

Solution Homework #4

2.008 Design and Manufacturing II Spring 2004

Problem 1:

The purpose of this problem is to have you understand the effect of heat intensity of various welding heat sources on the interaction time and the feed rate. For a planar heat source on steel, the interaction time, t_m , was given at the lecture as below. H.I. is the heat intensity, in W/cm^2 . You are supposed to weld a straight lap joint with a length of 40 cm.

$$t_m = (5000/\text{H.I.})^2$$

- a) You have manual oxyacetylene welding equipment, which has a weld pool size of 10 mm. How long will it take to finish the job? Assume the H.I. of an oxyacetylene welding source is $10^3 \text{ W}/\text{cm}^2$.
- b) If your boss buys you new SMAW (shielded Metal Arc Welding) equipment, which is 3 times more expensive than the oxyacetylene equipment, how long will it take to finish the same job? Will it justify the purchase of the SMAW tool? Assume that SMAW has H.I. of $10^4 \text{ W}/\text{cm}^2$ and the weld pool size is 5 mm.
- c) The upgrade in b) has been very successful, and made a huge increase of the productivity in your division. If your boss considers buying you the state-of-the-art laser welding system with a hope to make a big breakthrough one more time, what would be your advice to your boss before he buys one? Assume the laser has the HI of $10^6 \text{ W}/\text{cm}^2$ with a weld pool size of 1 mm. Consider your assessment in the following way:
 - What should be the minimum speed of the welding to avoid over melting (or vaporization)?
 - Can you handle it manually? Or will you need a robot to handle this heat source?

Solution

- a) interaction time: $t_m = (5000/10^3)^2 = 25\text{s}$
feed rate: $f = d/t_m = 1/25 = 0.4 \text{ mm}/\text{s}$
total time: $T = L/f = 400/0.4 = 1000\text{s} = 16.67 \text{ min}$

- b) interaction time: $t_m = (5000/10^4)^2 = 0.25\text{s}$
feed rate: $f = d/t_m = 1/0.25 = 4 \text{ mm}/\text{s}$
total time: $T = L/f = 400/4 = 100\text{s}$

The total time is 10 times less than before. The net increase of the productivity may be less than 5000%, but will more than enough to justify the purchase of the

SMAW equipment. However, the fast welding speed may require the use of a robot to maintain the process quality and uniformity, which would add additional cost of automation.

c) interaction time: $t_m = (5000/10^6)^2 = 25\mu\text{s}$
 feed rate = v_{min} $f = d/t_m = 1/25 \times 10^{-6} = 40 \text{ m/s}$

The minimum speed is 40 m/s which is clearly too high to be achieved either manually or automatically. Thus even the purchase of an industrial robot would not help to do the job successfully. You would better tell your boss to not buy the equipment!

Problem 2

Aligning an optical fiber to the laser light source with less than 1 μm transverse error is a demanding task. V-grooved Silicon substrate has been developed to enable accurate and cost effective interconnection without the use of highly skilled labor and expensive fixtures.

The technology is available through the KOH bulk micromachining of the {100} silicon. The mechanical tolerances delivered can be tight with this method at a relatively low processing cost. Assume that the diameter of an optical fiber is 160 μm and that the fiber is aligned along the B-B' direction of the groove. The cross sectional shape of the groove along A-A' is given in Figure 2-1.

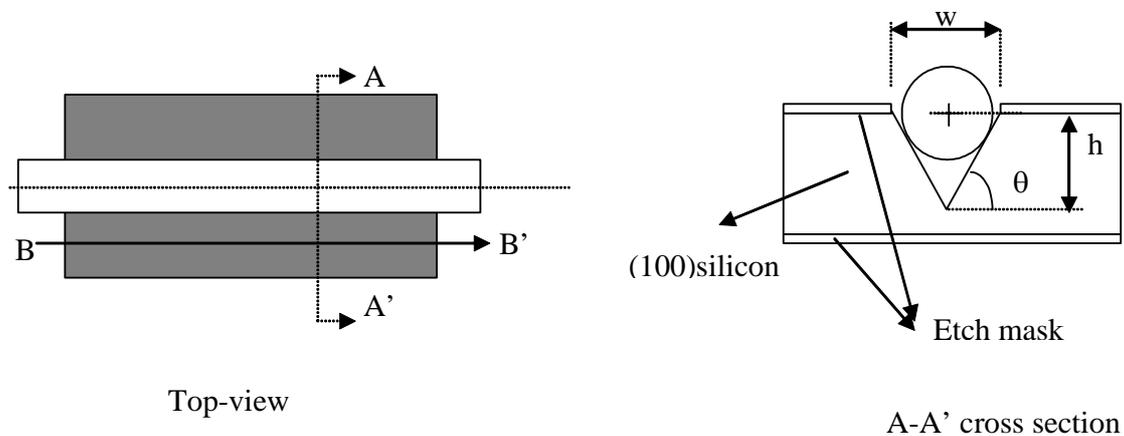


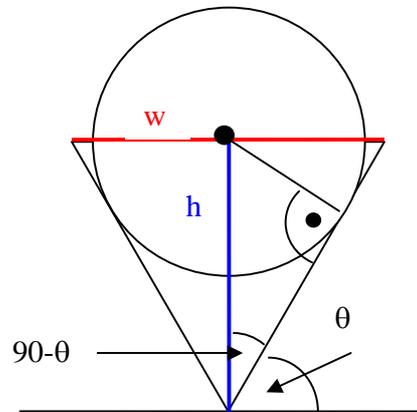
Figure 2-1 A self terminated V-groove is formed on the {100} plane.

- As etching proceeds, the exposed {100} planes etch rapidly while the {111} planes etch slowly, which causes the angle θ with the plane of the wafer. What is the magnitude of the angle θ ?
- The etch mask material is silicon nitride, which is better than silicon oxide in terms of dimensional accuracy of the V-groove. If the center of the fibercore is

- located exactly on the surface plane of the silicon, what is the depth of the V-groove, h , and width of the groove opening, w ?
- c) Assume the KOH solution etches the (100) silicon at $2 \mu\text{m}/\text{min}$ and the thickness of the wafer is $500 \mu\text{m}$. What will be the etching time needed for the V-groove in Figure 2-1?

Solution

- a) According to the lecture notes and corresponding literature $\theta = 54.7^\circ$.
- b)



The figure reveals the following relationships:

$$\sin(90-\theta) = d/2h$$

$$h = d/(2\sin(90-\theta)) = 138.4 \mu\text{m}$$

$$w = 2 \cdot h \cdot \tan(90-\theta) = 196 \mu\text{m}$$

c) $t = h/v = 138.4/2 \text{ min} = 69.2 \text{ min}$

This is a long process time to etch. Therefore this kind of bulk micromaching is not really adequate for mass production. Note that the V-groove etching stops when the two slopes from the top surface opening meet together at an angle of 54.7° , and that the thickness of the wafer should be greater than the depth h of the groove.