



Creating Higher-Education
Industry Programmes for the
Semiconductor Industry of Europe

Virtual Lab Class „Temperature Sensor“



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1. Introduction to VLabS

Semiconductor devices have become indispensable in our everyday lives. They are the foundation of our modern communication. We use them in smart homes as well as in charging stations for electric cars. And artificial intelligence is impossible without supporting hardware based on semiconductor components. But how are semiconductor components manufactured?

VLabS - the Virtual Laboratory for Semiconductor technology is being created within the EU-funded CHIPS of Europe project (www.chipsofeurope.eu). The goal is to provide insight into the exciting laboratory environment that makes it possible for tiny chips to make our lives amazing.

2. Objective of the virtual lab class on temperature sensor fabrication

Temperature sensors are used in many devices to set a certain temperature value or protect a system from overheating: kettle, washing machines, smartphones, or air conditioning are just a few examples. In most cases the smaller the sensor is, the easier it is to integrate it and the smarter the system becomes. Therefore, thin film technology as used in the semiconductor industry is so important.

The Virtual Lab Class „Temperature Sensor“ is intended to provide insight into typical fabrication processes in semiconductor technology. The temperature sensor fabricated in this class is based on a thin metallic meander fabricated on an oxidized silicon wafer. The metal meander changes its resistance when heated or cooled. Therefore, measuring the resistance allows to define the ambient temperature. The lab takes place in VLabS – the Virtual Laboratory for Semiconductor Technology. Processes such as

- optical lithography,
- metal deposition,
- structuring by lift-off
- screen printing
- wire bonding

are introduced. The following labs are going to be visited:



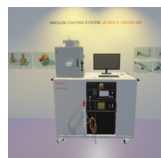
Resist
coating



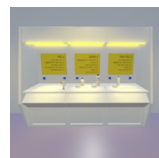
UV exposure



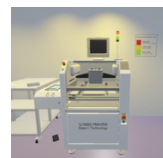
Development



Metal coating



Lift-Off



Screen
printing



Wire bonding

In VLabS you will find instructions on how to deal with the different tools and how to choose the correct process parameters.

3. Processes for fabricating a thin film temperature sensor

Cleanroom

A cleanroom is a laboratory:

- in which the particle concentration in the air is controlled,
- which is designed to ensure that few particles are introduced into or generated within the room,
- in which relevant parameters such as temperature, humidity, and pressure are controlled.

Cleanrooms are required in the microelectronics and semiconductor industries, because dust-free processes are essential. Quality assurance and process reproducibility are always the focus. In semiconductor technology structures in the micro- and nanometer range are created, which are smaller than typical dust particles. Contamination can therefore lead to short circuits or other undesirable disruptions to functionality. When working in a cleanroom people need to wear protective clothes, including an overall, special shoes, and gloves, to release as little particles as possible. When entering VLabS you will be asked to get dressed for the fascinating lab environment!

Wafer

A wafer is a thin, circular substrate in semiconductor technology. It can be made from silicon (Si), but other materials, such as Gallium Nitride (GaN), are nowadays interesting for high power applications as well. A wafer consists of polycrystalline or crystalline material and is usually several hundred micrometers thick. The diameter can be as big as 300mm. Wafers are marked with flats or with notches and labeled with a barcode.

In this class, an oxidized Si-wafer is used to carry the temperature sensor. The oxide is needed to prevent a short circuit between the meander lines of the sensor. Figure 1 shows an oxidized silicon wafer with temperature sensors made from evaporated aluminum.

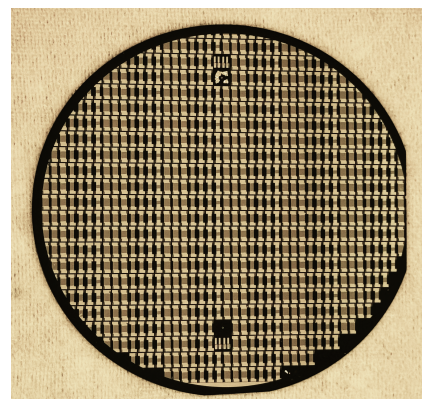


Fig. 1: 4-inch Wafer, labelled by a flat on the right, with aluminum temperature

Optical lithography

The entire process begins with the design of the temperature sensor on the computer. This design is then replicated and arranged on the wafer in such a way that the wafer can later be sliced into chips. Figure 2 shows such a design. Using this design, a mask for lithography is created, e.g. by e-beam lithography or laser writing.

Two options exist for creating metal structures in the lab: using lithography and lift-off or lithography and etching. The term lithography refers to the process of transferring a design into a light-sensitive layer, a so-called photo resist, on the wafer. In this class, the metal structures created for the temperature sensor are structured using lithography and lift-off. Nevertheless, both processes are outlined in Figure 3.

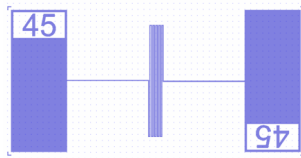


Fig. 2a: Single meander-shaped sensor with contact pads.

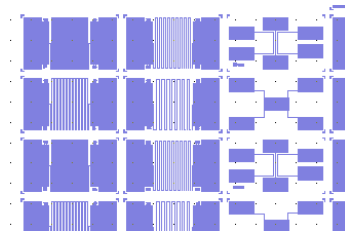


Fig. 2b: Several designs combined.

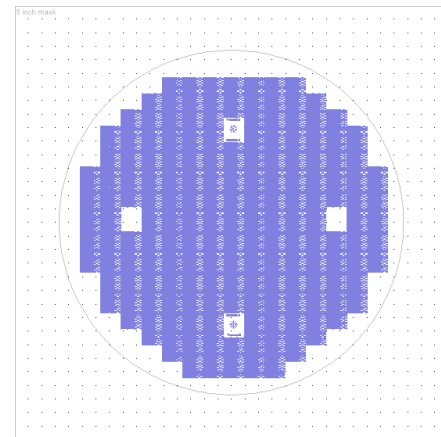


Fig. 2c: Designs aligned across a wafer.

Photoresists are sacrificial materials in the whole process flow. They are used to transfer the design, but do not remain on the wafer. A distinction is made between positive and negative resists. The main difference is that after exposure, in the case of positive resists, the exposed areas are dissolved during development, whereas in the case of negative resists, the exposed areas are cross-linked and remain on the wafer. Positive resists are preferred for structuring using etching techniques, and negative resists are preferred for lift-off processing.

A photoresist is spun on, hardened, and exposed through a mask with the desired structure design. During spin-coating, the rate in rounds per minute (rpm) determines the thickness of the resist. Typical rates are 3000–7000 rpm. As an alternative to spin-coating, photoresists can also be sprayed or applied by dip coating. Have a look at the gallery in VLabS!

When joining VLabS you will skip the process of mask fabrication and directly start with resist coating. You continue with the UV exposure necessary to define the meander structures on your wafer. The process of lithography is then finished by developing the negative resist.

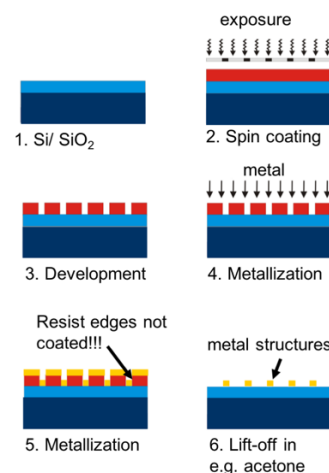


Fig. 3a: Structuring by Lift-Off.

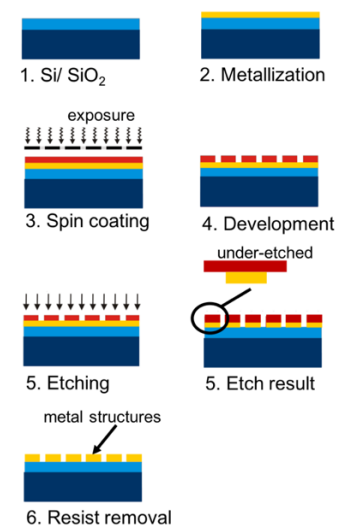


Fig. 3b: Structuring by etching.

Metal deposition

There are many options for creating thin layers. Sputtering, pulsed laser deposition, or molecular beam epitaxy are just a few such processes. In this lab, a thin metal layer will be deposited by thermal evaporation. A schematic is shown in Figure 4. This process takes place in a pre-evacuated chamber in order to avoid contaminants and oxidation. The target material to be deposited is located in a tungsten boat. The boat is heated using a current so that the material evaporates. Because the melting point of tungsten is higher than that of the material to be deposited, the boat remains intact. The vapor cloud spreads in the chamber. Because the substrate is cooler, material from the vapor cloud condenses on the substrate, and a thin layer grows. A quartz crystal serves to adjust the deposition rate and determine the end point. The thickness of the metal layer depends on the resistance you would like to achieve. The thicker the layer becomes the lower is the resistance. Typical evaporated layer thicknesses range from a few tens of nanometers to 500nm.

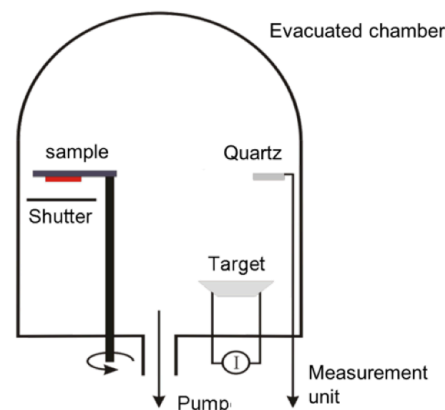


Fig. 4: Schematic of thermal evaporation.

Structuring by lift-off

After metal deposition the metal needs to be lifted-off where it is not needed (Fig. 3a). The thin metal layer is deposited on the whole wafer: it covers the resist as well as the meander-shaped openings in the resist. When rinsing the wafer in acetone, isopropanol, and de-ionized water the resist is dissolved and all the metal on top of the resist removed from the wafer. The wafer can be dried and the meander-shaped sensors can be tested on the wafer. A chip is produced by cutting the wafer along designated saw streets.

Screen printing

In parallel to chip fabrication a carrier for assembling the chip into a system is prepared. Contact pads for connecting the chip are fabricated on the carrier. These pads are made from screen-printed silver. For screen printing, a stencil is required. This stencil contains aligned openings that correspond to the desired structure. A squeegee is used to print the functional paste through these openings onto the carrier, after which it is heated in an oven.

After screen printing the chip is mounted onto the carrier, such as a printed circuit board or a ceramic substrate. Backside soldering is one assembly technique that can be used. In this experiment, the chip is glued onto the ceramic carrier.

Wire bonding

The front side contact of the sensor is created by wire bonding between chip and contact pad on the ceramic substrate. Ribbon, wedge-wedge and ball-wedge bonding are distinguished. The latter is used

in this experiment. Ball-wedge wire bonding is a crucial technique in semiconductor and microelectronics manufacturing, enabling reliable connections between a chip and its package or substrate. This method involves two key steps: creating a ball bond and forming a wedge bond, typically using a thin gold or copper wire.

The process starts with the formation of a ball bond. A small section of the wire protrudes from the capillary tool of the wire bonding machine and is melted using a precise electronic flame-off or an electric spark to create a spherical ball at the wire's end. This ball is then pressed onto the intended bonding pad on the chip, applying heat, pressure, and sometimes ultrasonic power, ensuring a secure connection.

Following the ball bond, the wire is strung to a corresponding pad on the substrate or package. The wire is manipulated to form the desired loop shape, accommodating thermal expansion or mechanical restrictions. The wedge bond is then formed by pressing the wire onto the second bonding pad with the capillary tool and applying similar thermal and ultrasonic effects.

This technique offers high reliability and precision, making it ideal for high-frequency and sensitive applications. Ball-wedge wire bonding is instrumental in ensuring electrical connectivity in integrated circuits and electronic devices, contributing fundamentally to their performance and endurance.

4. VLabS Preview

When joining VLabS you will start on the landing page where you are introduced to all partners. Take a tour around the lab building to see the partners represented on the campus or enter the lab building directly.

Please use the arrow keys or “W-A-S-D” to pass the gates and enter the lab. You can also use your mouse or touchpad to look around.



1. Campus site

Follow the instructions to get your way in.



2. Get dressed for the lab!

Have a look at the gallery and take your time to find about the connection of semiconductor processes and products to our daily life.



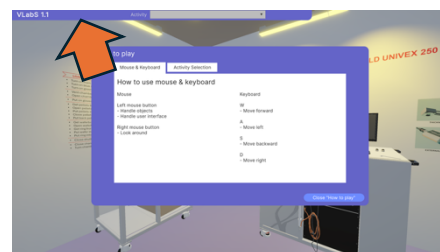
3. Have a look at the gallery!

Enter the lab and interact with the tool. Instructions can be found on the walls, tables, or in the menu bar. Maybe you need to adjust the zoom factor to see the menu bar. When clicking on “activity” you can pick the tool you want to interact with. Make sure, you are in the correct lab.



4. Enter the lab!

Need help? Just a click away behind the button “How to play”. A window opens explaining the use of mouse and keyboard and how to select an activity.



5. Let ´s play!

Join the lab: <https://sci-intern.hm.edu/06/chips/vlabs/>