Thin Films

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Subject: Chemistry, Mathematics, Physics

Grade Level: High School

Standards: Standards are taken from NYS Physical Setting: Chemistry Core Curriculum (http://www.p12.nysed.gov/ciai/mst/pub/chemist.pdf)

- Standard 1: Analysis, Inquiry, and Design
- Standard 4: The Physical Setting: Key Ideas 3.2 and 3.3
- Standard 6: Interconnectedness: Common Themes
- Standard 7: Interdisciplinary Problem Solving

Schedule: Two 80 minute blocks

Description:

- In this activity students will use their knowledge of chemistry and geometry to determine the thickness of a model thin film deposited on a wafer. As an extension, they will determine the mass change that would be observed if their thin film were to be completely oxidized.
- Students will then be introduced to methods that are used to produce thin films and analyze film thickness in research and industrial settings.

Objectives:

- Students will apply their knowledge of algebra to a scientific problem.
- Students will create a procedure and data tables in order to solve an experimental problem.
- Students will appropriately use tools of measurement including; physical measurement tools, units, and significant figures.
- Students will learn about thin film production, analysis, and applications.
- Students will apply their knowledge of stoichiometry to solve theoretical problems.

Vocabulary:

- Thin Film
- Stoichiometry
- Oxidation
- Density
- Physical Vapor Deposition
- Chemical Vapor Deposition
- Atomic Force Microscope
- Stylus Profilometer

Materials:

- CD (wafer)
- Foam block (bulk material) and sheet (thin film)
- Ruler
- Electronic balance
- Calculator

Safety:

- There are no chemical safety or disposal concerns in this activity.

Science Content for the Teacher:

Part 1 Thin Film Introduction:
Thin films are layers of atoms that are typically less than a micron in thickness. Thin films can be multi or monolayer. Their composition, structural arrangement, and thickness can vary based on the application for which they are used. Thin films are used in an extremely wide range of applications. A few examples are listed below:

-Optics: Thin films are often used in optical applications, one of which is mirrors. Two way mirrors in particular make use of metallic thin films that are less then one nanometer in thickness to produce their desired effect.

-Magnetic: Thin films have been exploited in order to increase the storage in hard drives.

-Energy: Thin film solar cells are used in the solar powered calculators you may have in your classroom and may one day replace traditional solar panels since they are lighter, more flexible, and lower in cost. Much research is being done to increase their efficiency.

-Electrical: Thin films are used in the production of computer chips.

-Mechanical: Thin films are used as coatings in various applications to improve durability.

Part 2 Creation of Procedure:
Below is an example of what a student should be producing before they may complete the exercise.

Formula used to determine height: $D= m/\prod r^2 h$

D= To be determined using bulk material (foam block). Density can be determined using d=m/V, where mass can be measured using the electronic balance and volume can be calculated by measuring the length, width, and height of the block (V=lwh)

Table 1. Density of material

Mass (g)	
Length (cm)	
Width (cm)	
Height (cm)	
Volume (cm^3)	
Density (g/cm^3)	

m= To be determined using the electronic balance. The mass of the wafer (CD) must first be measured, then the mass of the wafer with the film can be recorded. The difference between these two is the mass of the thin film.

Table 2. Mass of thin film

Mass of wafer (g)	
Mass of wafer + film (g)	
Mass of film (g)	

r= To be measured with a ruler. The diameter of the thin film can be measured with a ruler and then divided by two.

Table 3. Radius of thin film

Diameter of film (cm)	
Radius of film (cm)	

Note: Be sure that students have noted that they can use V=lwh to determine the volume of their bulk material (the foam block) to determine density. They may have a tendency to want to use the thin film (foam sheet) to determine density, but remind them that in a real life setting they would need this density before the thin film had been created. Another area where students are apt to try to take a shortcut is in the determination of the mass of the thin film. They may want to simply mass the film (foam sheet) alone. Remind them that in real life this would be attached to the wafer (CD), from which it could not be removed. They will thus need to mass the wafer alone, and then with the film in order to determine the mass of the thin film.

Part 3 Collection and Analysis of Data:
Sample Data and calculations are shown below.

Table 1. Density of material

Mass (g)	0.31
Length (cm)	3.85
Width (cm)	0.20
Height (cm)	4.00
Volume (cm^3)	3.1
Density (g/cm^3)	0.10

Table 2. Mass of thin film

Mass of wafer (g)	16.26
Mass of wafer + film (g)	19.31
Mass of film (g)	3.05

Table 3. Radius of thin film

Diameter of film (cm)	12.80
Radius of film (cm)	6.40

$D = m/\prod r^2 h$
$0.10\ g/cm^3 = (3.05g)/(\prod * (6.40cm)^2 * h)$
h= 0.24 cm

Measured thickness of film: 0.20 cm

% error of film thickness= $\frac{[\text{measured value-accepted value}]}{\text{accepted value}}$ x100

% error of film thickness= $\frac{[0.24\ cm-0.20\ cm]}{0.20\ cm}$ x100

% error of film thickness= 20 %

Part 4 Stoichiometry:
The calculations for the mass change of the film were it to be completely oxidized into copper (I) oxide and copper (II) oxide are shown below.

Copper (I) Oxide
mol Cu = mass Cu/gram formula mass Cu
mol Cu = 3.05 g/63.55g
mol Cu = 0.0480 mol

$\frac{2\ mol\ Cu}{0.0480\ mol\ Cu} = \frac{1\ mol\ O}{x\ mol\ O}$
x= 0.0240 mol O

mol O = mass O/gram formula mass O
0.0240 mol = x g/16.00g
x= 0.384 g O (Mass Change)

Copper (II) Oxide
mol Cu = mass Cu/gram formula mass Cu
mol Cu = 3.05 g/63.55g
mol Cu = 0.0480 mol

$\frac{1\ mol\ Cu}{0.0480\ mol\ Cu} = \frac{1\ mol\ O}{x\ mol\ O}$
x= 0.0480 mol O

mol O = mass O/gram formula mass O
0.0480 mol = x g/16.00g
x= 0.768 g O (Mass Change)

Part 5 Methods of Thin Film Production and Analysis:
The production of thin films is called thin film deposition. This can be done in a variety of ways. Both chemical and physical vapor deposition techniques can be used to produce thin films. Within these two types of deposition, several methodologies can be used. Chemical deposition can be achieved by plating or solution deposition amongst other methods. Physical deposition can be achieved by evaporation or sputtering techniques to name a few.

These films can be analyzed with a variety of tools including, atomic force microscopes and stylus profilometers. Though this is certainly not an exhaustive list of tools that can be used to analyze thin films, these are a few of the instruments you can discuss with your students. You can choose which methodologies best suit your class.
Atomic Force Microscope: Uses laser beam deflection off of a cantilever which holds a sharp probe that scans the surface of the film. This instrument gives 3-D surface analysis that can provide information about film thickness, grain size, and roughness.
Stylus Profilometer: Uses stylus displacement to provide 1-D analysis on data such as film thickness.

Classroom Procedure:

Teacher Preparation:
Instructors must gather materials and cut the foam sheets to cover the CDs before students begin the experiment. Instructors should provide to each group a CD, foam block, ruler, foam sheet, and calculator. Balances can be shared between groups.

Student Experience:
Part 1 Thin Film Introduction: Students should first be introduced to the idea of thin films. Background material can be provided to students in the method preferred by the teacher (examples: independent reading, lecture, independent research). Students should have an understanding of what thin films are and some of the applications for which they can be used.

Part 2 Creation of Procedure: Students, working in groups of two, should then be provided with the following formulas: density ($d=m/V$), volume of a cylinder ($V=\prod r^2h$). Students should also be provided with a list of the materials they will be given to complete the lab. The students will need to connect the mathematical formulas they have been given so that they can solve for the film thickness (h). When they feel they have a solution, they should write a short description of how each variable needed to determine film thickness will be measured and create a data table for the measurements required. This should then be brought to their teacher.

Part 3 Collection and Analysis of Data: When the teacher is satisfied with the students' understanding of the measurements needed to move forward the teacher should then provide each group with the lab materials. Students will then obtain the necessary data in accordance with their procedure. Students will then use the mathematical setup they have determined to calculate the film thickness. Units and significant figures should be taken into account. Students should then measure the thickness of their thin film. This measurement should be used as the accepted value so that students can determine a percent error.

Part 4 Stoichiometry: As an extension students and teachers can discuss the tendency for metallic films to oxidize. Students should be asked to assume that their film is made of copper. They will then be asked to use stoichiometry to determine the mass change that would be expected if their copper film were to oxidize completely to produce copper (I) oxide. They should then determine what the mass change would be if the copper were to oxidize completely to produce copper (II) oxide.

Part 5 Methods of Thin Film Production and Analysis: As a conclusion to this activity students will learn about the production and analysis of thin films in the real world. Teachers should point out to their students the difference in scale between the thin films modeled in the activity and those created for real world applications. This can lead into a discussion of how these films could be produced and analyzed on the scales on which they are created in research and industrial settings. The way that this information is presented may be at the teacher's discretion (ex. lecture, student research and/or presentation, field trip to local industrial or educational institution).

Assessment:

Students will be asked to write an individual lab report which includes the following sections:

1. Introduction: Includes a statement of the purpose of the experiment and a one to two sentence summary of how this was achieved.
2. Theory: Includes background information pertinent to the experiment performed.
3. Methodology: Includes a procedural summary of the experiment.
4. Results: Includes experimental findings.
5. Discussion: Includes analysis of results, particularly for conclusions that may be reached and sources of error.
6. Data: Includes data tables from the experiment.
7. Calculations: Includes sample calculations performed in the experiment.

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