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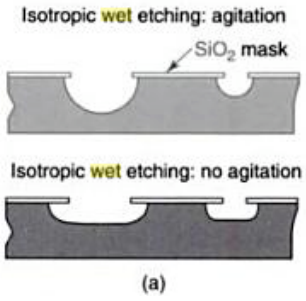
Due date: 10/05/2009
Class: ENEE416 Sec: 0102

Group Activity #3 Report
Bulk and Surface Micromachining

Bulk and surface micromachining are processes used to create microstructures on microelectromechanical MEMS devices. While both wet and dry etching techniques are available to both bulk and surface micromachining, bulk micromachining typically uses wet etching techniques while surface micromachining primarily uses dry etching techniques.

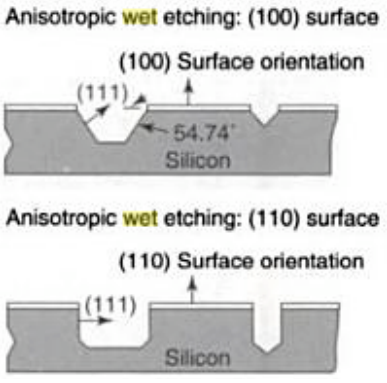
Bulk micromachining selectively etches the silicon substrate to create microstructures on MEMS devices. Wet etching is the predominantly used technique used in bulk micromachining. Typically, a layer of silicon dioxide is patterned onto a silicon wafer using a mask. The silicon dioxide is patterned to protect certain areas of the silicon substrate from etching. Wet etching refers to techniques that use aqueous chemicals to etch away the wafer surface. The etchant used is determined by the desired etch rate, and the level of anisotropy and selectivity required for the task. The most common isotropic wet etchant for silicon is a mixture of hydrofluoric acid, nitric acid, and acetic acid (HNA). However, since HNA also corrodes aluminum, it is not compatible with CMOS processes. Other common etchants used include potassium hydroxide (KOH), ethylenediamine pyrocatechol (EDP), $(CH_3)_4NOH$, also known as TMAH, and hydrazine-water.



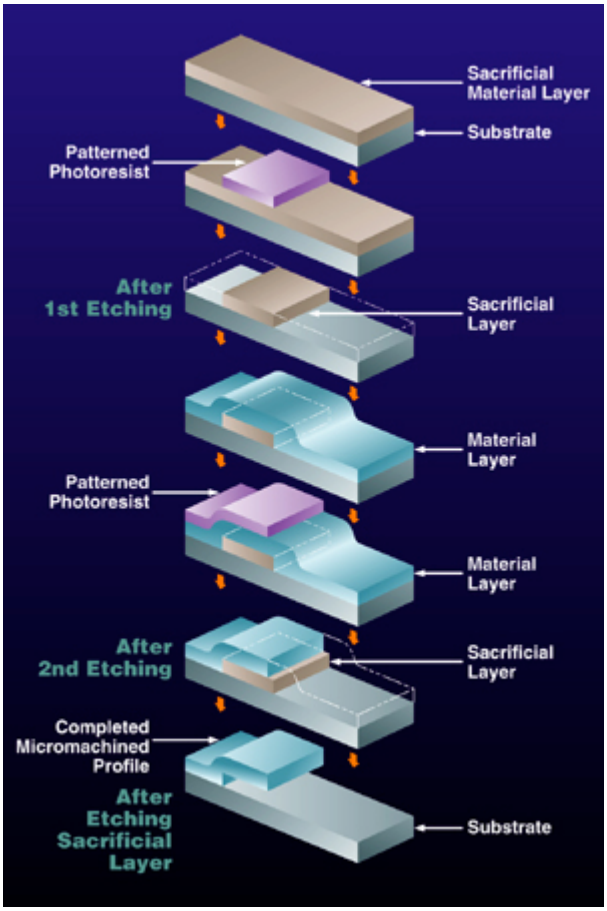
1 Undercut

Most wet etchants are isotropic, meaning that they etch silicon equally in all directions. This causes a well-known phenomenon in the microelectronics industry called undercut. Undercut refers to the silicon that is etched away under the protective layer due to isotropic etching. In order to prevent undercut-related functionality issues, the masks used to deposit the protective layer are designed so that the desired line-width is achieved including undercut. This is done by subtracting twice the etch-depth from the desired line width to get the line width of the mask.

Some wet etchants are valuable in MEMS production processes because they are planar selective. Since silicon has a crystalline structure, some etchants, such as KOH is has a higher selectivity for some planar orientations than others. For KOH,



2 anisotropic planar selectivity



3 surface micromachining process

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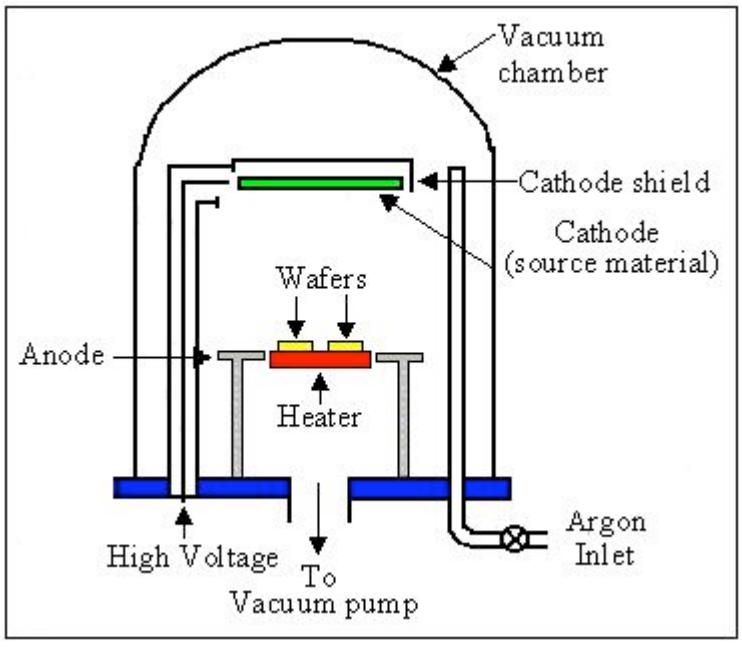
for the Miller Indices <110>:<100>:<111>, planar selectivity can be as high as 600:400:1. However, KOH is not used in micromachining because its potassium ion content bans it from clean room operations. Also, it is highly corrosive and attacks aluminum, which makes it undesirable for CMOS fabrication. XeF_2 is a useful dry etchant for silicon in bulk CMOS fabrication because it is highly selective for photoresist, silicon dioxide, silicon nitride and aluminum. It is also a gas at room temperature in low-pressure environments.

Surface micromachining is also used to create microstructures on MEMS devices. The difference between surface and bulk micromachining is that instead of etching the silicon substrate, surface micromachining etches away layers deposited on top of the silicon substrate. The process starts with a silicon wafer, upon which structural and sacrificial layers are deposited.

Structural layers are the layers that form the desired structures. Sacrificial layers are the layers that are etched away, and are used to support the structural layers until they are etched away. Typically, a sacrificial layer of silicon dioxide layer is formed by a combination of thermal and chemical vapor deposition processes. Phosphosilicate glass (PSG) is also often used as a sacrificial layer because of its high etch rate in hydrofluoric acid. After the polysilicon structural layers are selectively deposited on top of the sacrificial layer, the silicon dioxide is etched away using hydrofluoric acid. This process is useful for creating cantilever beams, bridges and sealed cavities. More complex structures, such as turbines, gear trains and micromotors can be formed by repeating this process, using multiple layers of polysilicon.

Dry surface micromachining techniques usually implement plasma systems to etch wafers. Such techniques include sputtering, also known as ion bombardment. This procedure needs to be performed in a vacuum chamber, in a low pressure environment. Typically, the pressure needs to be brought down to 10^{-6} Torr. An RF excitation system is used to ionize the gas, usually Ar+, which is introduced in controlled amounts to the vacuum chamber. Argon is preferred because it is a noble gas and therefore not very reactive. This is ideal because it is important to minimize unwanted chemical reactions during this process. This aspect also makes obvious the necessity for a vacuum chamber: it is essential to minimize the number of external particles, lest they become unintentionally embedded in the wafer. For example, oxygen in the air would easily oxidize the surface of the wafer if allowed to exist in the chamber. The silicon wafer is held on the anode of the system, facing upwards towards the cathode, which is covered by the source material, usually a metal. When the Argon gas ions collide with the source material molecules at the cathode, the source material particles



4 Sputtering

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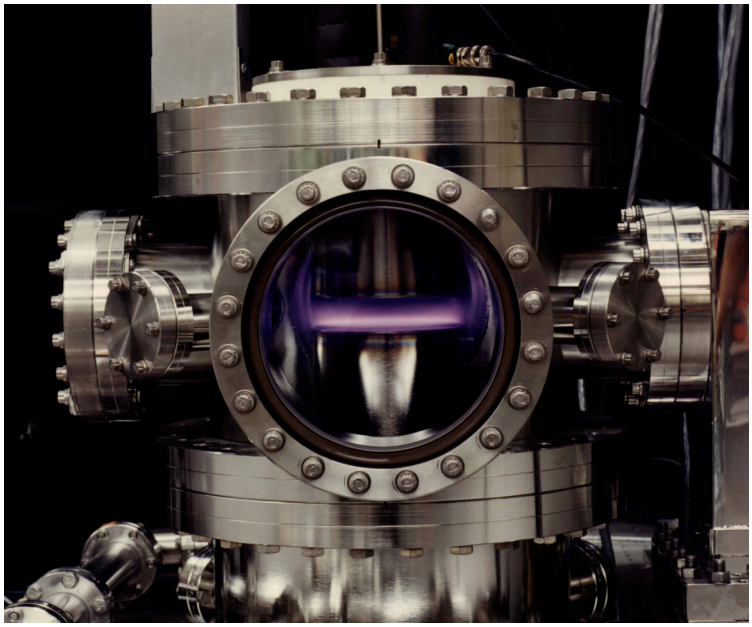
become positively charged and fall towards the anode, on which the wafer is located. The thickness of the deposition layer of source material can be controlled by varying chamber pressure, the amount of gas introduced, temperature, time, and the power of the RF system used.

Sputtering is often used in combination with reactive ion etching, also known as a combination of ion milling and plasma etching. Both Ion milling and plasma etching are performed in the same kind of chamber as sputtering, but the pressure is not required to be as low as 10^{-6} torr; typical chamber pressures are between 10^{-1} and 10^{-3}. Plasma etching is performed at higher pressures than ion milling. However, the main difference between sputtering and reactive ion etching is that while sputtering deposits metal layers on the silicon substrate, reactive ion etching etches away at this metal. It does this by switching the positions of the cathode and the anode; the silicon wafer is now placed on the cathode, facing upwards towards the anode. In this configuration, the free radicals, introduced in gaseous form into the chamber, move towards the wafer and collides with the wafer, etching away the top layer. Gas concentration, chamber pressure and temperature can be set to control the etch rate. Since plasma etching is more dependant on the chemical reactions between the gas and the etched layer, the gas used in the chamber depends mostly on the material that is being etched.



6 bulk micromachining applications
5 Plasma etching chamber, using Argon

Organic materials are best etched using O_2, SF_6, or CF_4. Polysilicon can be etched using CCl_4, CF_4, NF_3, or SF_6. Reactive ion etching can even be used to etch materials as hard as tungsten, using chlorine gas (Cl_2). Argon is also commonly used in addition to these gases to improve etch rate or selectivity, and is the preferred gas in ion milling because it is more anisotropic but provides higher selectivity than plasma etching. Lower pressure is required for ion milling because the gas does not react with the wafer surface, and the etch rate depends solely on how fast the ions hit the wafer; ions travel faster in lower pressure environments.

Applications of bulk micromachining usually include making microstructures like trenches and, holes. The techniques are often used to produce pressure sensors, silicon valves and silicon airbag accelerometers. It is used widely in MEMS structures as well as in CMOS fabrication. A great advantages bulk micromachining has over surface micromachining is that bulk wet etching techniques can be used quickly and uniformly over a large wafer surface area. This quality makes bulk micromachining a relatively cheap process, in terms of both money and time. The disadvantage of bulk micromachining is that it is not easily integrated with microelectronics, as surface micromachining is. This flaw is due to the isotropic nature of wet etching, which limits line width resolution. Surface micromachining is useful for forming free-

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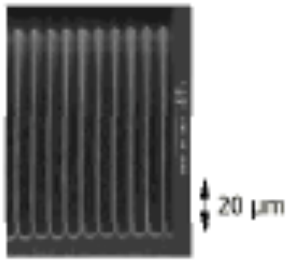
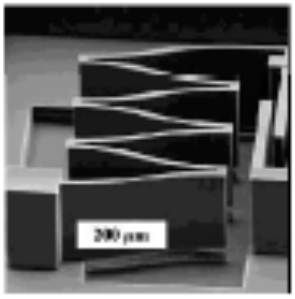
moving microstructures, including basic rotating structures that cannot be realized using bulk micromachining techniques. Surface micromachining is highly anisotropic, but since it relies on high speed, high energy ion collisions, there is a high potential for radiation damage to the surface of the wafer, and sometimes results in poor selectivity. This radiation often reduces yield for surface micromachining processes, making the process more costly than bulk micromachining. Also, surface micromachining techniques are often much more time-consuming than bulk micromachining techniques. Wet etching techniques often provide one to microns per minutes, whereas dry etching techniques provide only fractions of a micron per minute, at most. Also, maintaining a vacuum chamber, high pressure environment, and high degrees of thermal variability make surface micromachining extremely costly.



Trenches - *Surface Technology Systems*


Spring - Klaassen, *et al*, 1995

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