Subject 5: Electrical and optical characterization

1. Objective

During this session, you will characterize the samples from sessions 3 and 4. Three tools will be used for characterization: 1) an optical microscope to quickly observe the pattern shapes, 2) a scanning electron microscope (SEM) to examine the 3D structure of the geometric forms and 3) a four-point probe to measure the electrical resistances of aluminum layer.

2. Electrical characterization

Resistors :General considerations.

The resistor consists of a resistive layer that is shaped to achieve the desired resistance. These resistors can be fabricated from metal films deposited onto specific areas of the substrate. Due to their small dimensions, these resistors occupy very little space on the substrate. The resistance of the resistor body is given by :

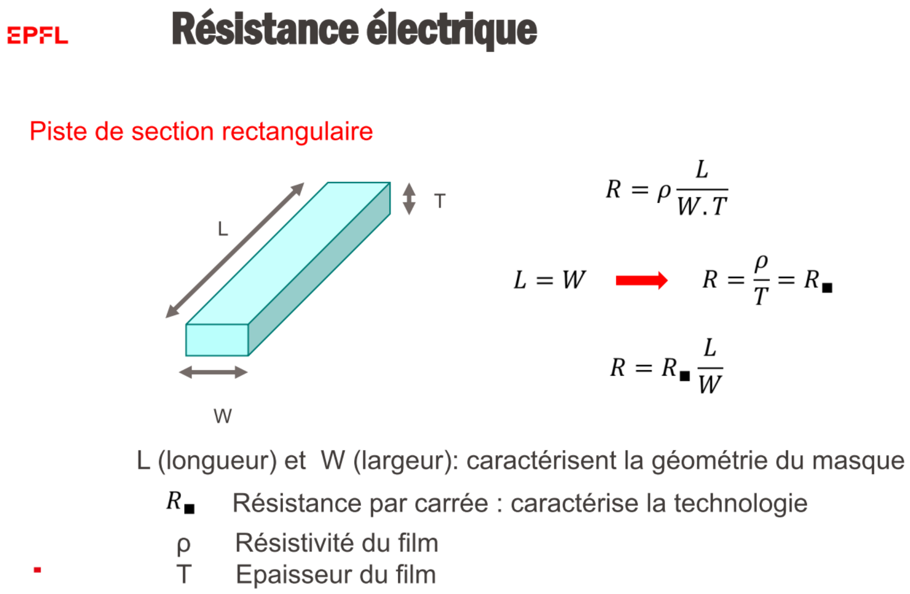
$$R = \frac{\rho}{t} \times \frac{L}{W}$$

In case where $L = W$, the film seen from the top presents a squared shape, which yields to a sheet resistance of the film, R_s,

$$R = R_s = \frac{\rho}{t}$$

Where:

- ρ is the electrical resistivity of the film
- t is the thickness of the film
- L is the length of the metal film,
- W is the width of the metal film.



EPFL **Résistance électrique**

Piste de section rectangulaire

$$R = \rho \frac{L}{W.T}$$

$$L = W \rightarrow R = \frac{\rho}{T} = R_\blacksquare$$

$$R = R_\blacksquare \frac{L}{W}$$

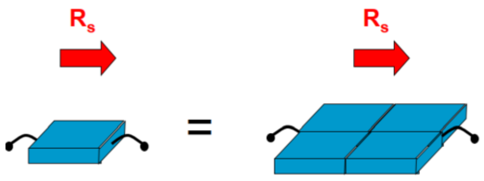
L (longueur) et W (largeur): caractérisent la géométrie du masque

$R_\blacksquare$ Résistance par carrée : caractérise la technologie

ρ Résistivité du film

T Epaisseur du film

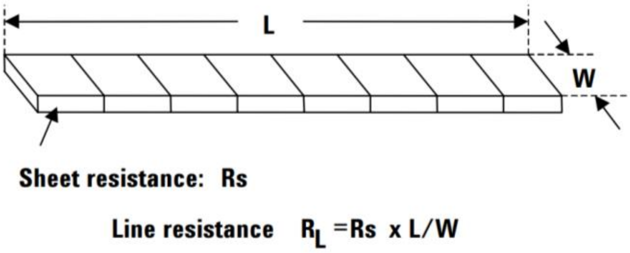
Sheet resistance is the resistance of a square of conductive thin film with uniform thickness. It depends only on the film's resistivity and thickness, and not on the area of the sheet. This means it remains unaffected by variations in area that may arise from factors like pattern misalignment or film etching



$$R_S = (R_S \parallel R_S) + (R_S \parallel R_S)$$

The relation beween the resistance of film and its sheet resistance is given by:

$$R = R_s \frac{L}{W}$$



Any simple metal line can be divided into square blocks. Since each square has the same sheet resistance (R_s), the resistance of the metal line is the number of square blocks (L/W) multiplied by the sheet resistance (R_s).

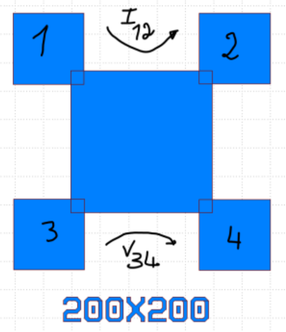
By measuring of the sheet resistance, it is possible to determine either resistivity or the thickness of the metal, depending on which of the two is known. It is also possible to measure the width of the line.

1. Four Point Probe Measurement Method

The most common method for measuring sheet resistance is the four-point probe technique. This method uses a set of four probes evenly spaced in a line. A current is passed through the two outer probes, which causes a voltage drop between the two inner probes. By measuring this voltage change, the sheet resistance can then be calculated.

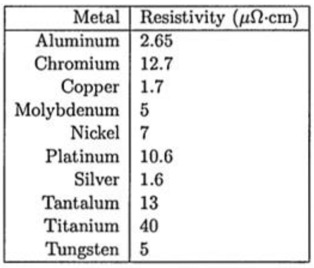
a. Sheet resistance measurement

Van der Pauw is a modification of the four-point method used to measure sheet resistivity with four probes placed on the periphery of an arbitrarily shaped sample. The technique is based on applying electrical current to two opposite corners of the sample and measuring the voltage across the other two corners. The results obtained are the same as those achieved with the traditional four-point probe method. A typical combined test structure for a Van der Pauw setup is configured as a Greek cross, as shown below:



Sheet resistance is measured using the Greek cross. Current is applied between two adjacent pads 1 and 2, while the voltage is measured between the other two adjacent pads 3 and 4. From these measurements, the sheet resistance, R_s, is calculated using the formula:

$$R_s = \frac{\pi}{ln2} \times \frac{V_{34}}{I_{12}} \qquad \left({}^{ohms}/_{square}\, ,\, {}^{\Omega}/_{\blacksquare}\right)$$



Metal	Resistivity ($\mu\Omega$·cm)
Aluminum	2.65
Chromium	12.7
Copper	1.7
Molybdenum	5
Nickel	7
Platinum	10.6
Silver	1.6
Tantalum	13
Titanium	40
Tungsten	5

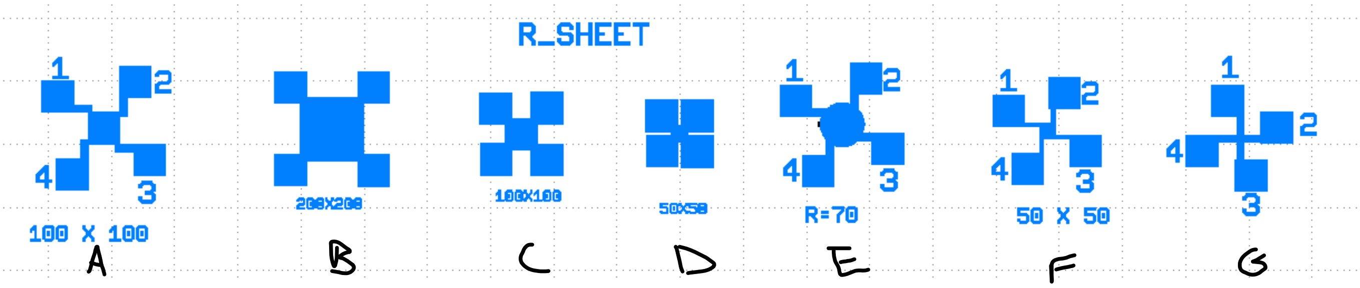
a. *Laboratory Procedure*

- Two probe tips for current injection, labeled I_1 and I_2. Under the optical microscope, use the micropositioning stage to place each tip on the corresponding pad on your sample.
    - Place the probe tips on the contact areas as follows:
        - for current injection: pads 1 and 2
        - for voltage measurement: pads 3 and 4.
        -
- Turn on the Keysight 34420A Nano_Volt/Micro_Ohm Meter and select Select the 4W mode, the resistance value is directly displayed.
    - The resistance value displayed is used to calculate the sheet resistance by the following formula:

$$Rs = \frac{\pi}{\ln 2} \times \frac{V_{34}}{I_{12}}$$

- Complete the following table :

structure	A	B	C	D	E	F	G
Rs (unit)							



- Comment on your results.

b. Transmission line method (TLM)

Resistors are tested and characterized with Karl Suss PM6 Probe station and the Keysight 34420A Nano_Volt/Micro_Ohm Meter. The devices to be tested are aluminum resistors obtained by chemical etching and lift-off methods. The layout of the resistors is shown in Figure below.

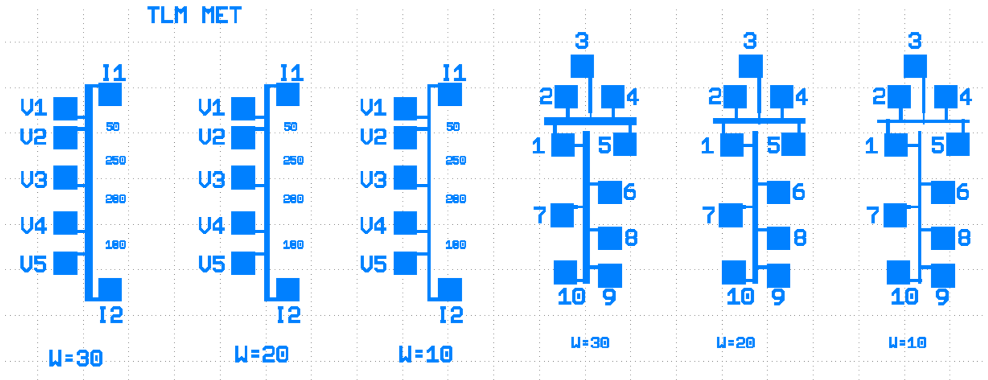


Figure . layout of resistor patterns

These structures will be used to plot the curve R versus L, where R is the electrical track resistance and L is the length of the resistor segment.

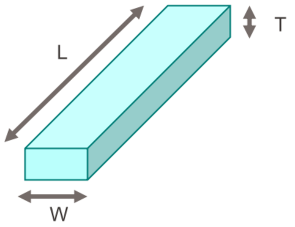
c. *Laboratory Procedure*

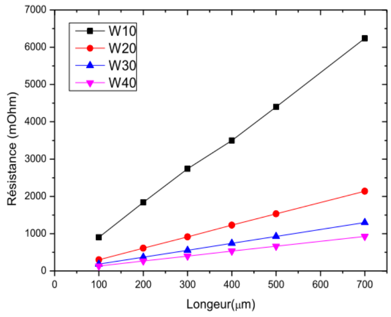
- Place the probe tips on the contact areas as follows:
  - Two probe tips for current injection, labeled I1 and I2. Under the optical microscope, use the micropositioning stage to place each tip on the corresponding pad on your sample with the same label of the probe tip.
  - Two probe tips for voltage measurement with labels V1 and V2. Under the optical microscope, place each tip on the corresponding pad on your sample.
  - Select the 4W mode on the Keysight 34420A Nano_Volt/Micro_Ohm Meter, the resistance value is directly displayed.
  - complete the following table:

contact	V1-V2	V1-V3	V2-V3	V2-V4	V3-V4	V4-V5	W (unit)	Student name
L(□m)	50	300	250	450	200	100		
R(unit)								
R(unit)								
R(unit)								
R(unit)								

Barre de section rectangulaire

$$R = R_{\blacksquare}\frac{L}{W}$$





$$pente = \frac{R_{\blacksquare}}{W}$$

Scanning electron microscope and optical microscope characterization

In this session, students will employ both a scanning electron microscope (SEM) and an optical microscope (OM) to make distinct observations of the samples they have prepared in topic 3 and 4. Through these tools, students will investigate how the sidewall profiles of the resist change in response to post-exposure baking (PEB) temperature and development time. The choice of the appropriate method will vary based on the specific information looking for and the material under investigation.

b. Laboratory Procedure

Under the optical microscope (Keyence digital microscope), observe your sample (from topic 3) on which you have already some patterned obtained under specific parameters.

- Each student characterizes his or her patterns.
- Measure the size of your patterns.
  - Observe your sample with NLOF 20 70 and AZ1512/LOR resists patterns obtained under different parameters.
  - For each sample, take pictures and measure the dimensions of the structures.
  - From topic 3, find the photoresist thickness
  - Based on these values, calculate the slop angle of the sidewalls, and propose a 3D shape of the pattern.
  - Observe both aluminum resistors obtained by etching and by lift off process.
    - Select one pattern of the same size, and compare between the two methods.

1. Optical microscope

Detecting the edges of resist patterns on substrates can be achieved using a simple method: optical microscopy (Keyence digital microscope). While optical microscopes offer good resolution, they may not provide detailed information about the sidewall profiles of the resist patterns, which are often the goal of this observation.

One advantage of the optical method is its convenience; samples can be easily loaded into a holder without the need for specific preparation procedures to secure them in place. Additionally, when dealing with transparent materials such as glass and nLOF negative resist, optical microscopes can be used in either transmission or reflection mode. However, when working with a silicon substrate, only the reflection mode is feasible.

Mount the sample on the sample holder, ensuring that the observed patterns are positioned at the top, facing the objective. Some typical examples are shown in the following figures. When viewed in transmission mode, both edges (the top and bottom ones) are easily visible

Using a microscope, it is possible to measure the difference between the edges under different experimental conditions.

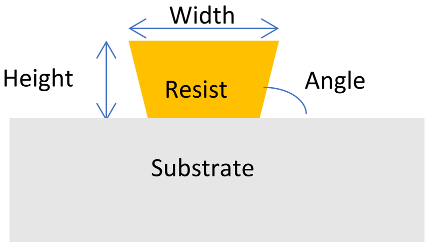
2. Scanning Electron Microscope (SEM)

The scanning electron microscope allows detailed examination of designs, assists in the development of new fabrication and production methods. The high-resolution capabilities of SEM have become indispensable in the quality control process. The information provided by SEM is related to the topography, composition, and morphology of the sample.

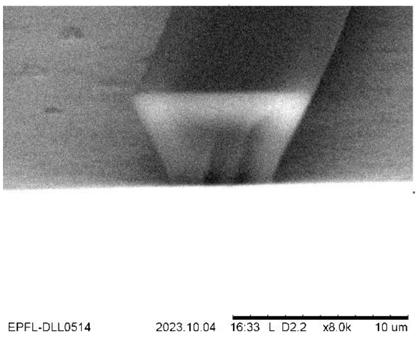
The samples are examined using a SEM (Hitachi tabletop Microscope, TM-1000) connected to computer for image capture. Thanks to the advancements in electronics and new techniques, this machine has become more accessible for many users, requiring only a short training period to operate effectively. However, achieving sharp and informative photos necessitates proper sample preparation and SEM parameters optimization.

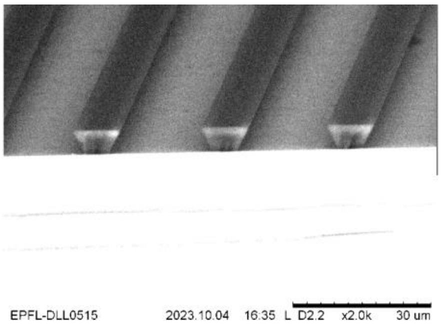
Sample Preparation

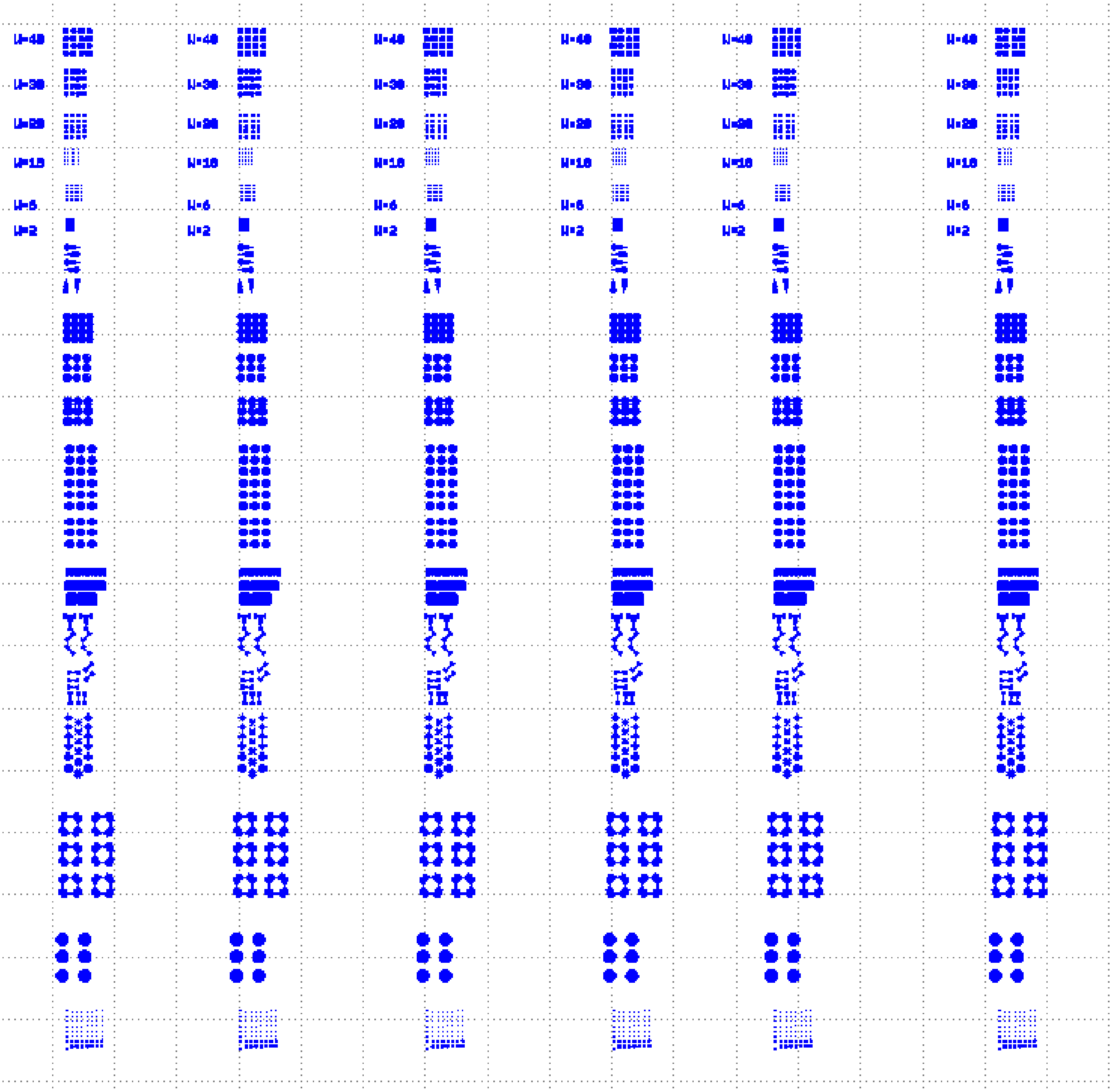
- First, it is important to consider the sample's size, its shape and state, and its conductive properties.
- For the observation of the cross-section of the patterned resist, the sample must be accurately cleaved along the specific area for analysis. Since cleavage is a manual operation, success is not guaranteed, and it must be performed with careful precision, often requiring repeated attempts.
- The appropriate sample position for SEM observation is achieved using a specialized holder, which allows the sample to be positioned at a tilted angle.
- Mount the sample on the sample holder and orient it at an angle, ensuring that the observed patterns are positioned at the top, facing the electron beam.
- From these digital SEM micrographs, determine as many shape parameters as possible, including width, height, and the angle of the sloped sidewalls, as illustrated in the following figure.



Following are SEM images of nLOF resist on silicon substrate with sloped sidewalls.



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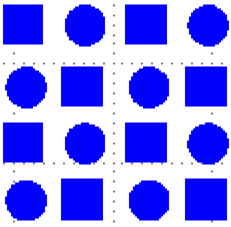

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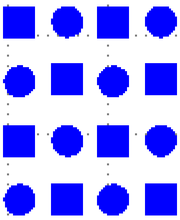

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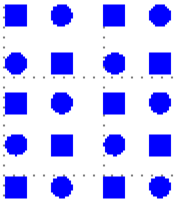

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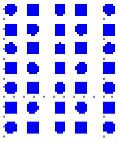

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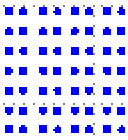

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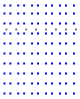

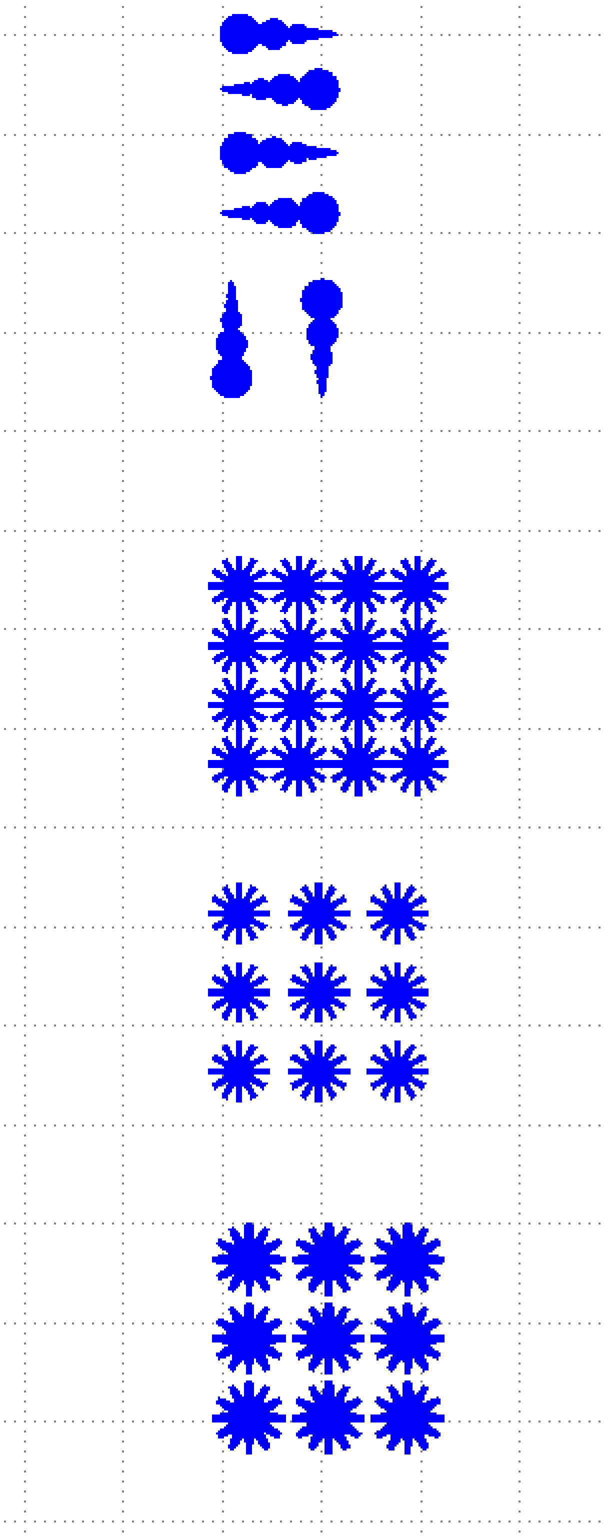

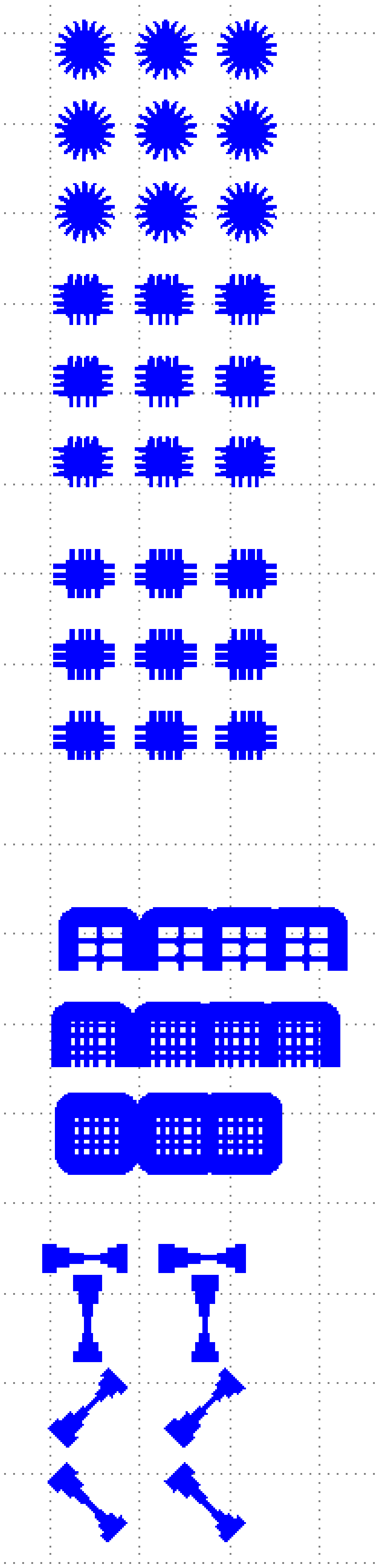

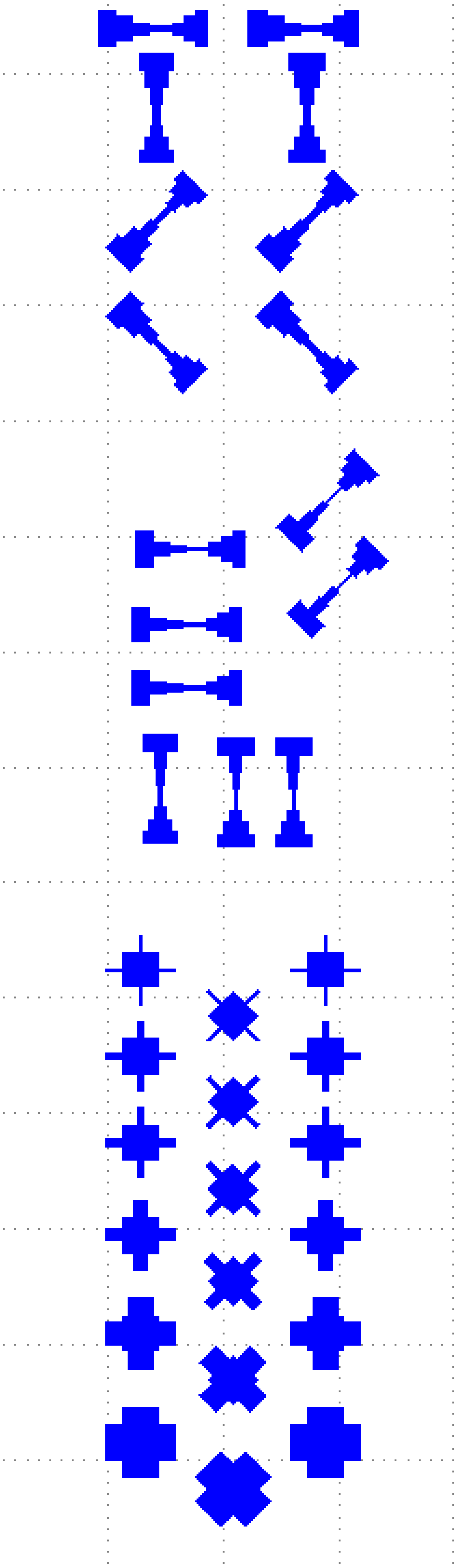

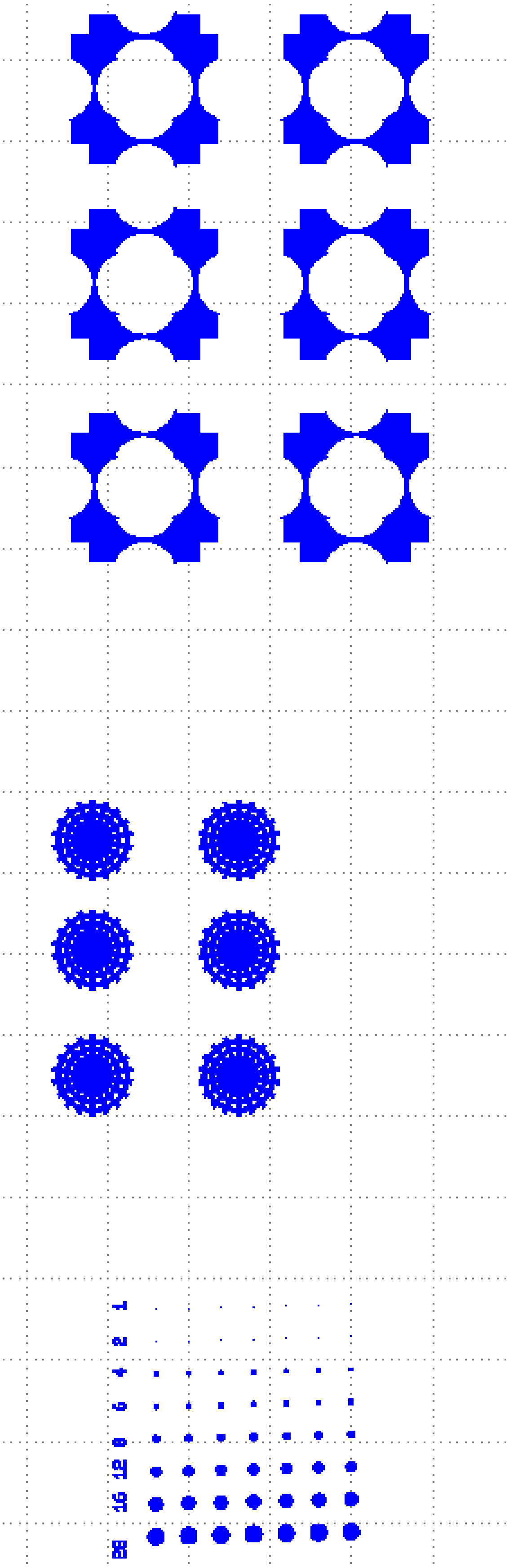
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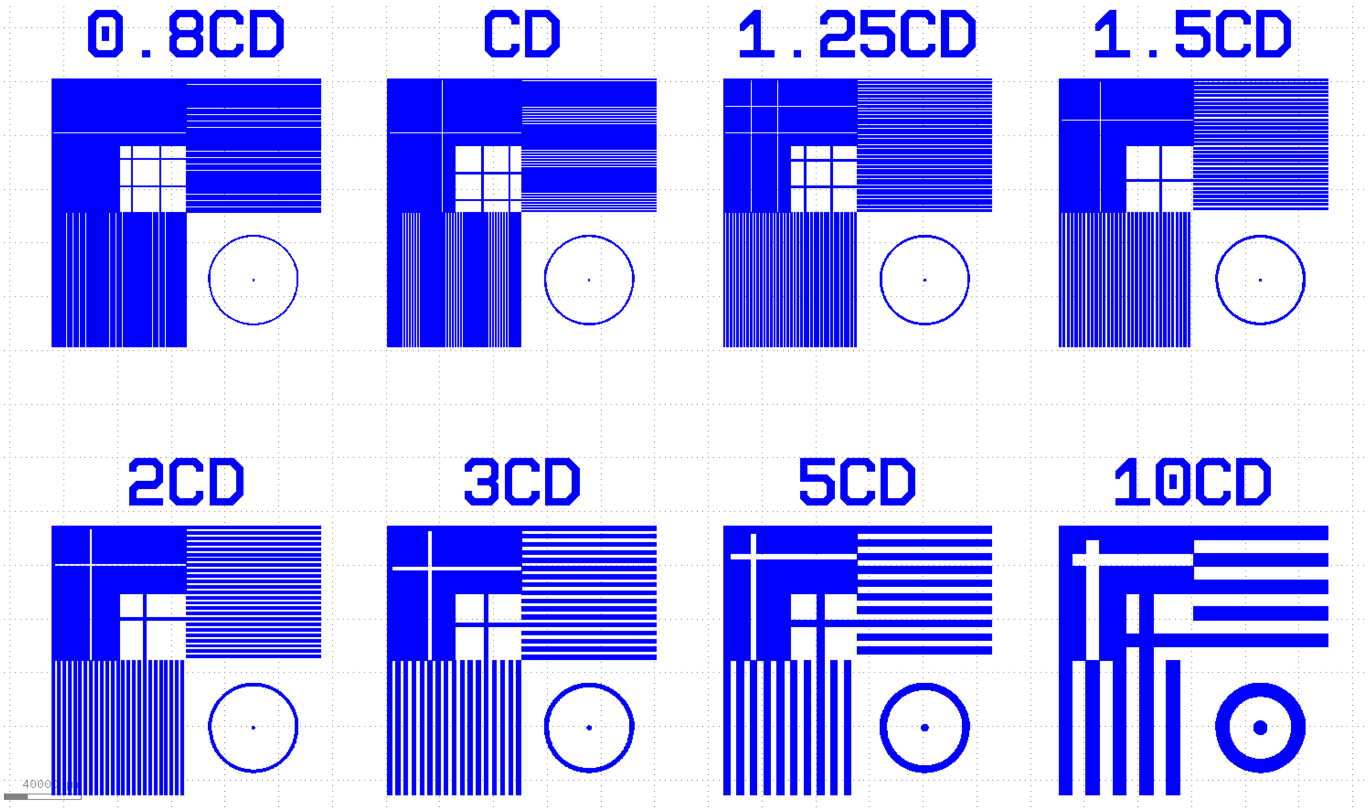
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