Course material

Course:

Micro and Nanofabrication (MEMS)

Video:

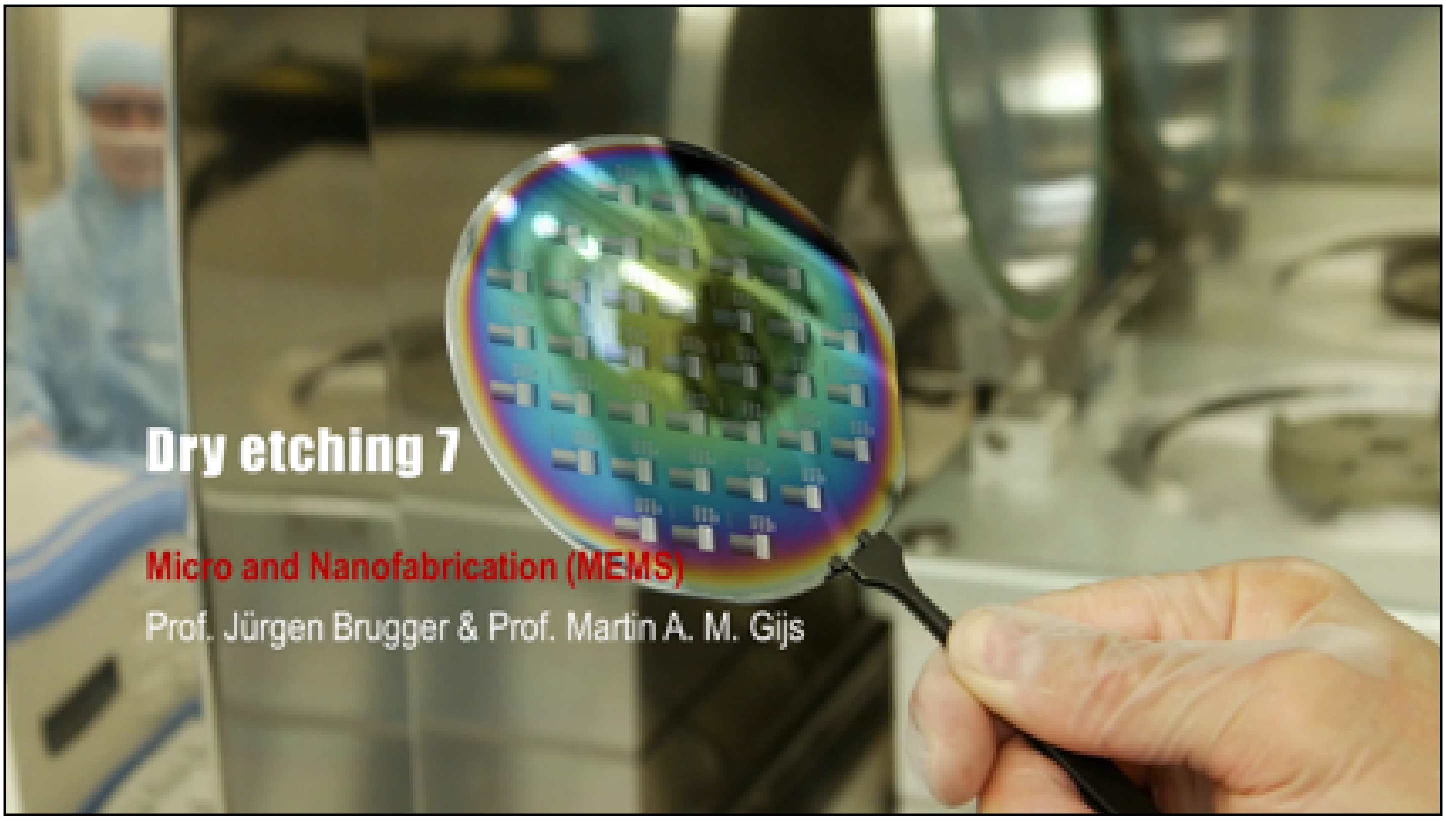
5.7 Dry etching 7

Concepts (extracted from automatically generated subtitles):

Dry etching of silicon. Consequence of the use of a reactive gas. Silicon-based materials. Oxygen plasma. Dry etching of organic films. Etched structure. Lower pressure. Chlorine radicals. Relatively low temperature. Effects of aluminum redeposition. Silicon dioxide. Mask materials. Etching of organic materials. Chemical vapor deposition system. Chlorine-containing residues.

to video sequence search
(within Micro and Nanofabrication (MEMS).)

to video

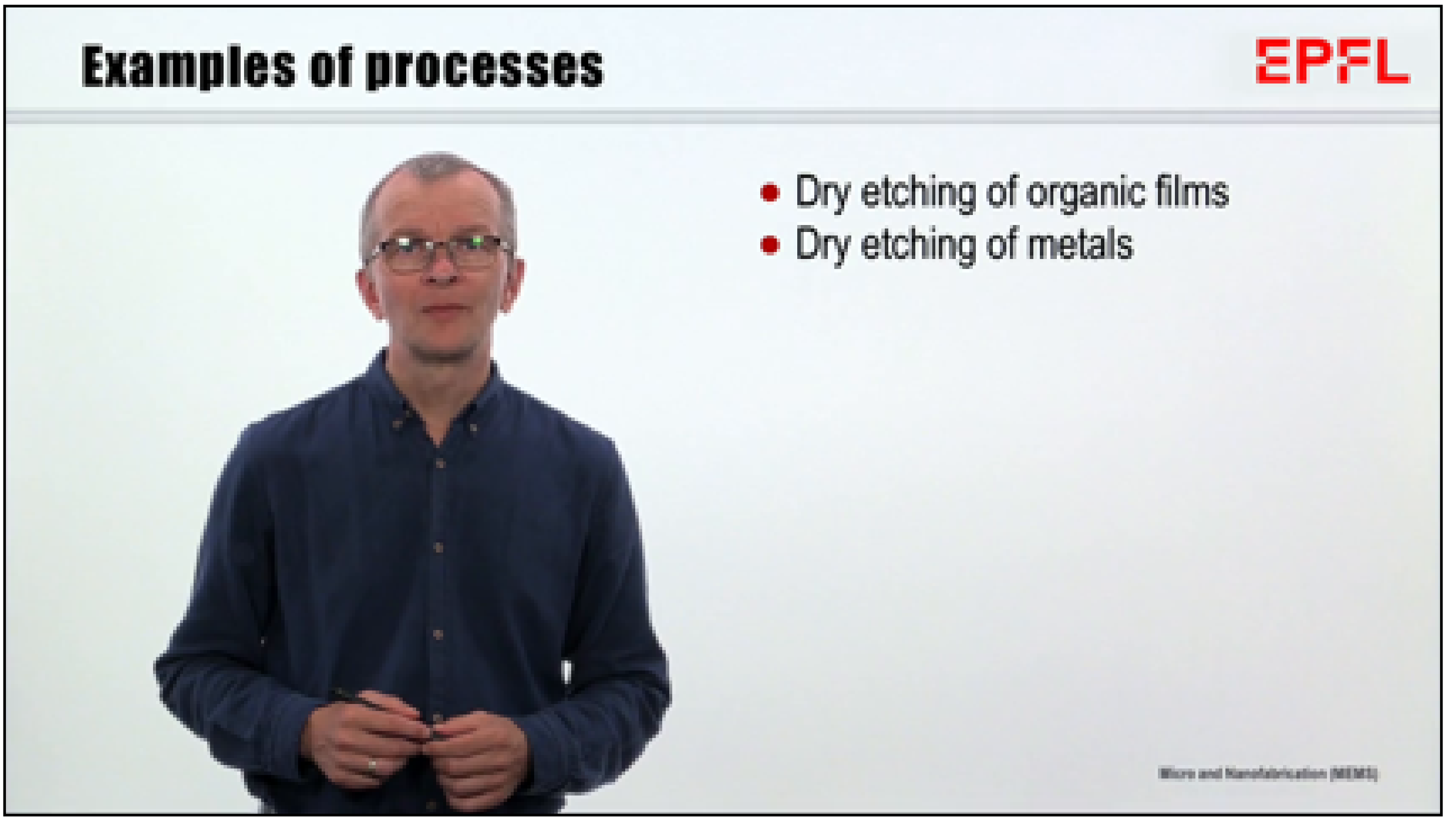


...

notes

summary

0m 0s

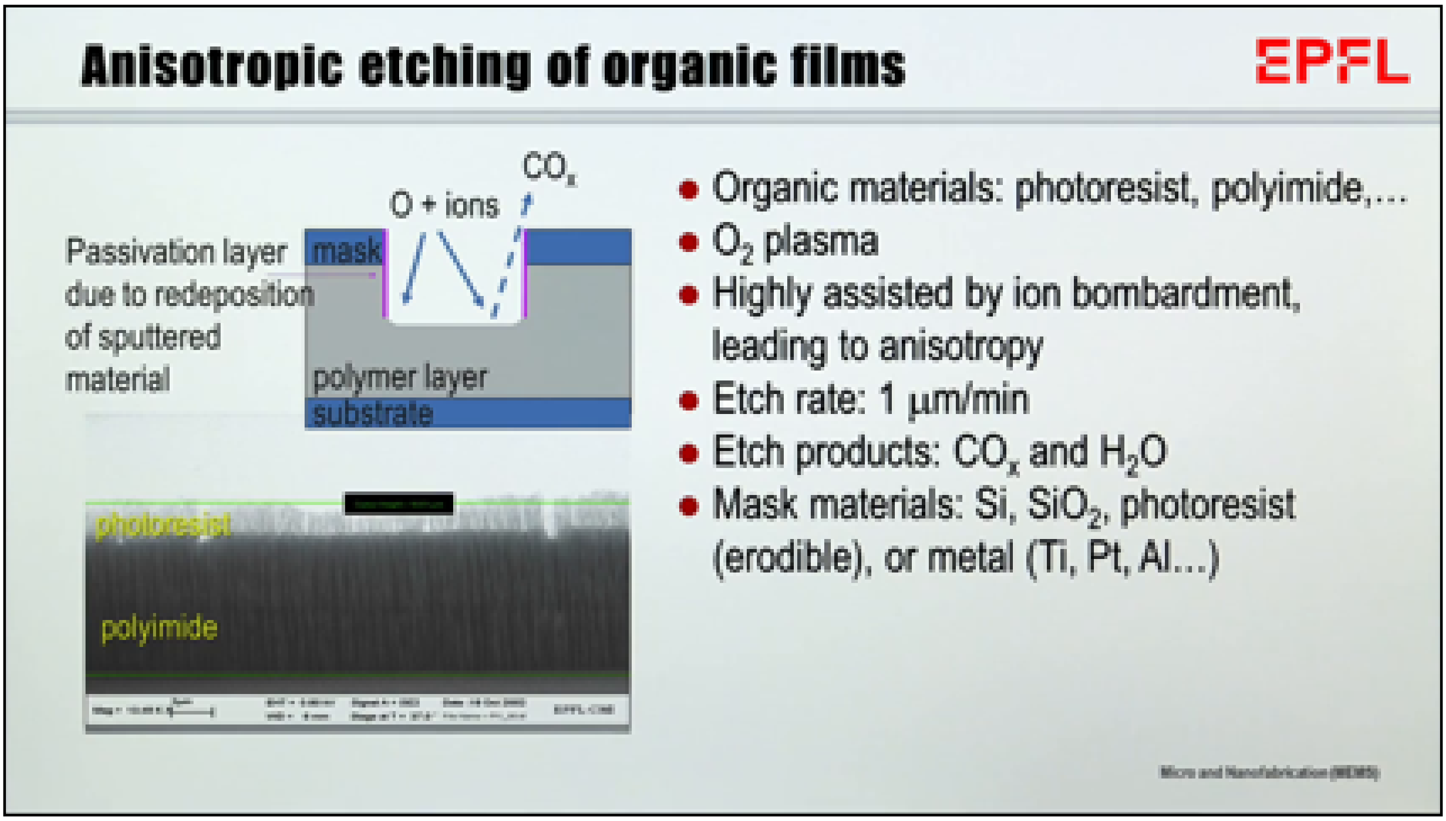


While previously we have discovered some of the processes used in dry etching

notes

summary

0m 1s

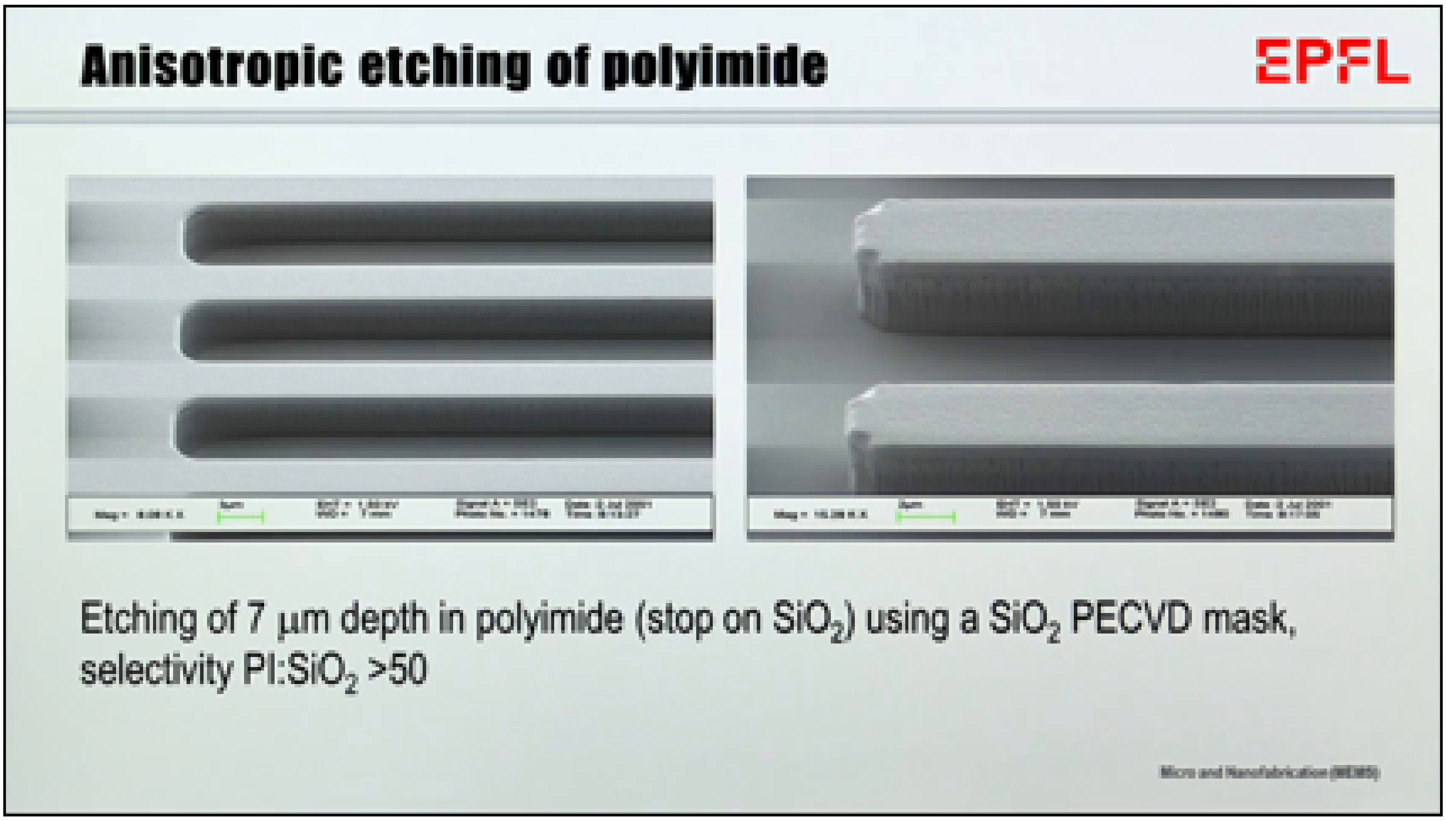


of silicon and silicon-based materials, now we focus on the dry etching of organic films, like photoresists, and the material, polyimide, and of metals.

notes

summary

0m 5s



One typically uses an oxygen plasma for the etching of organic materials like photoresist, polyimide, etc. If one uses ion bombardment, one gets anisotropic structures when one exploits the redeposition of sputtered material to the sidewalls. Etch products are water, CO gas, and CO2 gas, typically. There is a vast choice in mask materials, like silicon, silicon dioxide, photoresist, or metal. The picture shows a photoresist mask, which was put on a polyimide film to etch a microstructure in the polyimide layer. These pictures show the etching of a 7 micrometer thick polyimide layer that was deposited on a silicon dioxide layer,

notes

summary

0m 23s

Etching of polyimide with erodible mask

EPFL

Polyimide etching using an erodible PR mask

Polyimide etching with erodible mask to get tapered sidewall

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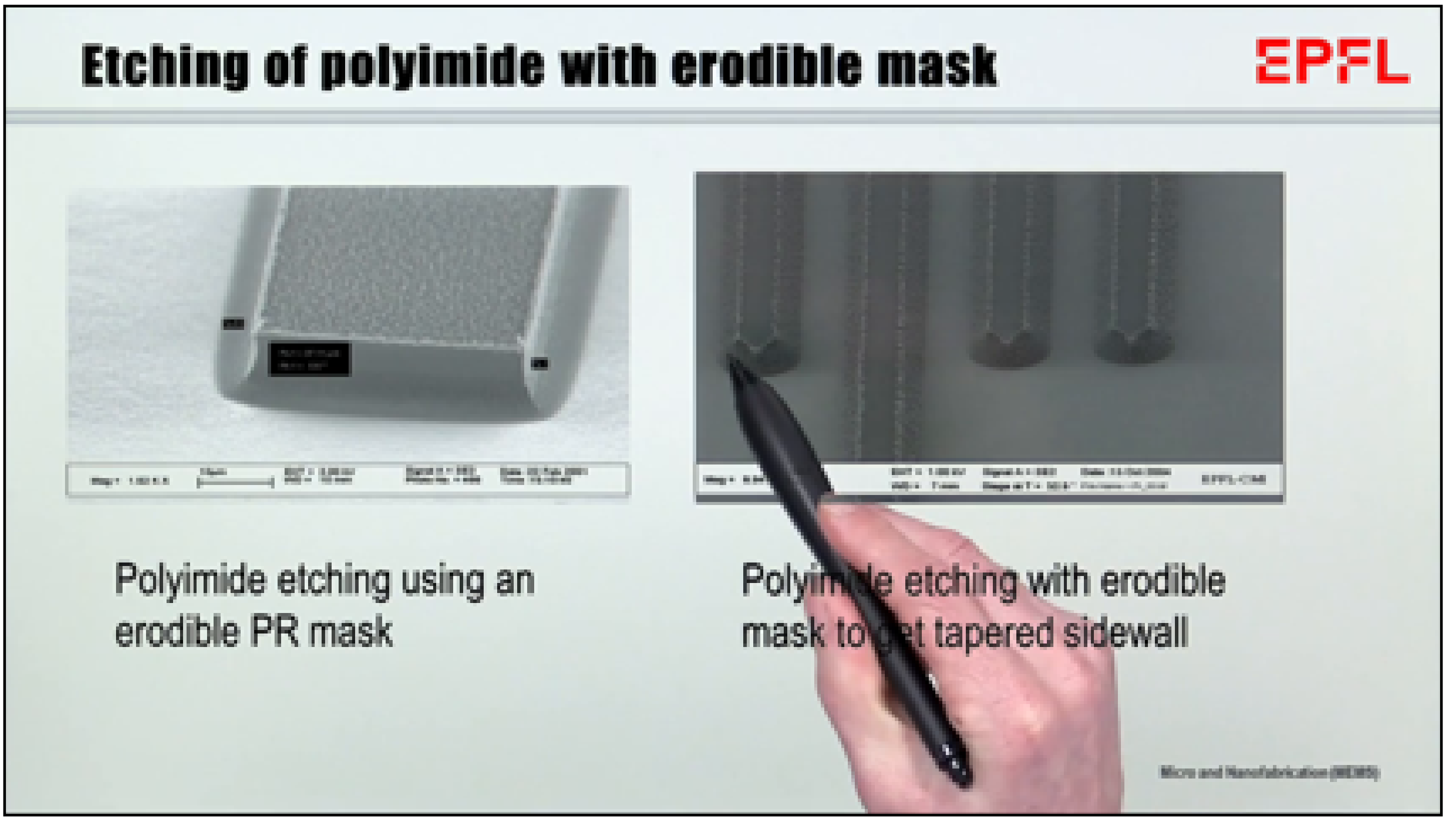
and where one has used silicon dioxide as a mask. The silicon dioxide was deposited using a plasma enhanced chemical vapor deposition system because one can apply then a relatively low temperature to the polyimide during deposition of the masking layer. The etching selectivity of the polyimide, with respect to the silicon dioxide, is over 50.

notes

summary

1m 25s

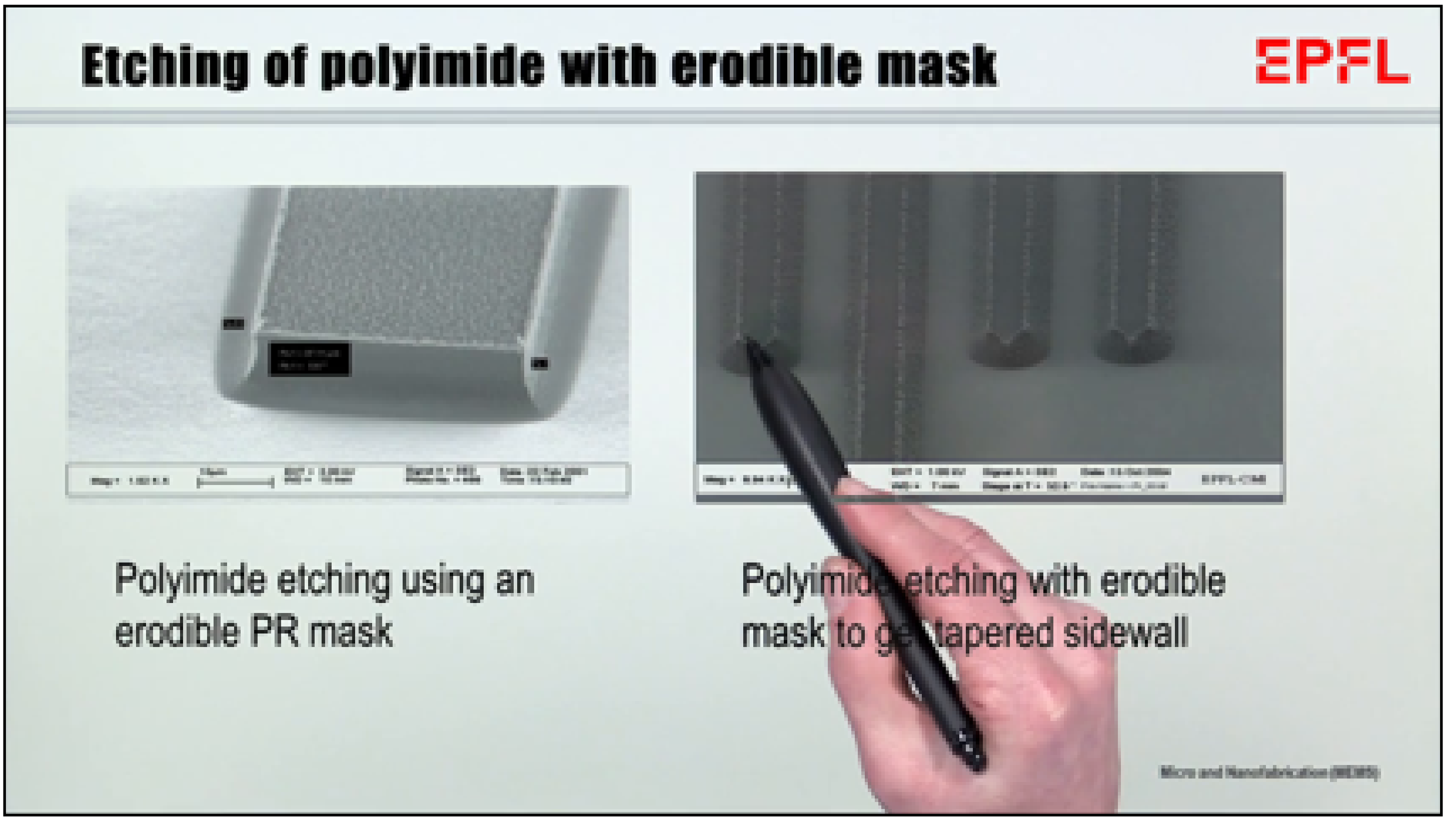


These pictures show the result of polyimide etching using an erodible mask of photoresist. Both polyimide and photoresist have similar etching rate, so that the photoresist is gradually consumed during etching, especially at its edges. That is why the resulting

notes

summary

1m 59s

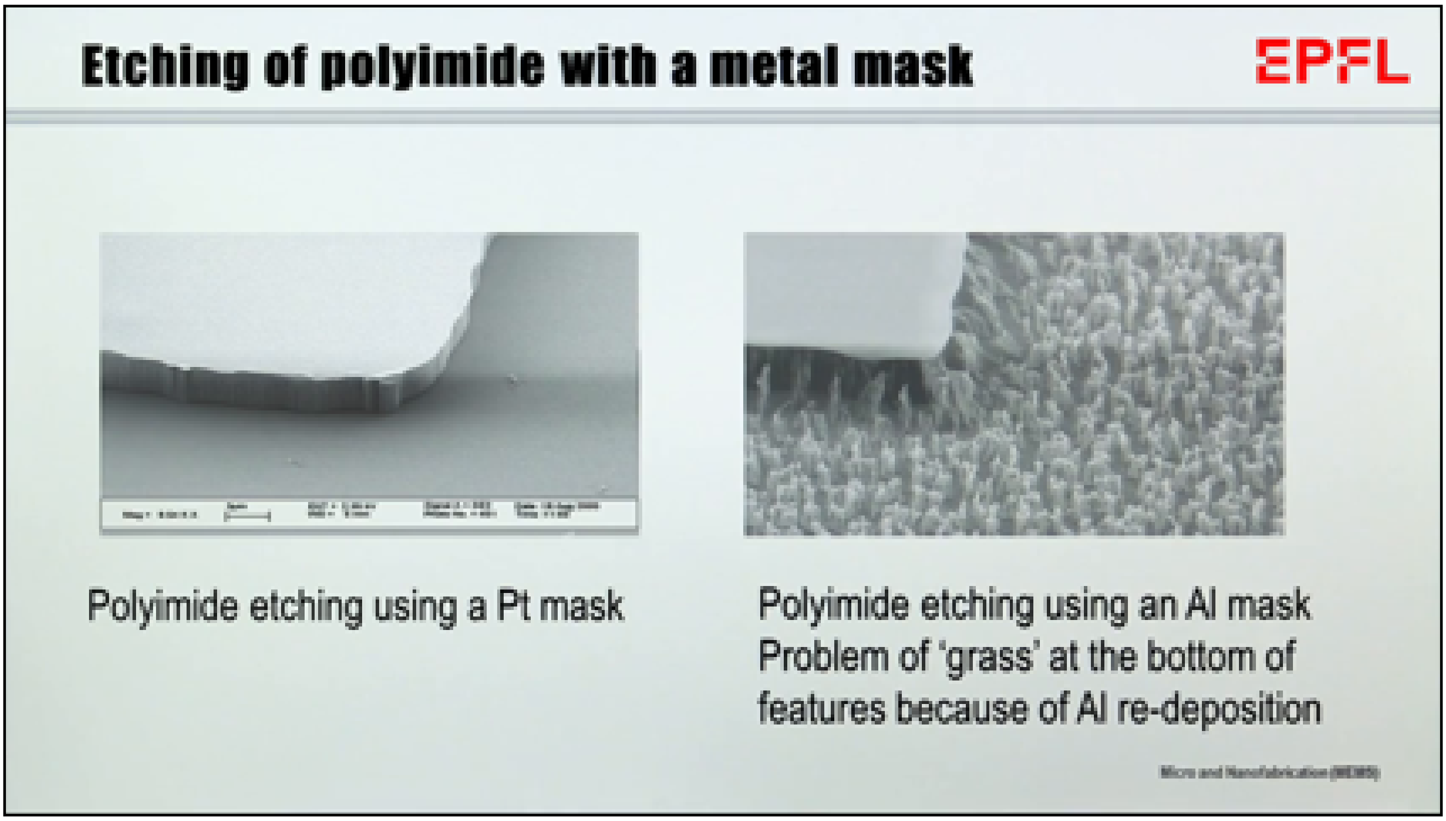


polyimide structure has tapered sidewalls, as the photoresist mask at its edges became thinner first, and first disappeared there.

notes

summary

2m 24s

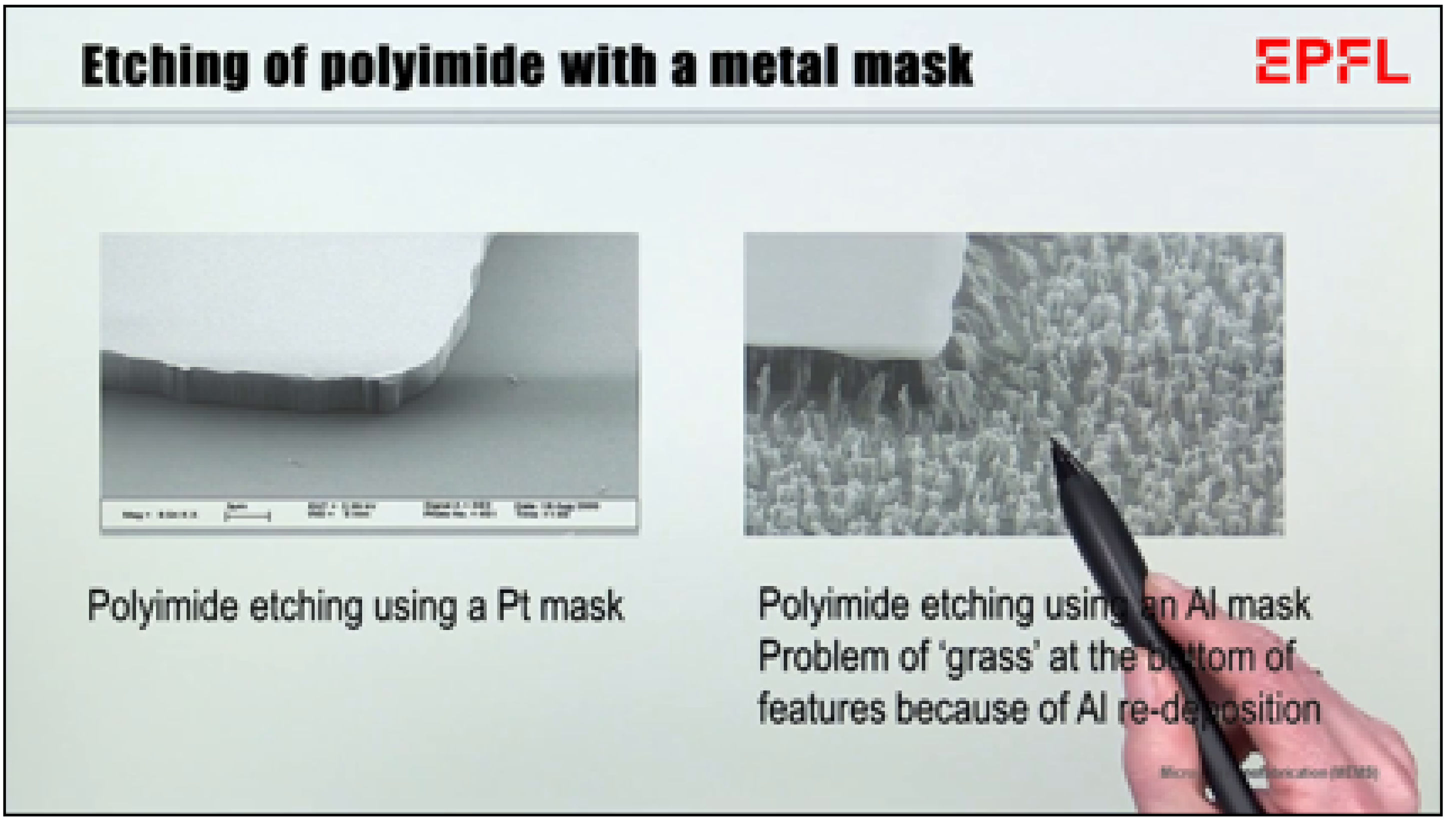


A metal mask, like platinum or aluminum,

notes

summary

2m 36s

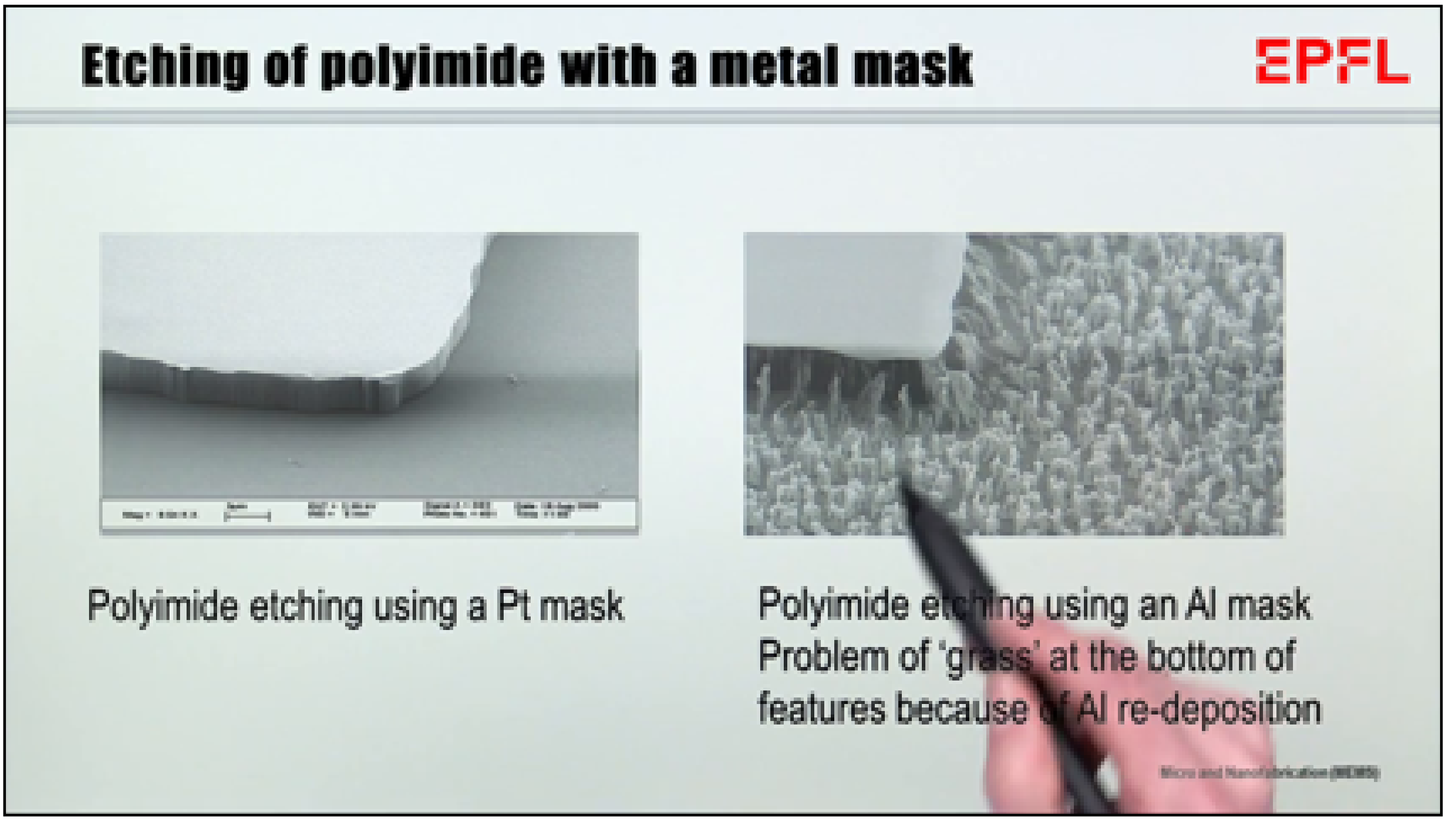


is much more resistant to the plasma, and hence, can be used to etch structures with vertical sidewalls. This picture shows effects of aluminum redeposition in the etched structure.

notes

summary

2m 39s

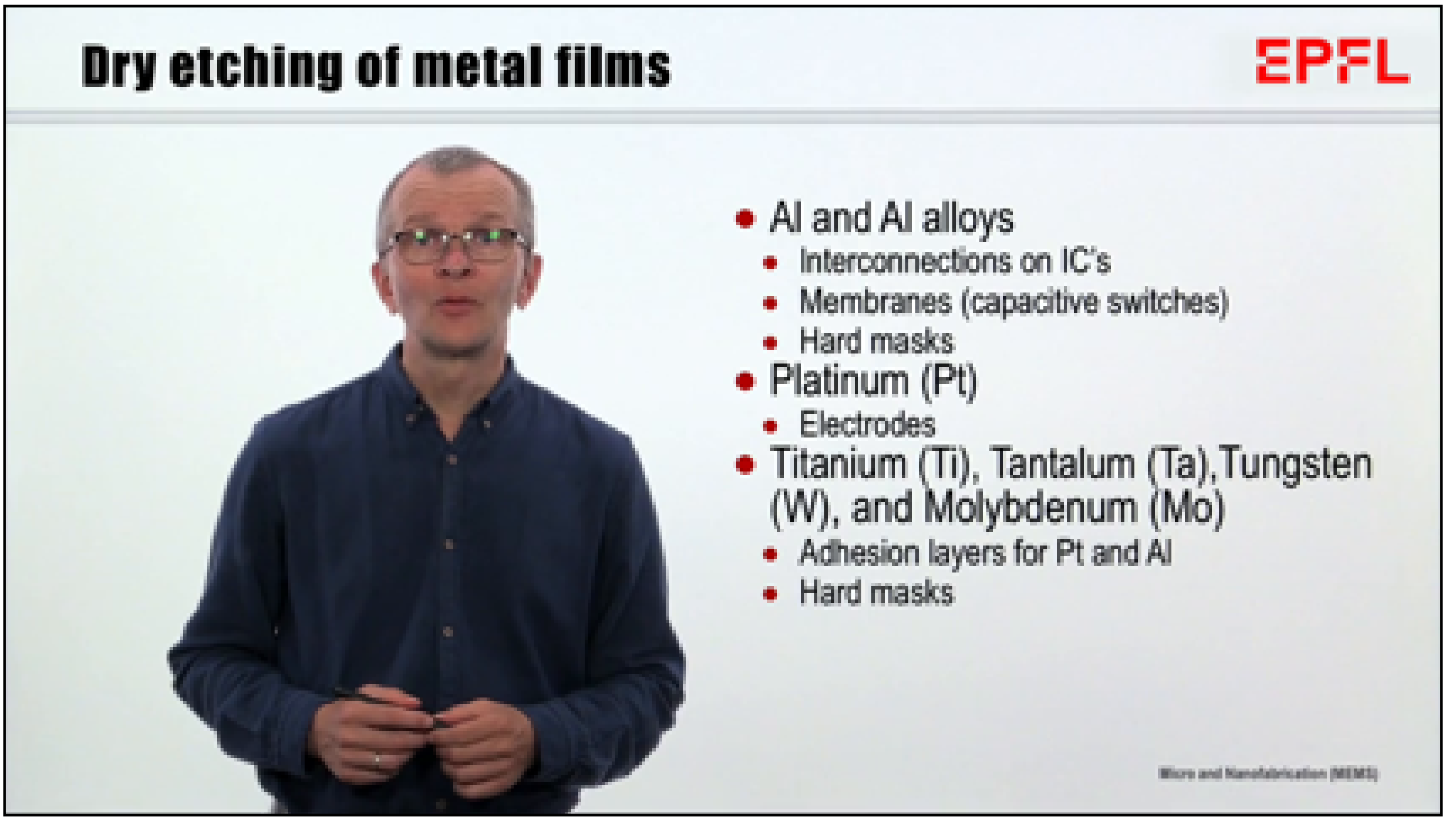


So, this material is removed, and it creates micro-masks in this region,

notes

summary

3m 1s



resulting in the generation of *grass* as the etching proceeds. Generally, such redeposition phenomena can be reduced when one uses a plasma at the lower pressure, in which the mean free path of molecules is larger. In this case, sputtered material can then be more easily evacuated from the zone of etching.

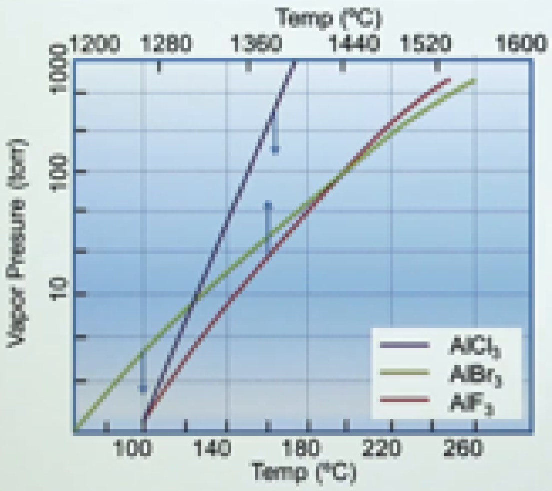
notes

summary

3m 7s

Etching of Al and Al alloys

EPFL



Vapor pressure of AlF_3, $AlCl_3$ and $AlBr_3$ as function of T
(after D.R. Stull, Ind. Engr. Chem., 39, 517, (1947))

- Al and Al alloys are used for interconnection lines in IC fabrication
- Fluorine chemistry (used for Si and SiO_2) doesn't work for Al etch, because the etch product AlF_3 has a very low vapor pressure
- Chlorine chemistry is used instead
  - Etch product is $AlCl_3$
  - Used gases: BCl_3, CCl_4, $SiCl_4$ and Cl_2

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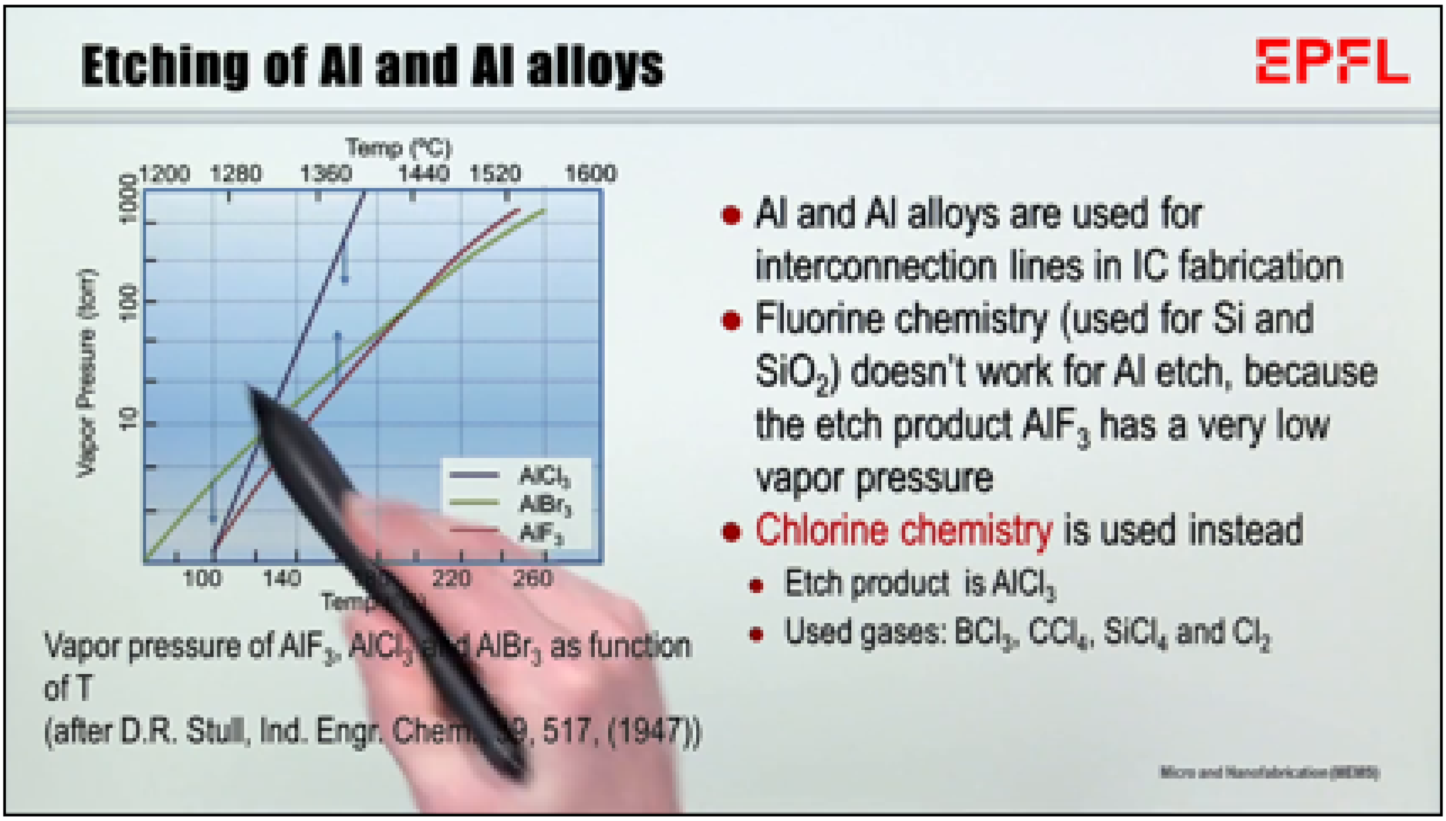
Now we will give a few examples of dry etching processes for metals. We will discuss the etching of aluminum and aluminum alloys. These materials are used for making interconnecting structures on integrated circuits. They can also be used as membranes in switching applications, or as hard masks in a dry etching process. Next, we discuss the dry etching of platinum, which is an important material for microfabrication of electrodes. Finally, we will discuss the etching of titanium, tantalum, tungsten, and molybdenum, which are frequently used as adhesion materials for the deposition of the noble metal, platinum, or aluminum. These materials also serve as hard masks in etching processes. Aluminum and aluminum alloys are used for making interconnection lines in integrated circuit fabrication.

notes

summary

3m 38s

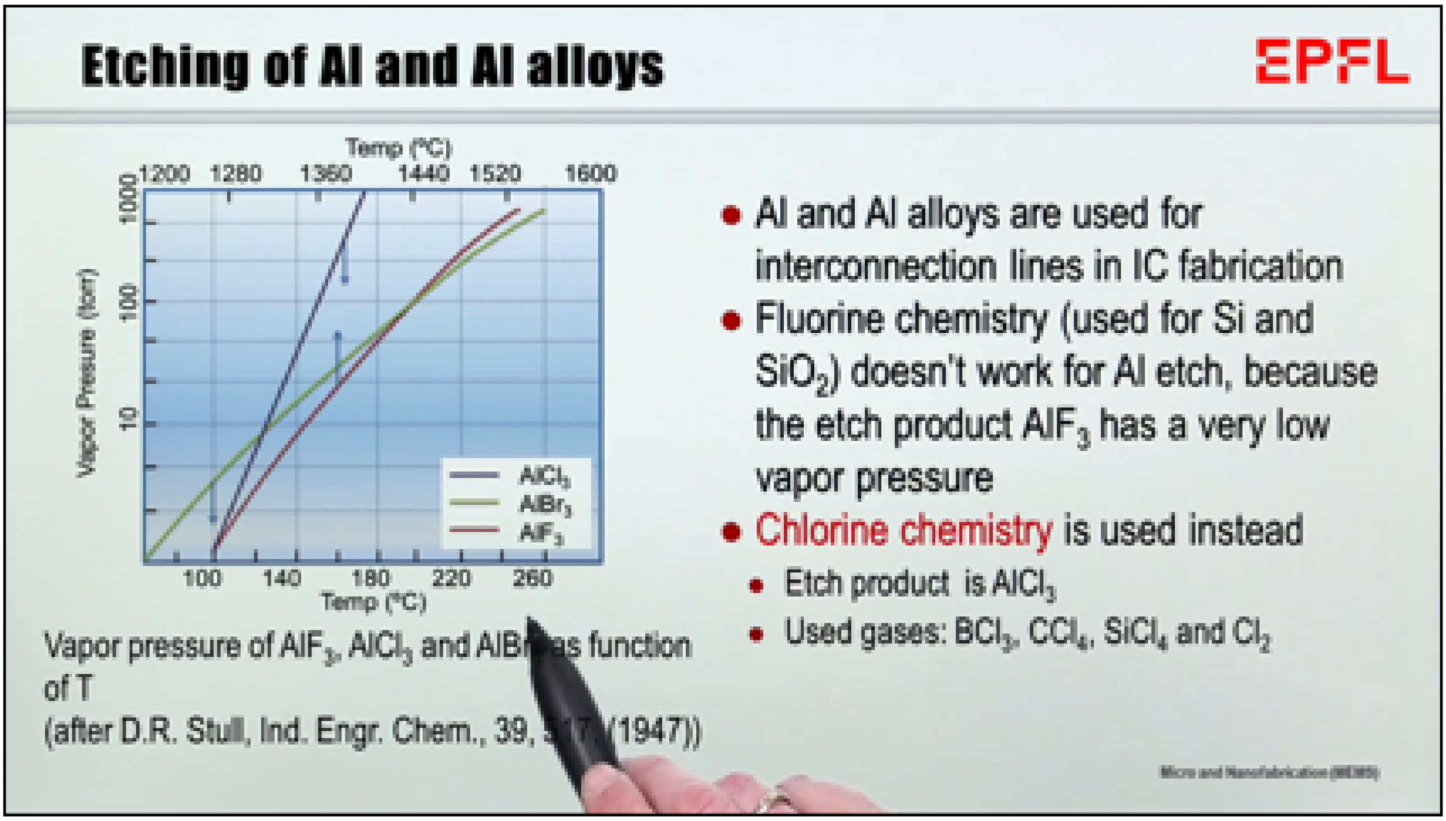


Because dry etching is a consequence of the use of a reactive gas, etching will be easier if the formed chemical product is more volatile.

notes

summary

4m 37s



This diagram shows the vapor pressure as function of temperature for three reaction compounds. If one uses fluorine as a reactive gas, the formed aluminum trifluoride product has a relatively low vapor pressure, so this curve refers to this temperature axis. So, vapor pressure is significant only at very high temperature, much higher than used in etching. These temperatures are clearly too high for microfabrication. That is why fluorine chemistry, which is successful for silicon and silicon dioxide etching, does not work for aluminum. Instead, one can use chloride chemistry. As the formed reaction product, aluminum trichloride, this curve refers to this temperature. So, for this material, one has an appreciable vapor pressure at much lower temperature,

notes

summary

4m 49s

Role of Al_2O_3 in Al etching

EPFL

- If the Al surface is not covered by aluminum oxide (Al_2O_3), the reaction $Al + Cl$ or $Cl_2 \rightarrow AlCl_3$ can proceed
- The native Al oxide layer (about 30 Å) should be etched first
  - Thickness can vary from run to run
  - No reaction with Cl and Cl_2
  - Sputtering with energetic ions is needed
  - Chemical reduction is possible: BCl_3 or CCl_4 dissociation generates oxide species capable of reducing Al_2O_3

    $Al_2O_3 + CCl_x \rightarrow AlCl_3 + CO$ ions
- Water vapor in the chamber should be avoided
  - It scavenges the oxide-reducing species
  - It reacts with exposed Al to form Al_2O_3

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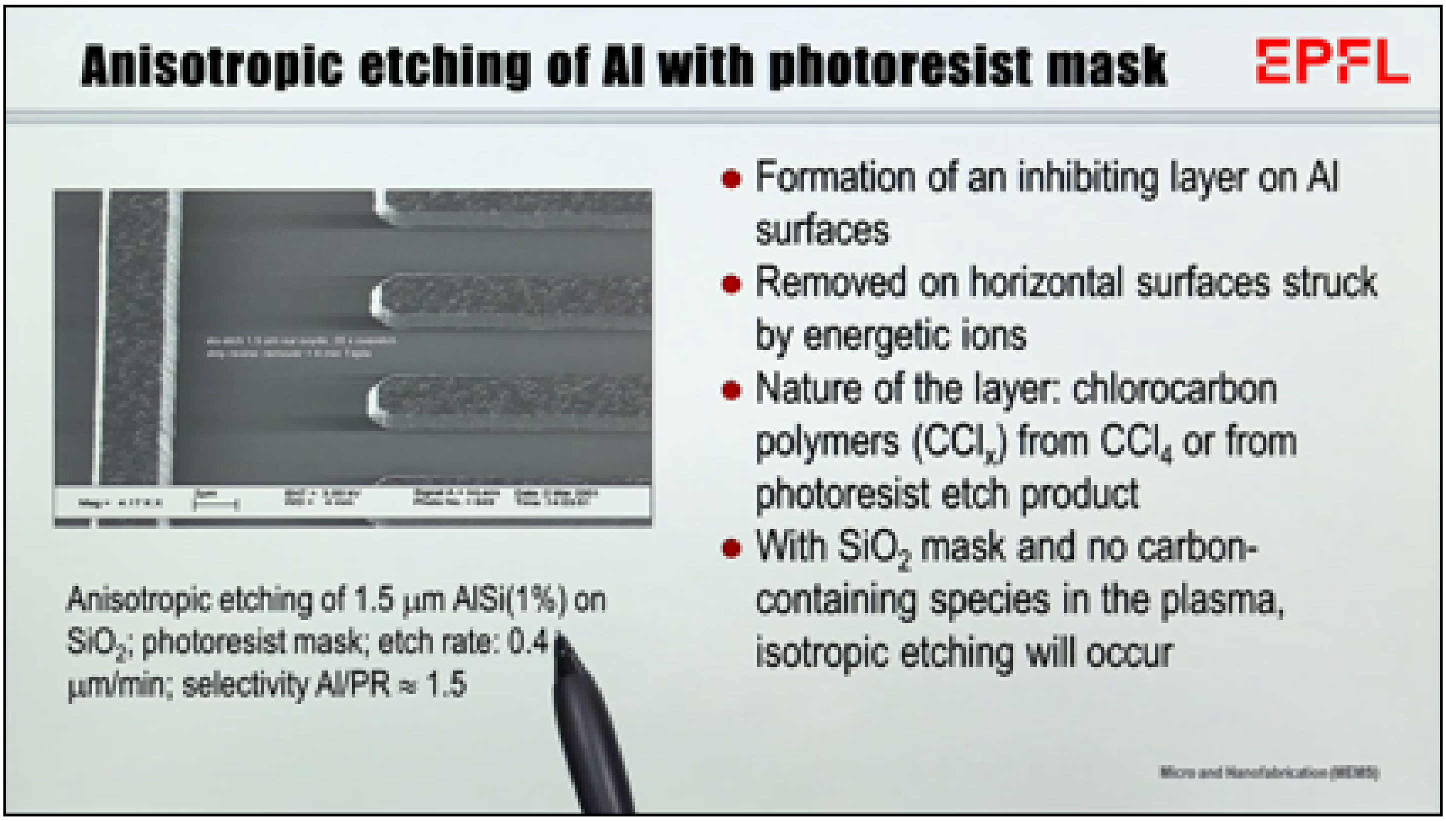
a temperature which is compatible with the dry etching temperature. The result is that this reaction product can be easily removed from the substrate after the chemical reaction.

notes

summary

6m 13s

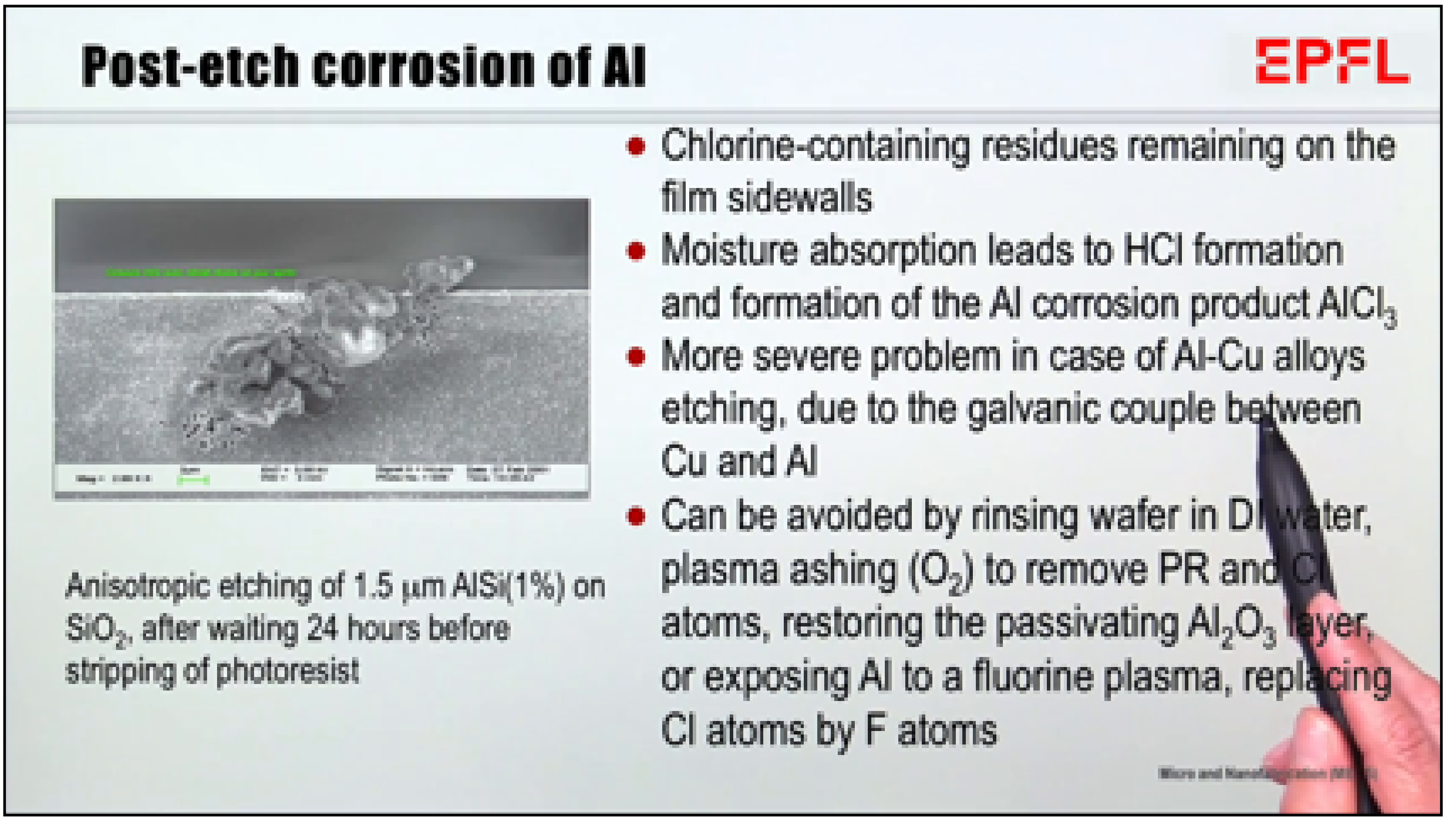


If one would have a pure aluminum surface that is not covered by an aluminum oxide layer, the reaction with chlorine radicals and molecules can immediately proceed. However, as aluminum is very reactive with oxygen, it always has a native aluminum oxide layer of about 30 angstrom, which should be etched away first. This thickness is, more or less, variable, and the oxide is so stable that there is no reaction with chloride atoms, *except* if sputtering with energetic ions is used. Then, only, the aluminum oxide can be dissociated, forming the volatile aluminum trichloride reaction product. Also, one should avoid water vapor in the reaction chamber as water can easily react with the chlorine radicals and with the exposed aluminum to form aluminum oxide. Here, we show the etching of a 1.5 micrometer thick aluminum silicon alloy

notes

summary

6m 30s

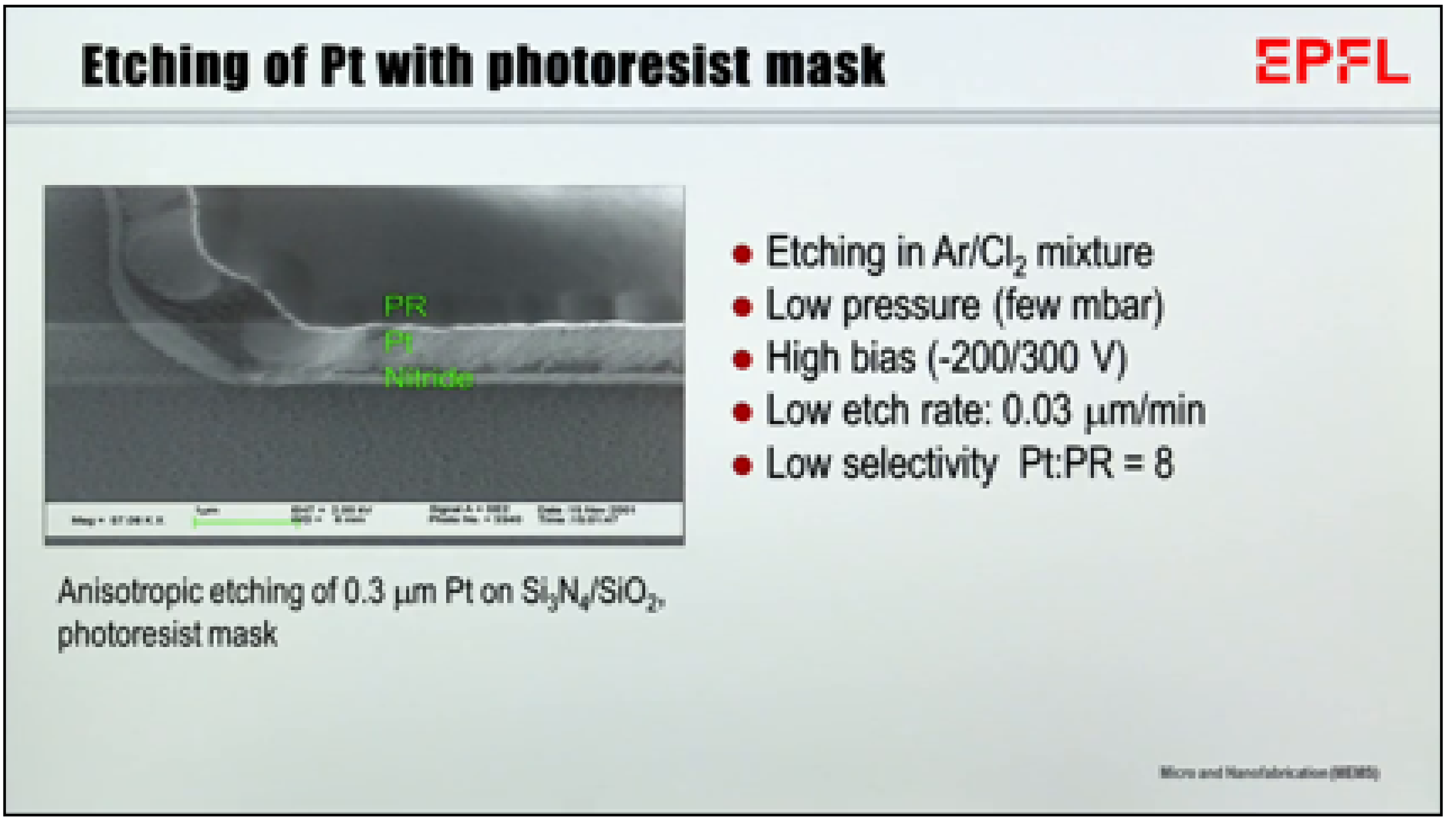


that was deposited on silicon dioxide. One has used photoresist as a mask, and obtained a selectivity around 1.5. That is, the aluminum etches almost as fast as the photoresist. Anisotropic etching profiles are, more or less, obtained because one has used a chlorocarbon plasma that results in polymer deposition on these sidewalls. Also, redeposition of sputtered photoresist on the sidewalls is possible. If, instead of a photoresist mask, one would have used a silicon dioxide mask, and a plasma gas that did not contain carbon, or few carbons, one would have obtained a purely isotropic etching process. Sometimes, we observe corrosion phenomena on the etched aluminum structures. This is believed to originate from chlorine-containing residues that remain on the etched film sidewalls. If these residues are combined with moisture absorption, the corrosive acid, HCl, forms, and this leads to aluminum corrosion products like aluminum trichloride. The problem is even more severe for aluminum copper alloys.

notes

summary

7m 49s

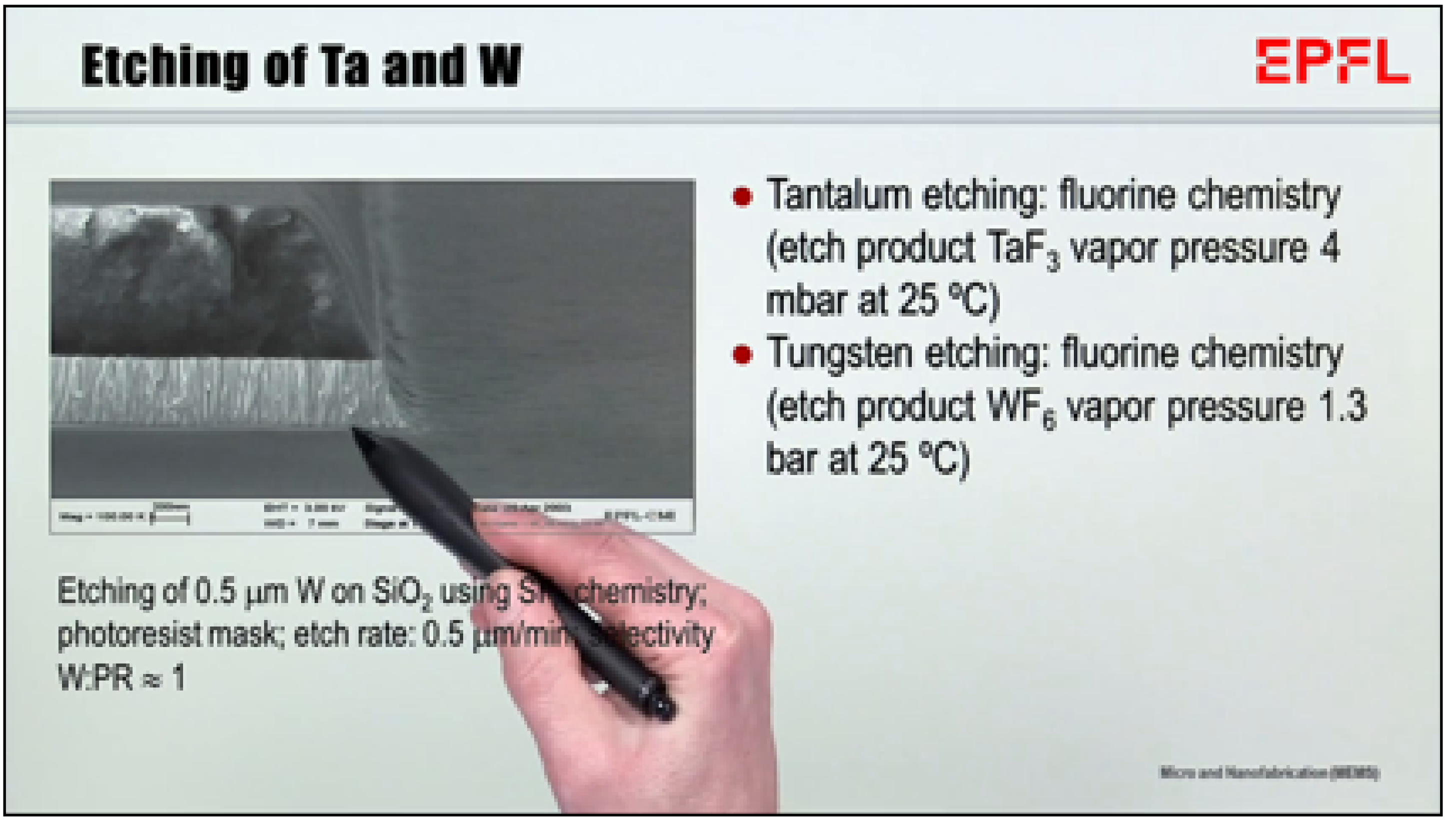


Corrosion can be prevented by rinsing well the wafer in deionized water after removal from the chlorine plasma. Also, one can apply a plasma etching step in oxygen to remove residual photoresist and chlorine atoms, and at the same time, restore a thin passivating aluminum oxide layer. Another possibility is to expose the etched structure to a fluorine plasma, during which chlorine atoms are replaced by fluorine atoms.

notes

summary

9m 25s

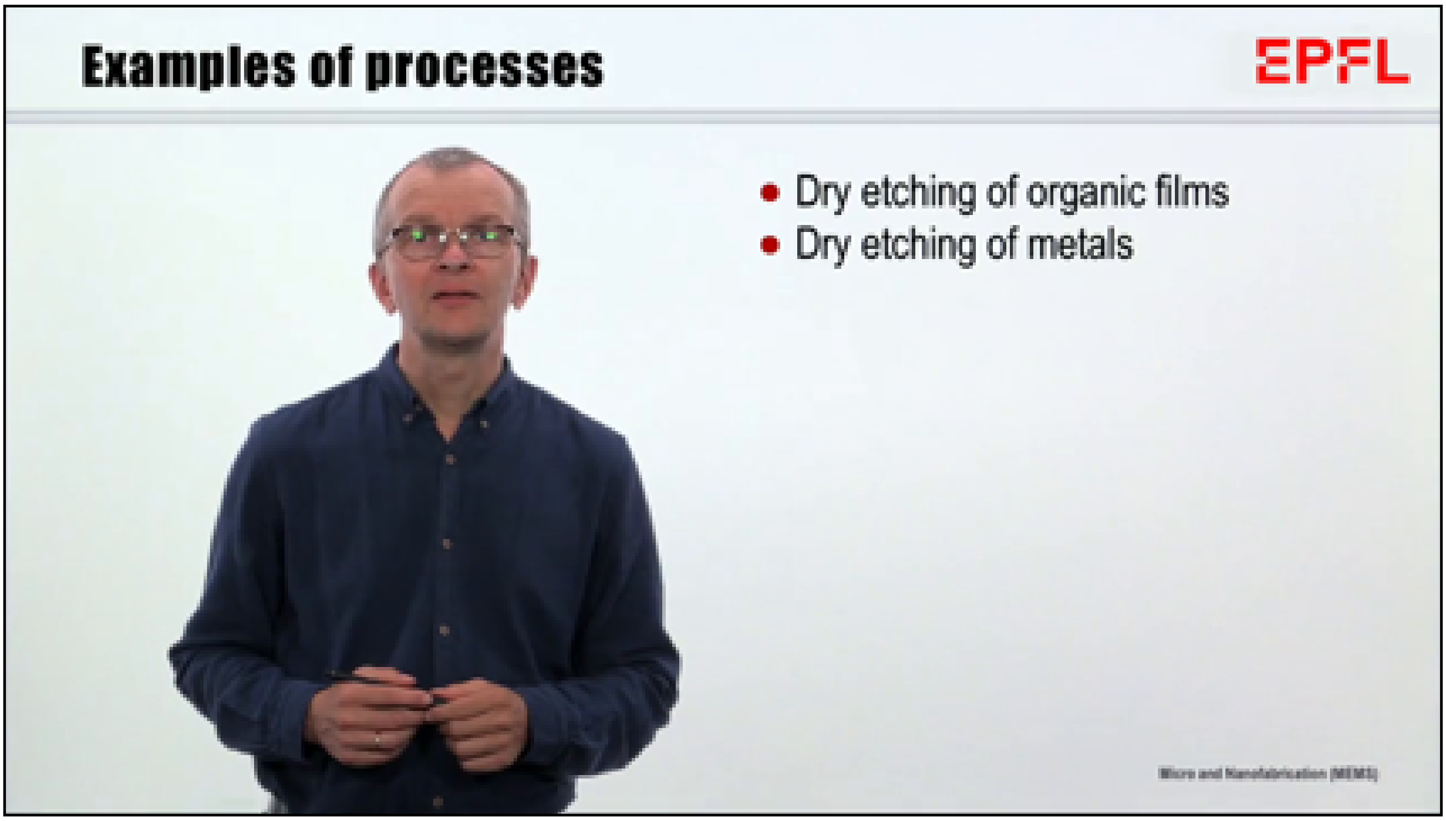


Here, we show the etching of a platinum film using a photoresist mask. The platinum was deposited on a thin silicon nitride layer on a silicon dioxide layer. The etch rate is very low, and the selectivity is also relatively low: 8, because the platinum is such chemically inert material. We have used here a low pressure argon chlorine mixed plasma with a high negative voltage bias on the substrate. In the picture, almost all of the photoresist has been consumed for etching through the platinum layer. The picture here shows the etching of a 0.5 micron thick tungsten layer

notes

summary

10m 8s



deposited on a silicon dioxide layer, and one has used here fluorine chemistry and a photoresist mask. The selectivity is only 1. The etched product formed is tungsten hexafluoride. The metal tantalum can be etched in a very similar way. This picture shows the etching of a 0.2 micrometer thick titanium layer, which was deposited on an amorphous carbon film. One has used chlorine chemistry and a photoresist mask. The process has only a low selectivity, 2. When etching molybdenum in a fluorine plasma, similar results can be obtained.

notes

summary

11m 1s

This ends our lesson on the dry etching of organic materials, like photoresist and polyimide and metals. Etching organic layers is a relatively easy task using a plasma, as volatile reaction products can be easily created. On the other hand, etching metals is more difficult, and one needs ion bombardment for etching to occur. Whether one uses a chlorine or a fluorine plasma depends on if a suitable volatile chemical reaction product can be formed at the temperature of the etching process.

notes

summary

11m 55s