Course material

Course:

Micro and Nanofabrication (MEMS)

Video:

3.6 PVD4, Sputtering DC, RF

Concepts (extracted from automatically generated subtitles):

Material target. Bombardment of positive ions. High dc voltage. Rf field. Magnetic field. Magnetron sputtering. Extensive use. Dc sputtering. Configuration of a sputtering system. Magnetic field lines. High frequency rf voltage. Closer look. Main advantage of this system. Accumulation of positive argon ions. Positive ions.

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

to video

...

notes

summary

0m 0s

PVD 4: Sputtering

EPFL

- Physical principle
  - Plasma, spatial zones, Paschen law
- Sputter variations
  - DC sputtering
  - RF sputtering
  - Magnetron sputtering
- Ions-target interactions
- Sputter examples
- Other PVD methods
- Film growth and control parameters

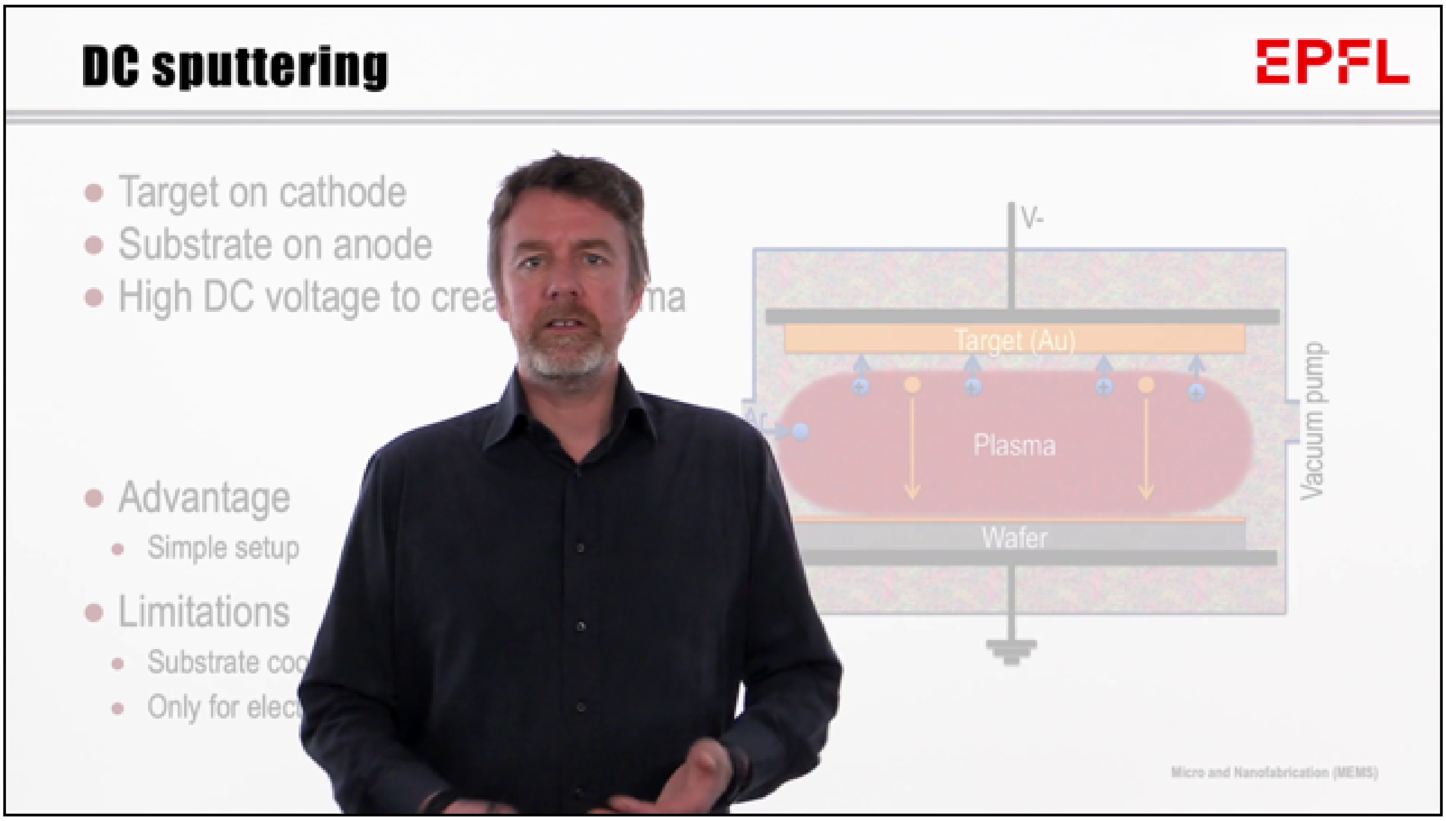
Micro and Nanofabrication (MEMS)

Now, we'll have a closer look how in a clean room the various

notes

summary

0m 1s

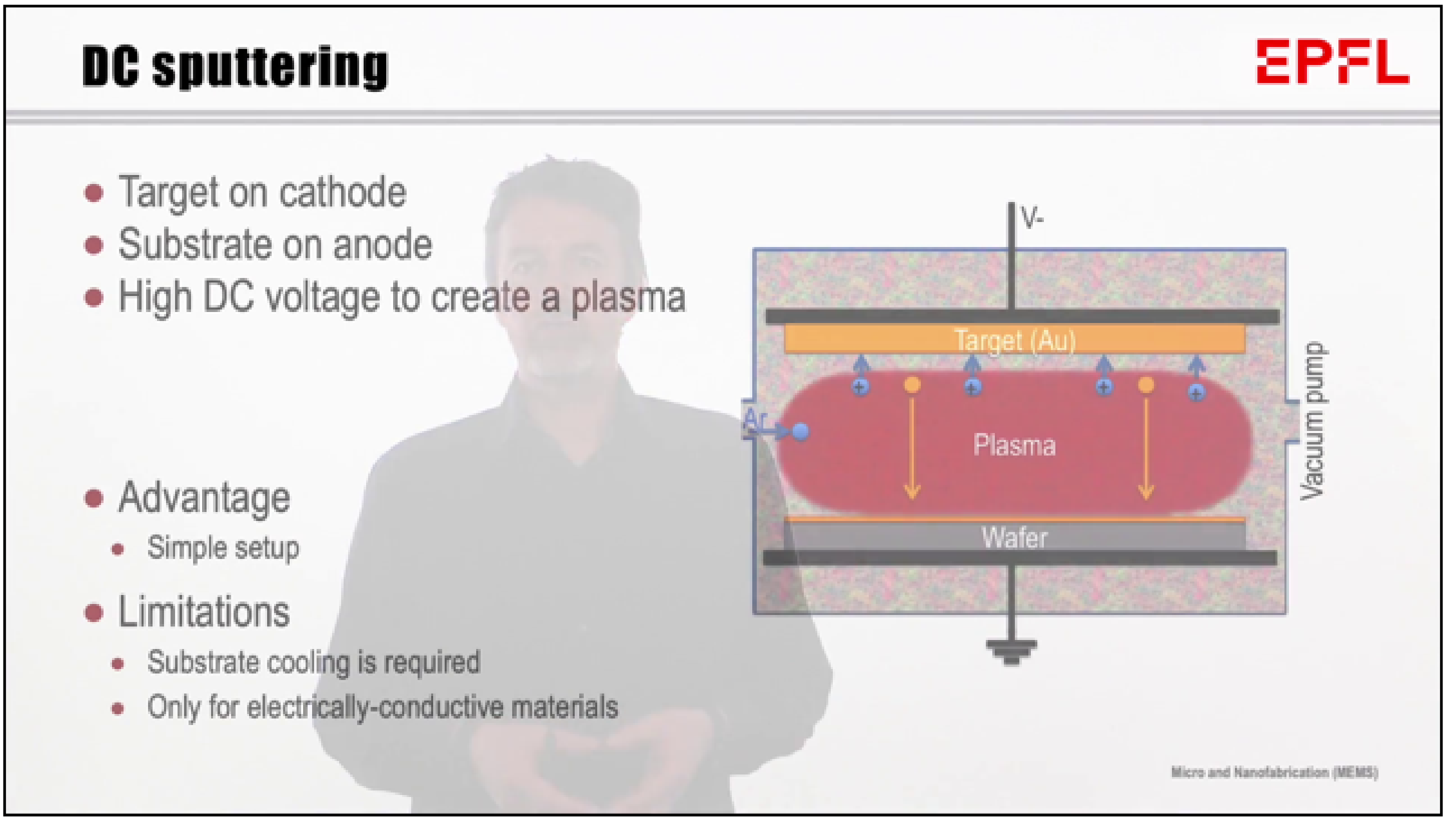


sputter equipment are working. I will show DC, RF, and Magnetron sputtering.

notes

summary

0m 5s



DC sputtering is one configuration of a sputtering system shown here on the right of the slide. As in every sputtering systems, the material target is placed on the cathode while the substrate is placed on the anode. To create a plasma, a high DC voltage in the order of 1kV or more, is applied between the electrodes. This is why we call the system "DC sputtering".

notes

summary

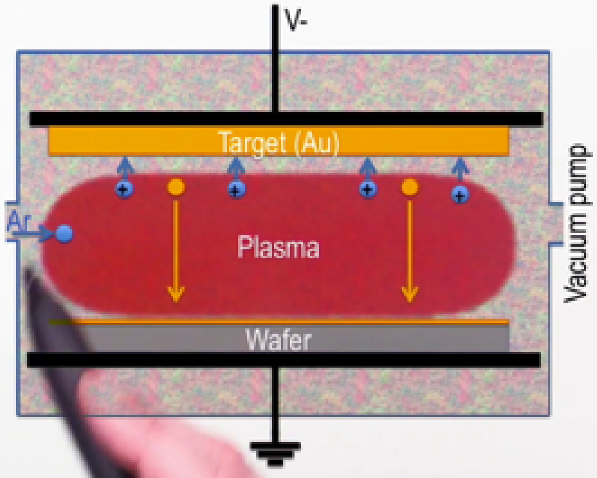
0m 15s

DC sputtering

EPFL

- Target on cathode
- Substrate on anode
- High DC voltage to create a plasma

- Advantage
  - Simple setup
- Limitations
  - Substrate cooling is required
  - Only for electrically-conductive materials



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Usually the anode is grounded and the negative voltage is applied to the cathode. Atoms that are ejected from the target under the bombardment of positive ions condense on the wafer thereby forming the desired thin film, like shown here. The main advantage of this system is it's relative simplicity. However, it suffers from two main limitations. Firstly, the plasma is present in the entire area between the electrodes

notes

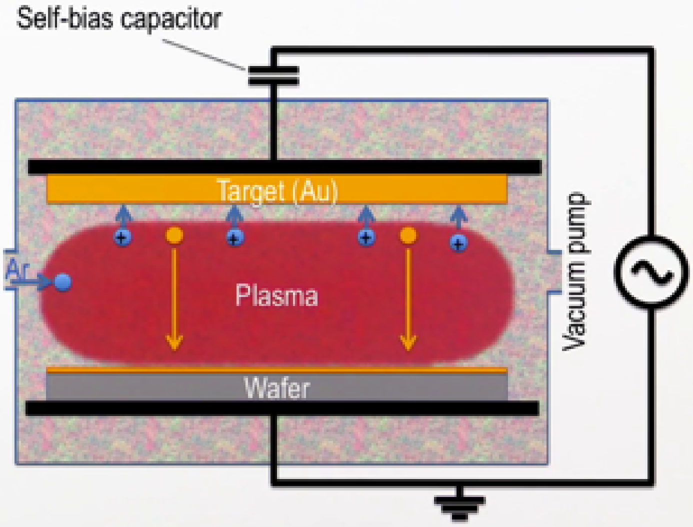
summary

0m 41s

RF sputtering

EPFL

- Target on cathode
- Substrate on anode
- RF voltage to create a plasma
- Capacitance for self-DC bias



- RF sputtering conditions:
  1. Avoid target charging: f > 50 [kHz]
  2. Energetic ions sputtering the target: f > 5 [MHz] & cathode capacitive coupling
  3. Sputtering on cathode only: anode larger than cathode

Micro and Nanofabrication (MEMS)

which has the consequence that this space is filled with electrons which are repulsed by the negative cathode and collide on the substrate. As a result, the substrate substantially heats up and efficient substrate cooling is required. Secondly, it is possible to deposit only electrically conductive materials with DC sputtering. Indeed, if an electrically insulating target is used it will charge within a few milliseconds due to the accumulation of positive Argon ions on the target. As a result, the plasma would stop. RF sputtering main difference with DC sputtering is the way how the plasma is created. As in the case of DC sputtering, the target is placed on the cathode to attract the positive ions and the substrate is placed on the anode. The difference is that, here the plasma is created applying a high frequency RF voltage between the electrodes. As you will see in details, using AC voltage instead of DC voltage has the main advantage to avoid target charging and thus allows the position of electrically insulating materials such a dielectrics. The key element to add to a system using an AC voltage is a self-bias capacitor, shown here. To enable RF sputtering, the following three conditions are required. First, avoid target charging as the cathode where the target is placed will alternate between positive and negative voltages. Both ions and electrons will accumulate on the target resulting in a null overall charge of the target. However, if the frequency is too low accumulation of ions during one single negative period of the signal can be sufficient to charge the target if it's electrically insulating, and to terminate the plasma. Using frequencies higher than 50kHz allows overcoming this throwback as charging time becomes shorter than a millisecond, which is too short to charge the target. Second, it is required to have energetic ions colliding on the target. If you simply use the AC voltage to

notes

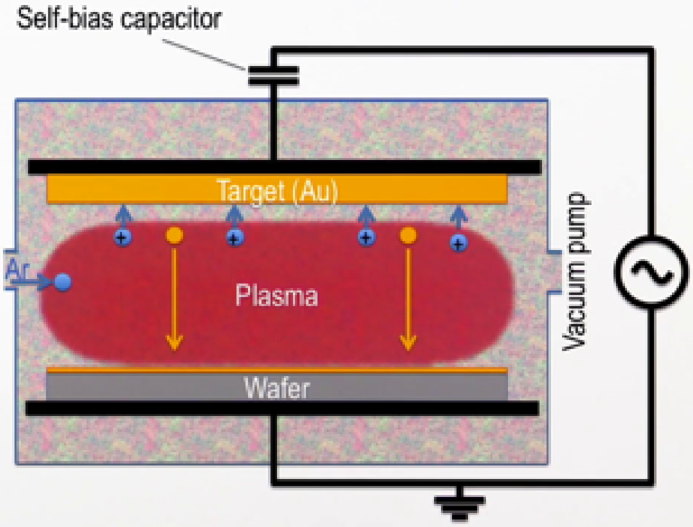
summary

1m 13s

RF sputtering

EPFL

- Target on cathode
- Substrate on anode
- RF voltage to create a plasma
- Capacitance for self-DC bias



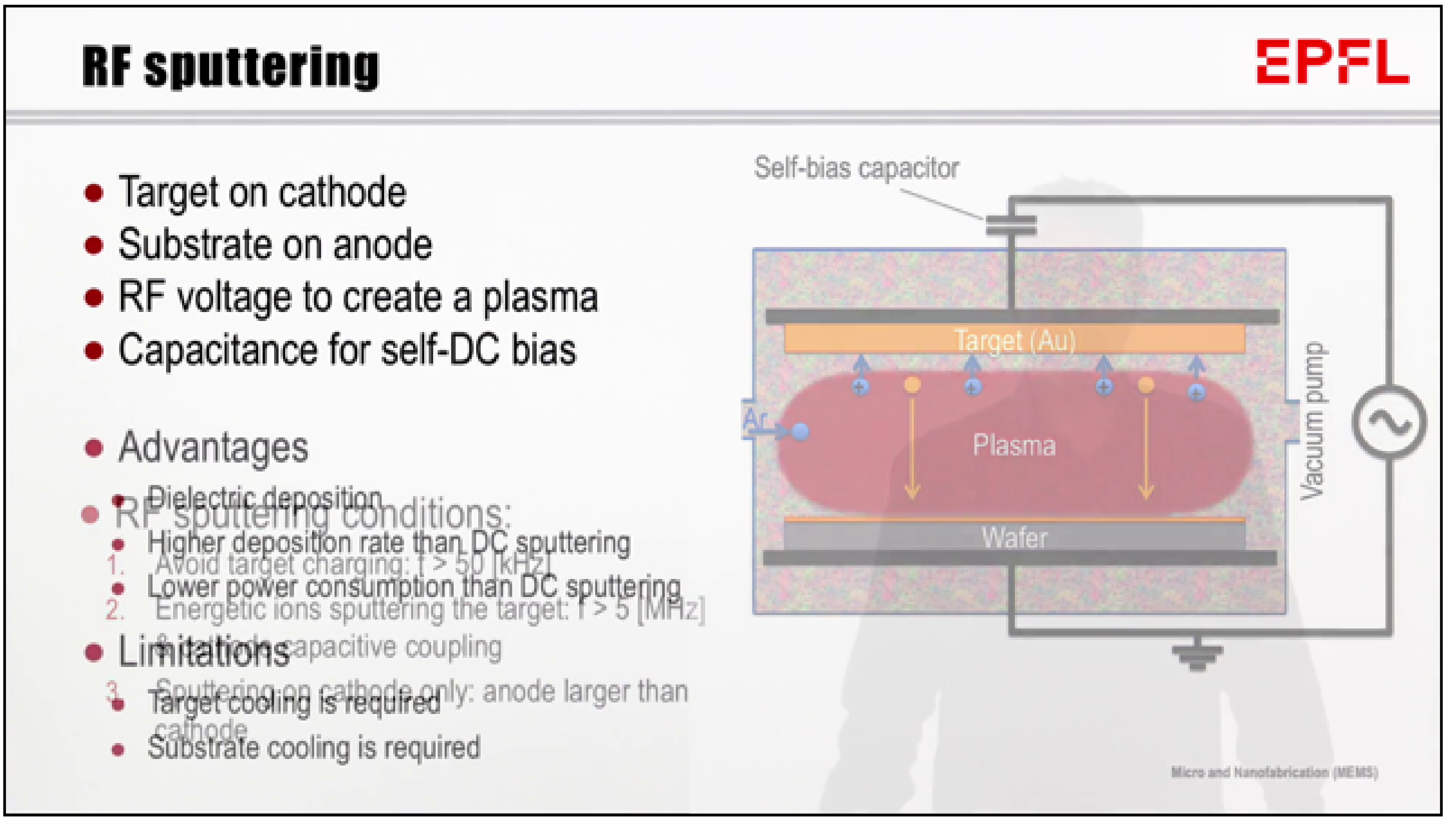
- RF sputtering conditions:
  1. Avoid target charging: f > 50 [kHz]
  2. Energetic ions sputtering the target: f > 5 [MHz] & cathode capacitive coupling
  3. Sputtering on cathode only: anode larger than cathode

Micro and Nanofabrication (MEMS)

accelerate ions the energy they will gain during on cycle is too low to eject atoms from the target. A solution to overcome this effect is to use frequencies larger than 5MHz typically, 30.56MHz, and the capacitor at the cathode for DC self-bias. At such high frequencies, ions cannot follow the RF field anymore, due to their mass. On the other hand, electrons are lighter and can follow the RF field. They will then alternatively strike the cathode and the anode. However, because of the capacitor at the cathode they will accumulate there, and the cathode will progressively be negatively biased. This negative DC voltage will then accelerate positive ions from the plasma, and enable the sputtering process. The third condition is to avoid sputtering of other surfaces than the target. For example, avoid having ions colliding somewhere else than on the target. To do so, the anode must be larger than the cathode. This result is studied in more details in the chapter about dry etching given by my colleague, professor Martin Gijs. The reason behind is that having a smaller cathode allows having a larger potential drop and thus more bombardment, because of current conservation. In a typical RF sputter system, the anode and the entire chamber

notes

summary

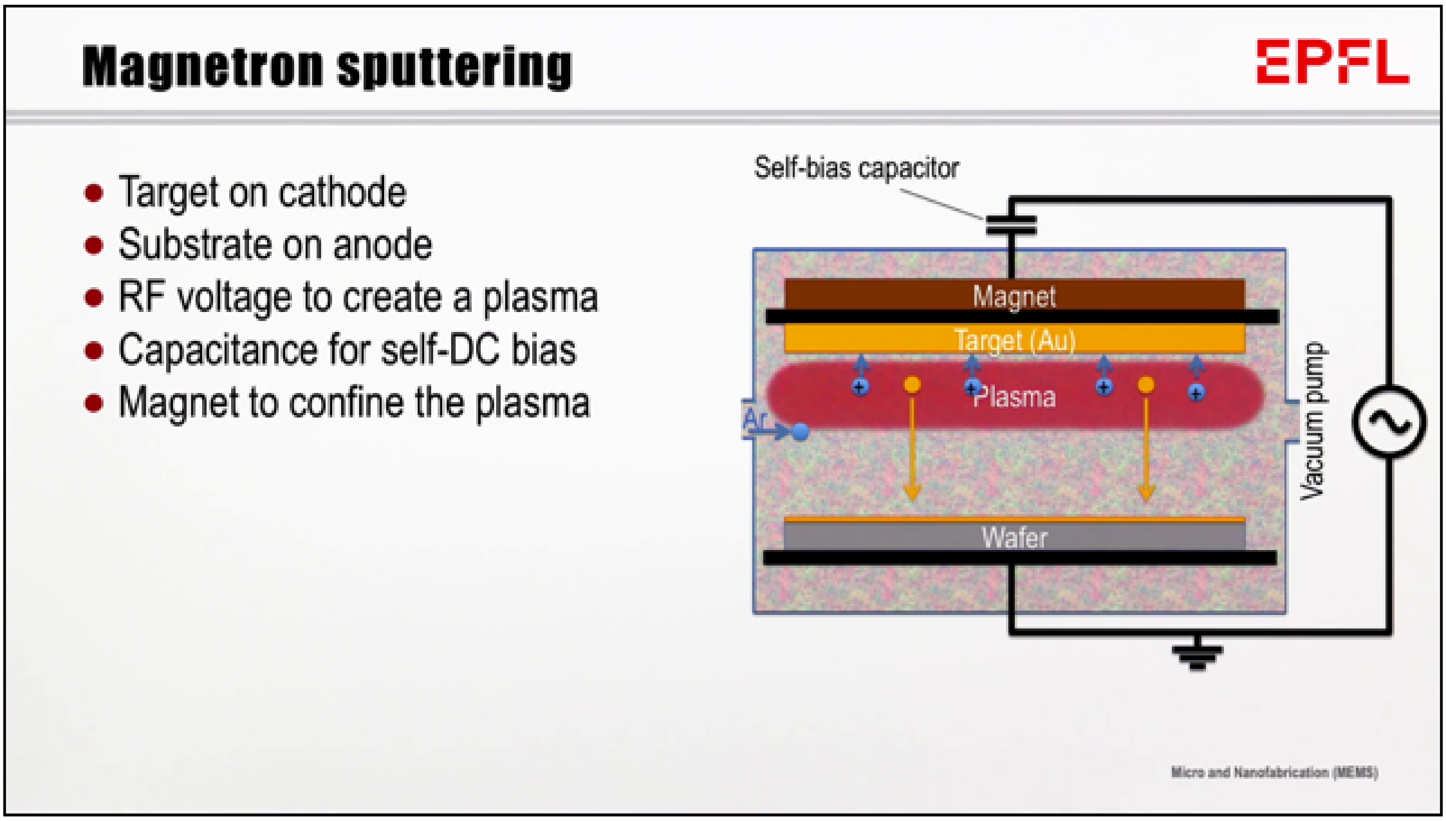


are therefor grounded to satisfy this condition.

notes

summary

5m 1s

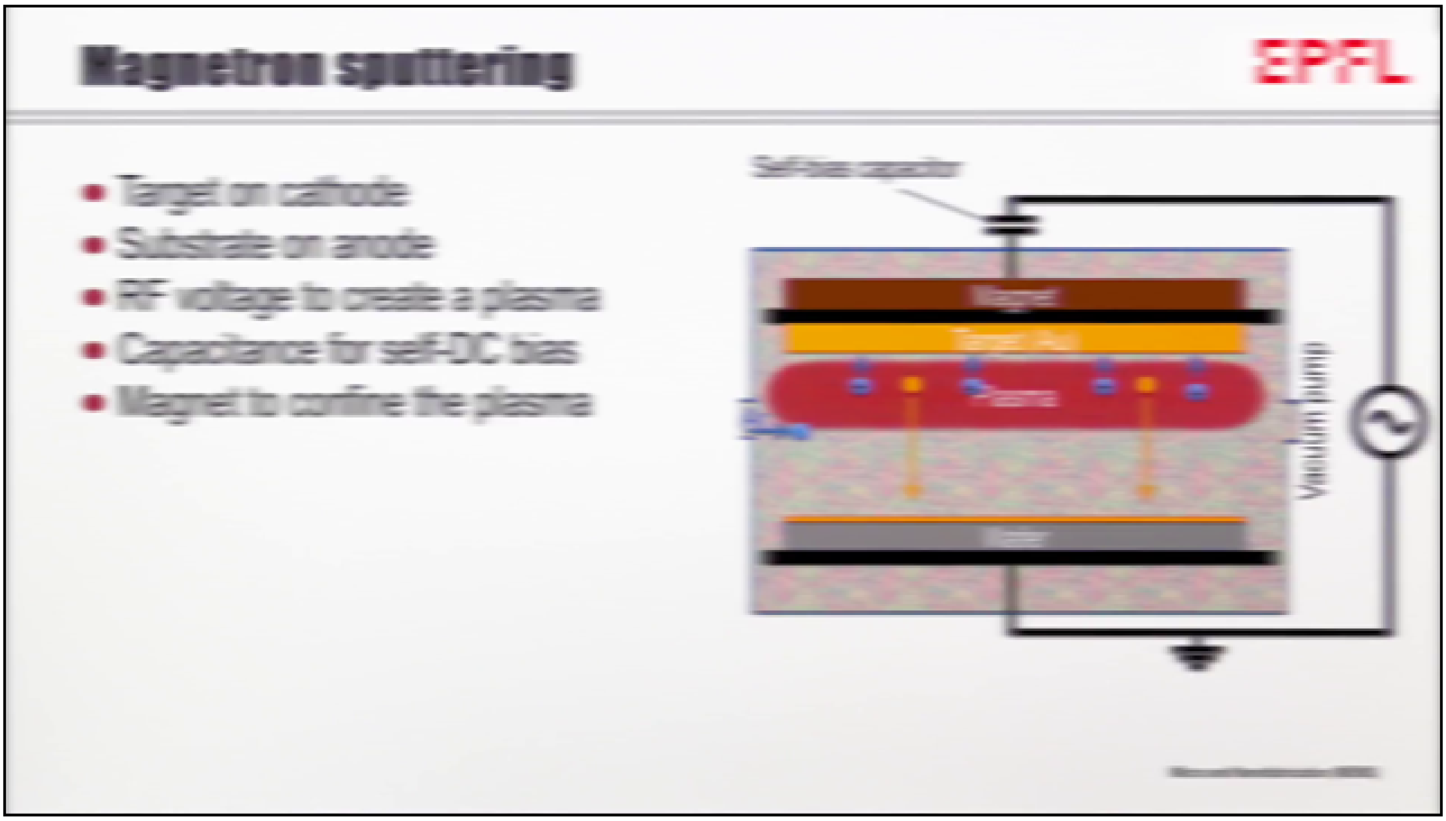


The main advantage of RF sputtering over DC sputtering is it's ability to overcome charging problems and thus to deposit electrically insulating materials, such as dielectrics. In addition, electrons oscillating in the RF field couple the energy more efficiently to the plasma, as a result, compared to DC sputtering, higher deposition rates are achieved and lower power consumption is required in the RF sputtering. However, there's one main drawback leading to the deposition of the electrically insulating materials. These materials are often poor heat conductors which requires very efficient cooling of the target during the sputtering. In addition, as for the DC sputtering, the plasma is not localized and many electrons hit the substrate and heat it up thus substrate cooling is also required. To even further increase the plasma efficiency and thus the deposition rate magnetron sputtering systems are introduced.

notes

summary

5m 4s



The added feature compared to the RF system is the magnet placed behind the cathode, shown here which creates a magnetic field, who's goal is to confine electrons so they stay close to the cathode, and induce a lot of collisions with argon atoms to ionize them and contribute to the sputter process.

notes

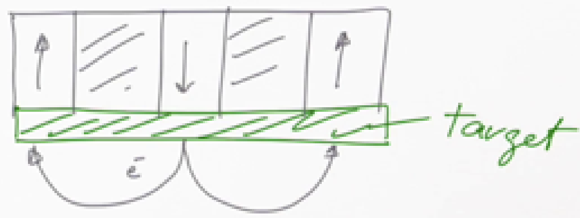
summary

6m 13s

Magnetron sputtering

EPFL

- Target on cathode
- Substrate on anode
- RF voltage to create a plasma
- Capacitance for self-DC bias
- Magnet to confine the plasma



- Lorenz force $\vec{F} = q\vec{v} \wedge \vec{B}$

F = force in [N]
q = elementary charge in [C]
v = particle speed in [m/s]
B = magnetic field in [T]

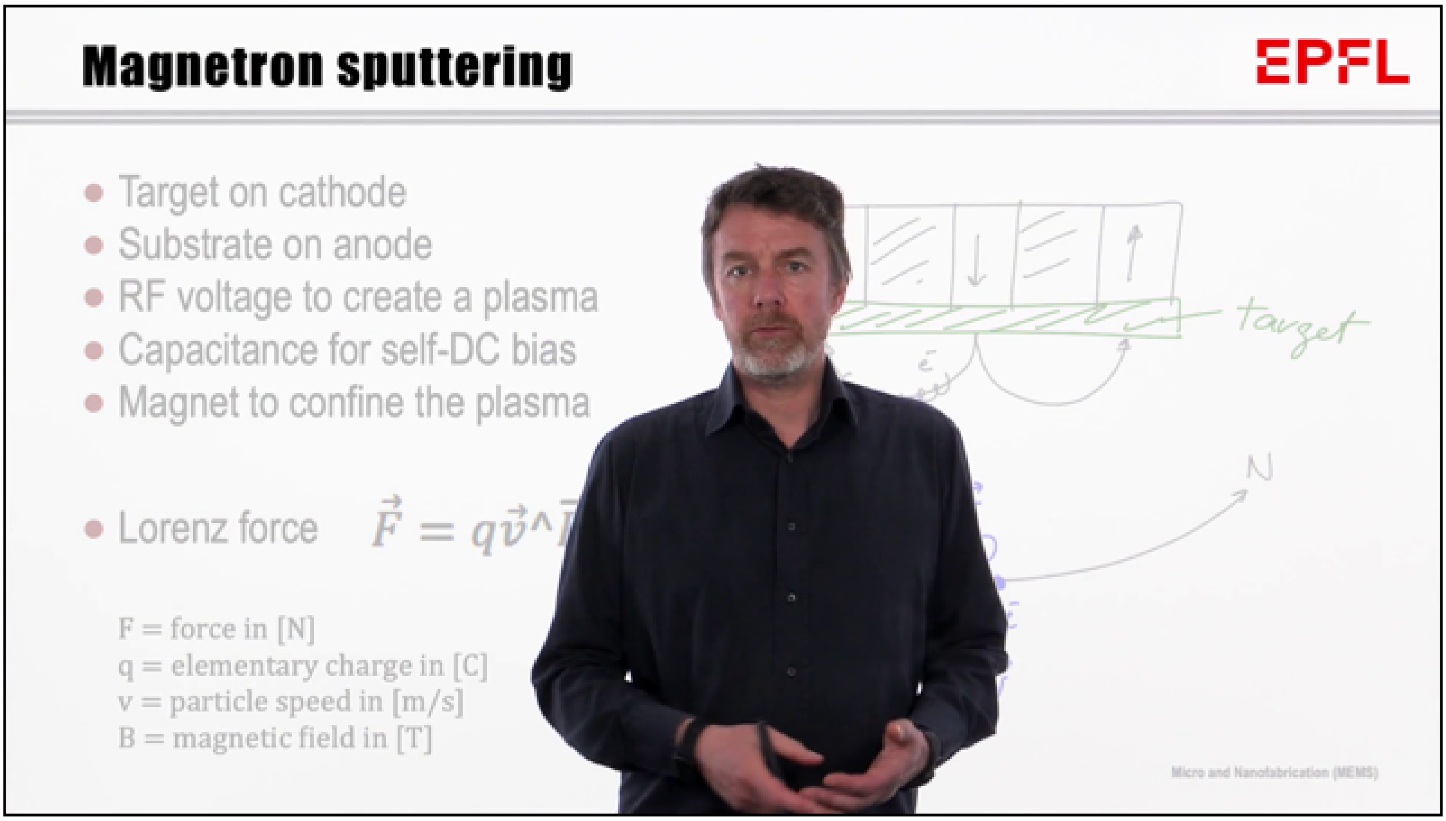
Micro and Nanofabrication (MEMS)

Let's have a closer look how this works and what it brings. So, let's assume that we have here our target material that we want to sputter any metal or dielectric so we mount our target on a setup that includes a magnet so, here we have a magnet, which has magnetic field lines showing like this and that means we have here to close the magnetic field here, magnetic field, that are going into the plasma and here we have an electron

notes

summary

6m 34s



in this area it will spiral and follow the field line as schematically show here. So why is that? You all know that we have here the south and north pole of the magnet and we have here, an electron that has a certain velocity V and within the magnetic field B, that we have then a force that is orthogonal to the two vectors of the velocity and the magnetic field so that, this electron has no other choice than spiraling around the magnetic field line, and follow it, basically.

notes

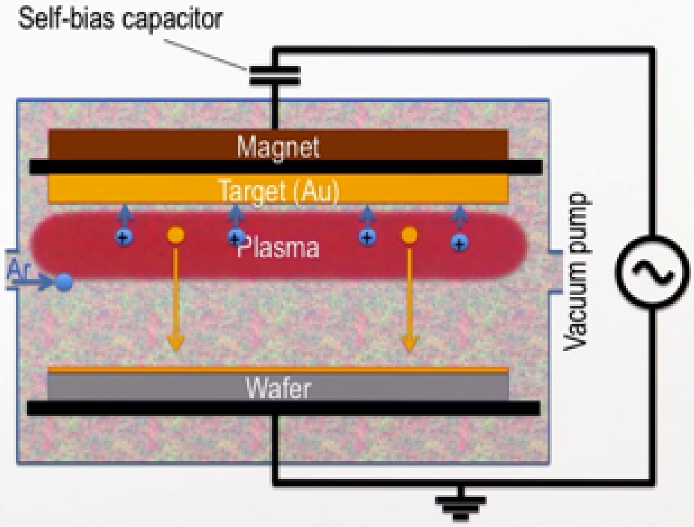
summary

7m 25s

Magnetron sputtering

EPFL

- Advantages
  - Lower voltages
  - Lower pressure = higher purity
  - Higher deposition rate
  - Less substrate heating
- Limitations
  - Complex system
  - Non uniform wear of the target



- Magnetron with RF and DC sputtering

Micro and Nanofabrication (MEMS)

Due to Lorentz forces, electrons follow a helical trajectory while ion trajectory is not influenced because of their higher mass. So, having a magnet behind the target allows to confine electrons close to the target.

notes

summary

8m 20s

Magnetron sputtering

EPFL

Target after short usage
~ 254 x 127 mm

Extensively used target

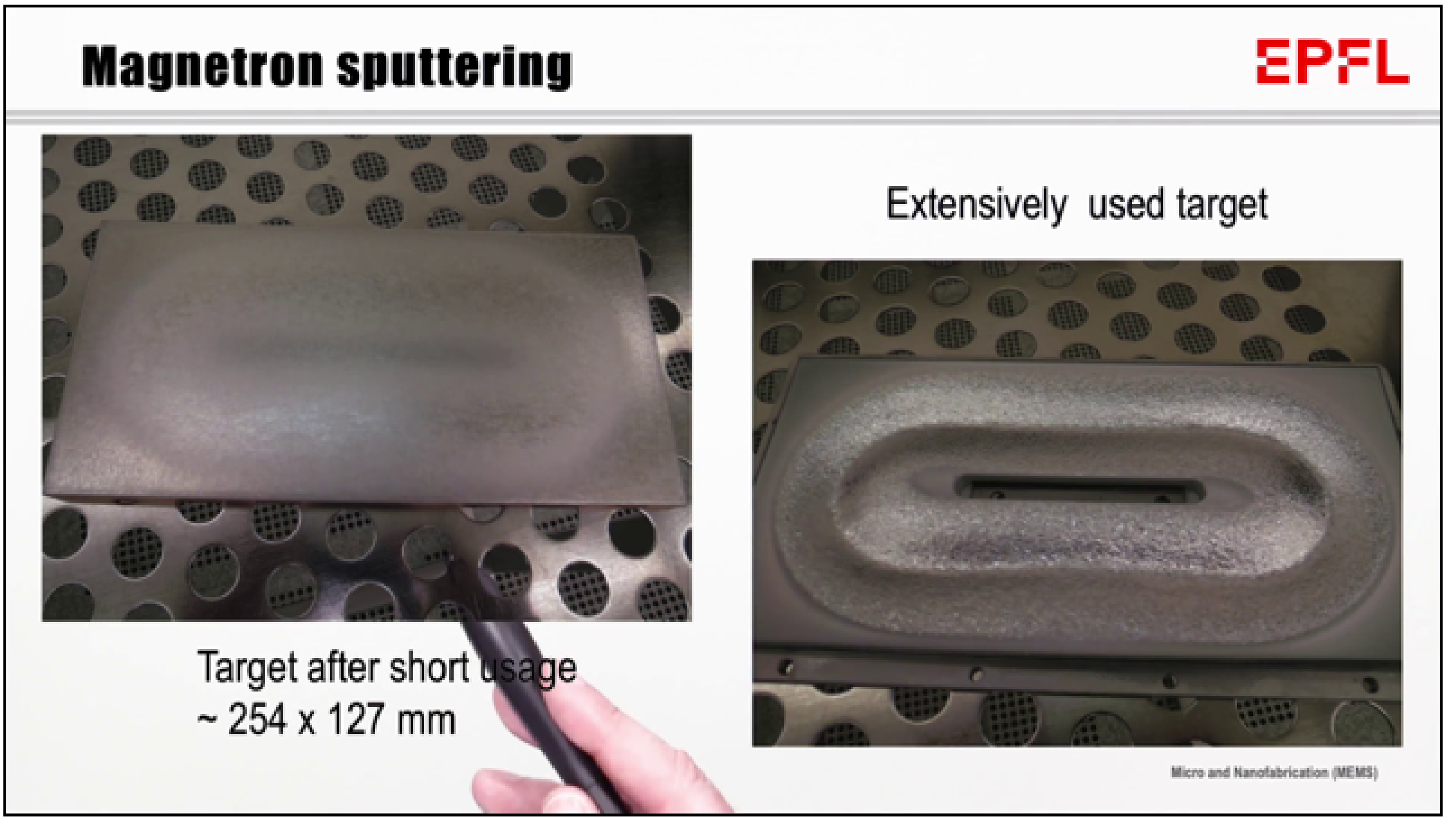
Micro and Nanofabrication (MEMS)

This improves ionization efficiency, because of the larger amount of collisions between Argon atoms and electrons. As a result, it is possible to use lower voltages and lower pressure, which allows deposition of film with higher purity. In addition, the plasma is localized. This enables higher deposition rates because of the larger amount of ions impacting the target, and also decreases substrate heating, as less electrons collide on the wafer. On the other hand, the system becomes more complex and the wear of the target is non-uniform. Here on these two photographs you can see two targets of a magnetron sputtering tool. The left image shows the target after some short term usage where we can start seeing how the material is being eroded.

notes

summary

8m 37s

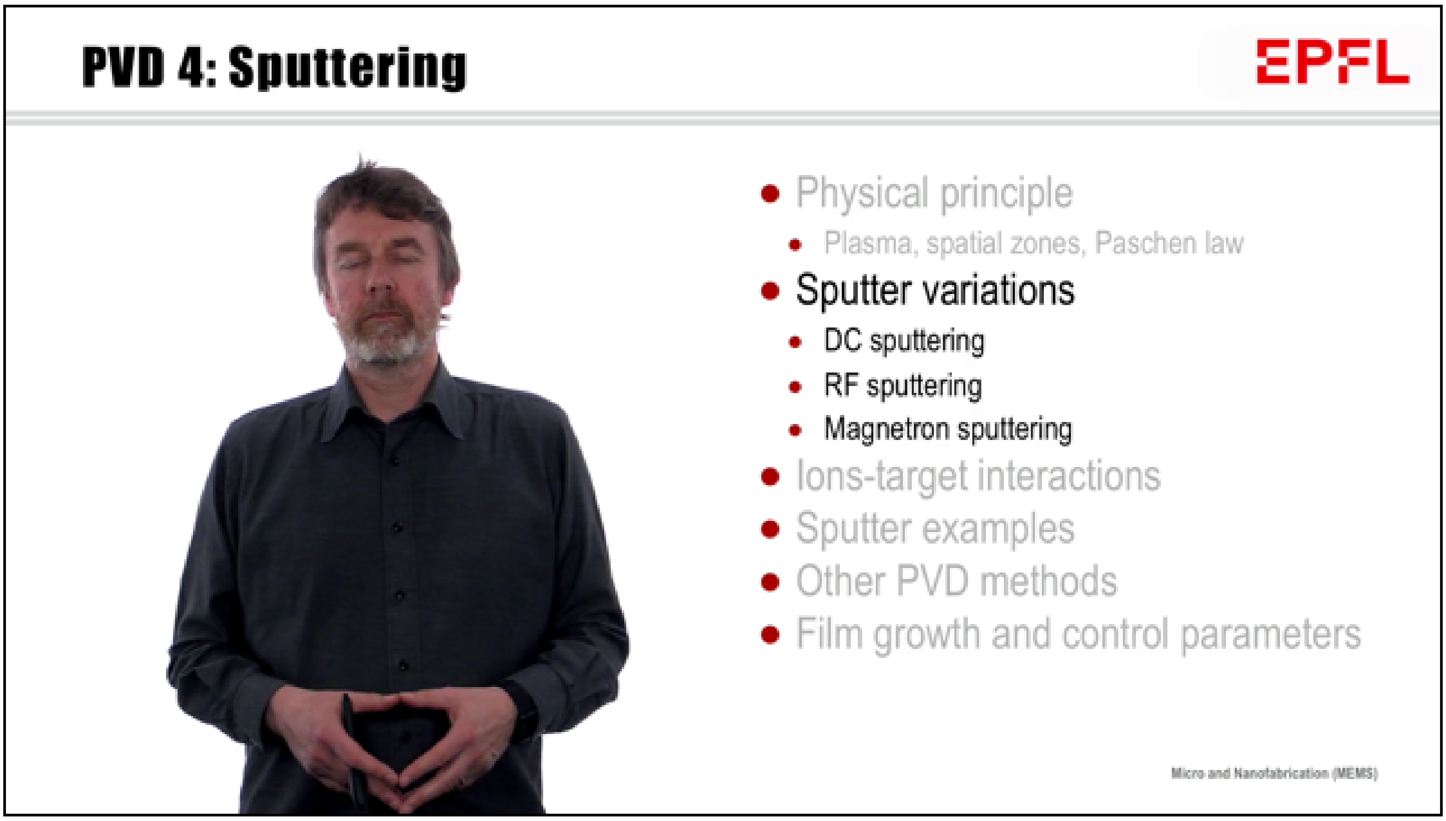


On the right photo, we see a similar target

notes

summary

9m 25s



after extensive use where a lot of the material has actually been removed. The pattern here shows the ion distribution as a function of the magnetic field provided in the magnetron sputtering tool. So now we have seen how DC, RF and magnetron sputtering are working. Let's have a closer look how actually the ions are interacting with the target material to be able to remove material and deposit it on the substrate.

notes

summary

9m 26s