Solutions for the end-of-the-chapter exercises in

Chapter 2

2.1 *Which of the following transduction mechanisms can be used to realize a micromachined accelerometer? (a) piezoresitivity, (b) piezoelectricity, (c) Peltier effect, (d) Hall effect, and (e) photoelectric effect. For those transduction techniques useful in making an accelerometer, draw a sketch and explain how such an accelerometer would work.*

Solution

Piezoresistive and piezoelectric effects are widely used in making micromachined accelerometers. Hall effect is used to make proximity (distance-measuring) sensor chips. So, it can also be used to measure acceleration. Peltier and photoelectric effects are suitable for measuring acceleration directly.

2.2 As compared with the size of the other components (e.g. fan, lamp, lens, etc.) in a digital projector, the size of the micromirror array chip is quite small. Argue why it is necessary to make the chip so small. What happens if the size of each mirror is increased?

Solution

If the micro-mirror is large, we need a bigger beam of light to call on it. More scattering occurs when light travels over larger distances involved in a larger mirror. Also, more energy is needed to move larger mirrors. Hence, making them small makes sense. Perhaps slightly larger size might not be too bad either if it results in cheaper fabrication even if the performance is slightly compromised.

2.3 Collect data on electrostatic comb-drives to answer the following questions:
a. Why is a comb arrangement with many interdigitated fingers used?
b. Is the force vs. deflection characteristic of a comb-drive actuator linear?
c. How much force and displacement can be generated with a typical comb-drive?
d. Will a comb-drive work in aqueous environments?

Solution

a. More fingers means more force.
b. Actually, to first order, the force is constant with displacement. If fringing fields are taken into account, some nonlinearity will be evident.
c. A few 10s of μN force (perhaps a mN with difficulty) over a few μm can be generated with an electrostatic comb-drive micro-actuator.
d. No, unless the water is de-ionized and made non-conducting.

2.4 We discussed a conductometric gas sensor in this chapter. What are other methods that are used to detect gases? Which one has been used in microsystems? Which ones could be used and which ones cannot be used? Support your answers with suitable arguments.

Solution

Correlation spectrometry can be used for detecting gases, even remotely. Here, by using reference spectrum cell, one can check what wavelengths are missing from the light coming from a gas. Microsystems technology has been used for generating the reference wavelengths. There is company called Polychromix that makes such devices.

2.5 Find an used inkjet print head. Break it open to see where the chip is and how it is connected to the components that are around it. Do the same for the ink-cartridge. Identify *different components that make the microsystems chip in them useful in practice. Comment on the importance of packaging in microsystems in this example.*

Solution

It is a hands-on exercise to encourage students to be curious about things. Modern ink-cartridges are quite simple: they contain an ink-reservoir and a nozzle at the end. The plastic case is the main component in it. The inkjet printhead is more complicated. One has to open it up to see what is inside.

2.6 Visit a molecular biology laboratory that uses a PCR system and discuss with its users how they use it and what for what purpose. If they are using a system that does not use microsystems components, how would you convince them to switch over to a microsystems-based PCR system?

Solution

Small sample size, perhaps less time for analysis, ease of handling, and lower price are some of the reasons that can be used to "sell" micromachined PCR systems. Novel techniques are now available in which there is no need to cycle the temperature in a PCR. This is much cheaper and much more convenient.

2.7 This chapter included a description of smart materials. A beam made of a ''normal'' material bends when a load is applied to it. A beam made of a ''smart'' piezoelectric material not only bends but produces an electric charge when a load is applied. Both materials behave in their specific ways. Then, why is that we consider some materials to be smart? Does smartness lie in the way we use the material or in their very nature?

Solution

This is a debatable point. Whatever behaviour that are observed more recently (say in 20th century and after) are considered smart even if it is simply the very nature of materials. Another way to look at this is if the observed phenomenon involves one energy domain or more than one. But then expansion due to heating is not considered smart even though it involves more than one energy domain. So, whatever is common and known for a long time is not considered smart.

2.8 Search the literature and identify a few devices that use smart materials. Which of these have been miniaturized using microsystems technology?

Solution

A cigarette lighter or a gas-stove lighter use piezoelectric materials. Microphones and buzzers also use piezoelectric materials. The latter are miniaturized already. Shape memory alloys are used in dental braces (no need to miniaturize) and stents (miniature to the extent needed). Other smart materials are not used as widely in consumer applications.

2.9 Choose a system that you consider ''smart'' and explain why you think it is smart. Is mobile phone a smart system? Is a motorcycle a smart system? How about a washing machine and a home water-purifier?

Solution

Many appliances and transport vehicles today are smart. Cars and motorcycles tell us when they are out of fuel. They have many other sensors and actuators that function automatically in response to changing environmental conditions. A mobile phone is certainly smart: it knows where it is; can take pictures; some can even guide on eating patterns, etc. Washing machine and water purifier are relatively less smart as they do not have that many sensors. So, equipping a thing with sensors decides the 'smartness'.

2.10 Are biological materials smart in the sense we call some materials smart? Explain with examples.

Solution

Most certainly. Living biological materials can do a lot of sensing and can appropriately respond to the external stimuli. They can also heal themselves under certain conditions. They can make their own food too. So, they are undoubtedly smarter than engineered materials.

Solutions to Exercise Problems in Chapter-3

Exercise 3.1: It is required to fabricate a polysilicon cantilever beam whose dimensions are: length × breadth × thickness = 2000 μm × 10 μm × 2 μm. The sacrificial oxide thickness is 1 μm. Discuss the anchor pad size you would choose and explain whether it is possible to realize such a structure by surface micromachining. Give reasons for your answer.

Solution:

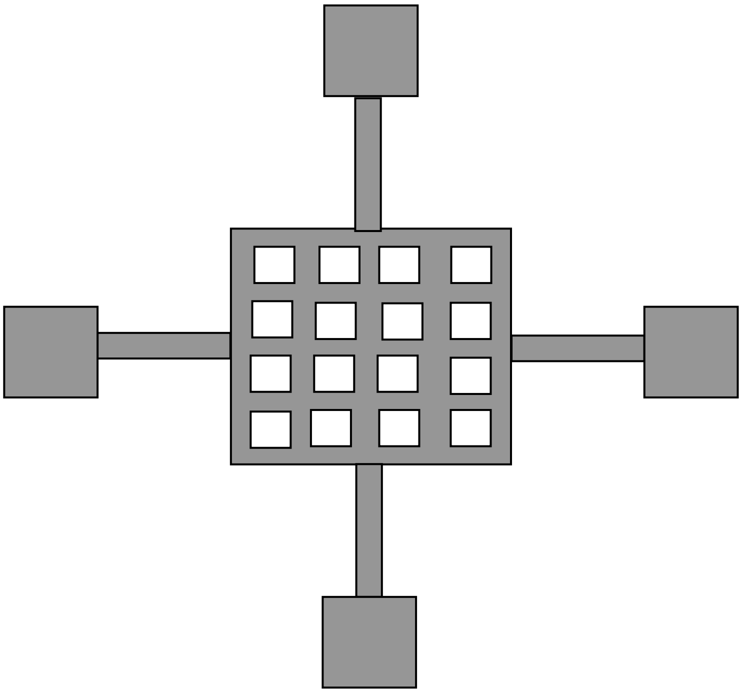
During sacrificial layer etching , the etchant etches from either siude of the breadth of the beam . As the width of the breadth of the beam is 10μm , by the time the beam is released by etching the sacrificial oxide underneath it, the timeing should be such that the lateral oxide is etched 5μm laterally. Therefore the anchor pad should be at least 50μm x 50μm, so that after the beam is released the anchored area is 45μm x 45μm.

As the beam thickness is only 2 μm , the spring constant of the beam is very low with a beam length of 2mm (=2000μm). Therefore it will be difficult to realize this structure by surface micromachining using polycrystalline silicon.

Exercise 3.2: In one of the designs of an accelerometer, the structure of the seismic mass (500 μm x500μm) and the four supporting springs (20μm wide) were first obtained by etching a silicon layer of thickness 10 μm. [FIG3.43] The top view of this structure and the anchor pads are shown in Fig. 3.43. It was required to release the mass and the spring while keeping the oxide below the anchor pads (150μm x150μm) intact. The oxide is only 1μm thick. Suggest any modifications that would be necessary in the structure for its successful release.

Solution:

When the mass (500μm x 500μm) is released by etching the 1μm thick oxide underneath them using the pattern shown in the figure, the pad whose size is only 150μm x 150μm would collapse because all the oxide underneath would be etched fully. The mask pattern should modified and etch hole patterns must be provided on the mass pattern so that by the time the beam is released the mass is also released. This can be achieved with the modified the mask pattern shown below. The hole size and the number of holes in the mass pattern should be chosen such that the gap between the holes should be equal to the breadth (=20μm) of the beam. With this pattern,, the anchor region after releasing the beams and the mass will be 140μm x 140μm when the mass is just released.



Exercise 3.3: A silicon wafer has been etched through square a window opening of size 10 μm × 10 μm in the oxide layer. Draw cross-sectional profiles and mark all dimensions of etched silicon for the following cases: