure in atmospheres inside an evacuated reaction chamber if the chamber has 5.0×10^{-5} moles of silane, Temperature of 25 °C, volume is 5.0 liters. (R = 0.08205746L-atm/mol-K) Write the formula and show how you algebraically manipulate it to find the unknown.

   P = ? , n = 5.0×10^{-5} moles, T = 25°C, V = 5.0 Liters, R = 0.08205746L-atm/mol-K

   $PV = nRT \longrightarrow P = nRT/V$

   $$P = \frac{(5.0 \times 10^{-5} \text{ moles})(0.08205746 \text{L-atm/mol-K})(298\text{K})}{5.0 \text{ Liters}} = 2.4 \times 10^{-4} \text{ atm.}$$

2. Convert the pressure you found in problem #1 into Torr.

   $$2.4 \times 10^{-4} \text{ atm } \frac{(760 \text{ torr})}{(1 \text{ atm})} = 1.9 \times 10^{-1} \text{ torr.}$$

3. Using the energy equation E=hv, calculate the energy in joules of a photon in the infrared portion of the spectrum if it has v (frequency) = $1 \times 10^{13}\ s^{-1}$. (h = $6.62606876 \times 10^{-34}$ J-s)

   E = ?, h = $6.62606876 \times 10^{-34}$ J-s, v = $1 \times 10^{13}\ s^{-1}$

   E = ($6.62606876 \times 10^{-34}$ J-s)($1 \times 10^{13}\ s^{-1}$) = 7×10^{-21} Joules

4. Calculate the molar masses for SiH and SiH_4. Write the masses to the hundredth of a gram.

   SiH:

1 mole Silicon	28.09 grams
1 mole Hydrogen	1.008 grams
1 mole SiH =	29.10 grams

   SiH_4:

1 mole Silicon	28.09 grams
4 moles Hydrogen	4.032 grams
1 mole SiH_4 =	32.12 grams

5. Calculate how many molecules are in 3.00×10^{5} kg of SiH_2.

   3.00×10^{-2} kg of SiH_2 $\left(\frac{1000 \text{ grams}}{1.0 \text{ kg}}\right)\left(\frac{1 \text{ mole } SiH_2}{30.11 \text{grams}}\right)\left(\frac{6.02 \times 10^{23}\ SiH_2 \text{ molecules}}{1 \text{ mole } SiH_2}\right)$

   = 6.00×10^{23} SiH_2 molecules

Section IV: Sentence completion. On the answer sheet, print the word, or words that best completes the following sentences. 2 points each.

1. Radicals have at least one unpaired electron which make them highly reactive.

2. To detect silane derived radicals on the silicon substrate we can use a process called infrared spectroscopy.

3. The molecular model of silane has four single bonds.

4. The Lewis dot structure of SiH_3 has one unpaired electron.

5. The electron configuration of $1s^2 2s^2 2p^2$ represents the element Carbon.

Section V: Multiple Choice. On the answer sheet, circle the letter corresponds to the best answer. Only one answer is correct. 2 points each.

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   D. vibrational energy.
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   B. ions in a reaction chamber.
   C. grow amorphous silicon thin films.
   D. mass of silane derived radicals.
   E. both and A and C.

3. The name of the document where a scientist can find safety information regarding a particular chemical is called?
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   C. The Chemistry Handbook.
   D. The Material Safety Data Sheet.
   E. The Physics Handbook.

4. When Silane gas decomposes it can contribute to
   A. the precursor gas.
   B. a time of flight laser.
   C. the hot wire filament.
   D. the super conducting super collider.
   E. none of the above.

5. HWCVD can lead to the development of
   A. infrared spectroscopy.
   B. precursor gases.
   C. high powered solar cells, thin film transistor arrays and gas sensors.
   D. studentitus.
   E. single photon ionization (spi)

Section VI: **Matching.** On the answer sheet, indicate the word, or words from column A that match with the word, words or the equations from column B. **Print** the letter from column B that best matches the word in column A and place it next to its number. Each of the two questions below has at least one match, but no more than two. 2 points each.

1.

Column A	Column B
i. **D** **infrared spectroscopy**	A. SiH_4.
ii. **B** **silane derived radical**	B. SiH.
iii. **A** **precursor gas**	C. a unit of light energy.
iv. **C** **photon**	D. a detection technique.
v **E** **substrate deposition**	E. an amorphous thin film.

2.

Column A	Column B
i. **A** **hot wire filament**	A. is used to decompose silane.
ii. **E** **oxidation by radicals**	B. can behave like springs and vibrate.
iii. **D** **silicon substrate**	C. the Material Safety Data Sheet.
iv. **B** **bonds between atoms in a compound**	D. a deposition site for silane derived radicals.
v. **C** **MSDS**	E. can lead to aging.

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