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2.830J / 6.780J / ESD.63J Control of Manufacturing Processes (SMA 6303)
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2.830J/6.780J Control of Manufacturing Processes

Spring 2008

Assignment 1

Out 2/7/2008; due 2/14/2008

The goal of this assignment is to exercise the new perspective on manufacturing processes that you will gain from lectures 1–3. In problems 1 and 2 you will practice creating functional process models for processes that you may already be familiar with; in problem 3 you will explore sensitivity and variation in a particular semiconductor fabrication process.

Problem 1

From the list of product components given below, please select *one* and do the following. (If you wish, you may substitute a product–process combination with which you are more familiar than with those on the list, but it should contain at least two discrete processing steps.)

- a) Determine the key quality characteristics that you would worry about if you were the customer for the part. In other words, what are the key measures of output geometry (*e.g.* diameter) and of output constitutive properties (*e.g.* hardness) for the part? (While aesthetic considerations might well be of concern to the customer, we are concerned here purely with measurable, functional outputs.)
- b) Based on the processes listed for your chosen component, describe how the component is made and what the principal determinants of the part's geometry and its final constitutive properties will be.
- c) For each process used to make your component, identify the key process parameters:
 - Equipment state
 - Equipment properties
 - Material states
 - Material propertiesFor equipment and material *states*, list the appropriate power and energy variables.
- d) What variable(s) are typically used to control the processes?
- e) What variables can be expected to cause variation in the output and why?
- f) How would *you* “control” the processes to achieve the desired geometry/final physical properties and to minimize the chance that parts are unacceptable?
- g) Draw a block diagram of the equipment and material, showing the inputs, parameters, energy transfer and output(s).

Please check your answers for consistency with the process model presented in class.

Component	Processes		
Hard drive disk	Precision turning	Metal oxide coating	
Hard drive head control arm	Die casting	Machining	
Cell phone base	Injection molding	Screen printing	
CD-R blank	Injection molding	Joining (to sandwich the metal foil)	
Fuselage skin panel	Sheet forming	Edge trimming	Rivet hole drilling
Fuselage ribs	Roll forming	Edge trimming	
Cell phone key pad inserts	Thermoforming	Screen printing	
Ship hull plates	Flame cutting	Roll bending	
Circuit boards	Masking and etching	Hole drilling	
Automobile roof	Blanking to shape	Forming to contour	Edge or hem binding
Disk brake rotors	Sand casting	Machining	
IC contact “trees”	Cutting (blanking)	Forming of “legs” or pins	
Keyboard keys	Injection molding of key	Injection molding of letter insert	
Cantilever-beam MEMS accelerometer	Photolithography	Wet chemical etching	
Engine piston	Turning	Boring (for wrist pin)	
Fuel injector housing	Die casting	Machining	
Fuel injection throttle body	Die casting or injection molding	Machining (or not)	

Problem 2

For the processes you have chosen, discuss:

- a) The dominant energy interaction between equipment and material;
- b) The area or volume of that interaction relative to the total area or volume of the part.
- c) Using the process taxonomy chart in the handout “Processes and Process Control”, parse each process according to transformation mode, serial/parallel, and energy domain.

Note

- Please collaborate with your classmates to help select a product–process combination, but then work on the problem individually. If you are still unsure about the product or process, then state a set of assumptions, and proceed.
- You may use any source necessary for information about these products and processes, including basic manufacturing texts, such as those listed below, and more specific sources found in the library.

Kalpakjian, *Manufacturing Processes for Engineering Materials*, Addison Wesley

Doyle, Keyser, Leach, Schrader and Singer, *Manufacturing Processes and Materials for Engineering*, Prentice Hall

Schey, *Introduction to Manufacturing Processes*, McGraw Hill

<http://www.howstuffworks.com/>

Problem 3

Potassium hydroxide (KOH) in aqueous solution is a typical etchant for silicon. In this question we will consider the sensitivity of the etched depth to variations of etch time, KOH concentration and temperature.

a) Determine the sensitivity of etched depth to

- i. etch time;
- ii. KOH concentration;
- iii. solution temperature

for the following two sets of nominal parameters:

1. etch time = 5 minutes; KOH concentration = 40 wt%; solution temperature = 72 °C;
2. etch time = 1 hour; KOH concentration = 20 wt%; solution temperature = 40 °C.

To answer this question you can use the information in Figure 1, which is taken from Seidel *et al.*, *J. Electrochemical Society*, vol. 137, no. 11, pp. 3612–3626, 1990. You may also assume that the etch rate, R , follows the Arrhenius relation: $R = R_0 \exp(-E_a/kT)$ with an activation energy E_a of 0.6 eV, independent of temperature and KOH concentration. R_0 may be derived from Figure 1, and may be assumed to be a function of KOH concentration but independent of temperature. T is the temperature in Kelvin, k is Boltzmann's constant (1.38×10^{-23} J/K), and there are 1.60×10^{-19} J in 1 eV.

b) Provide reasoned estimates of how well it is possible to control:

- i. etch time (hint: the silicon wafer to be etched is usually immersed in a bath of the KOH solution during etching);
- ii. KOH concentration (hint: the KOH solution is prepared either by diluting concentrated solution or by dissolving KOH pellets in water);
- iii. solution temperature (hint: the KOH solution is usually contained in a temperature-controlled water bath).

c) Using your answers to (a) and (b), deduce which of the three machine states (temperature, time, concentration) contributes the largest portion of the variability of the etched depth in each of the two cases evaluated.

d) If you needed to etch to a depth of 100 μm , what is the smallest depth variability that could be achieved using a timed KOH etch? (Hint: focus on the sensitivity of etched depth to temperature. Express the sensitivity of etched depth to temperature in terms of the target depth, temperature and physical constants. Then decide what temperature to use and compute the likely resulting variability. Think about physical constraints on your selection of parameters. Finally, check the depth variability due to time and concentration variations.)

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**Figure 1. Etch rate of <100> silicon in KOH solution as a function of KOH concentration, for a temperature of 72 °C.
Source: Seidel *et al.*, *J. Electrochemical Society*, vol. 137, no. 11, pp. 3612–3626, 1990.**