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Completed on	Monday, 14 November 2022, 13:16
Time taken	8 mins 26 secs
Marks	16.58/18.00
Grade	**9.21** out of 10.00 (**92**%)

Question **1**

Partially correct

Mark 0.67 out of 1.00

T-SPL versus EBL

What are the advantages of thermal scanning probe lithography over e-beam lithography?

- ☐ Fast patterning over large areas.
- ☑ Thermal scanning probe lithography does not require vacuum. ✔
- ☑ Closed-loop lithography allows rapid prototyping of novel structures. ✔
- ☐ Patterning on electron sensitive fragile substrates is possible.

Your answer is partially correct.

You have correctly selected 2.
See video “Alternative patterning methods: scanning probe lithography”. Although SPL is becoming fast, this is not an advantage over EBL that remains of greater throughput.

The correct answers are: Patterning on electron sensitive fragile substrates is possible.,
Closed-loop lithography allows rapid prototyping of novel structures.,

Thermal scanning probe lithography does not require vacuum.

Question **2**

Partially correct

Mark 0.50 out of 1.00

Which of the following statements are true considering the properties of electron guns?

- ☑ The tip of Schottky field emitters are coated with ZrO_2 to reduce the working function. ✔
- ☐ The purpose of a suppressor in an electron gun is to limit the emission of electrons to the tip apex region.
- ☐ The more anodes in an electron gun, the better the resolution.

Your answer is partially correct.

You have correctly selected 1.
See video “Electron beam lithography: tool overview” – slides about the electron gun.

The correct answers are:
The purpose of a suppressor in an electron gun is to limit the emission of electrons to the tip apex region. ,

The tip of Schottky field emitters are coated with ZrO_2 to reduce the working function.

Question **3**

Correct

Mark 1.00 out of 1.00

Lithography using photons is limited by optical diffraction which is a function of the wavelength used. Lithography using electrons is not affected by electron diffraction (but by scattering) at the resolution we are currently capable of patterning (nanometer scale). Nevertheless it is of interest to know the equivalent wavelength of electrons.

The De-Broglie wavelength of an electron accelerated to 100 kV is around 4 [pm] ✔ .

fm | μm | nm

Your answer is correct.

The electron wavelength can be calculated using the De-Broglie λ=h/mv, where the velocity of the electron will be determined by the acceleration voltage. At 100 kV the wavelength of an electron is around 3.8 pm.

The correct answer is:
Lithography using photons is limited by optical diffraction which is a function of the wavelength used. Lithography using electrons is not affected by electron diffraction (but by scattering) at the resolution we are currently capable of patterning (nanometer scale). Nevertheless it is of interest to know the equivalent wavelength of electrons.

The De-Broglie wavelength of an electron accelerated to 100 kV is around 4 [pm].

Question **4**

Correct

Mark 1.00 out of 1.00

Resolution enhancement in electron beam lithography (EBL)

The resolution in EBL is limited by forward scattering of the electrons and it can be improved by using a [thinner] ✔ resist and by [increasing the acceleration voltage] ✔ .

decreasing the acceleration voltage | increasing the size of the electron source

thicker

Your answer is correct.

When hitting the resist, the electron beam broadens because of forward scattering. The thinner the resist layer, the smaller the impact of this broadening in the final structures. On the contrary, the acceleration voltage needs to be increased to decrease the forward scattering.

The correct answer is:
Resolution enhancement in electron beam lithography (EBL)

The resolution in EBL is limited by forward scattering of the electrons and it can be improved by using a [thinner] resist and by [increasing the acceleration voltage].

Question **5**

Correct

Mark 1.00 out of 1.00

Lithography normally uses a binary mode of illumination (either light or no light). Grayscale lithography is a variation where 3D structures can be obtained in resist.

In order to obtain 3 different heights in the patterned photo-resist structure after development, lithography can be performed both by direct write laser and using a photomask.

Select one:

- True ✔
- False

Although more cumbersome, there are ways of exposing parts of a wafers with different energies without necessarily having to use direct laser writing. The mask used in mask-based lithography can be fabricated with different thicknesses of chromium, which result in different transmission coefficients. It is also possible to code the grayscale values in spatial modulations of the patterns that form the mask.

The correct answer is 'True'.

Question **6**

Correct

Mark 1.00 out of 1.00

Consider a photolithography process that uses a UV wavelength of 405 nm and in which the process parameters k_1 and k_2 are both equal to 0.5. A resolution smaller than 1 µm and a DOF larger than 0.7 µm are desired. The numerical aperture of the system can be chosen to satisfy the specifications.

Which of the following values of NA are compatible with the desired resolution and DOF? (hint: 2 values are correct).

- [ ] 0.85
- [ ] 0.65
- [ ] 1.05
- [ ] 1.25
- [x] 0.45 ✔
- [x] 0.25 ✔

Your answer is correct.

The expression of the resolution is $R=k_1 \lambda/NA$ and the expression for the depth of field is $DOF=k_2 \lambda/NA^2$. By imposing that R needs to be lower than 1 μm and the DOF larger than 0.7 μm one can find a range of acceptable values for NA: 0.2<NA<0.53. Therefore just 0.25 and 0.45 are acceptable answers.

The correct answers are:
0.25,

0.45

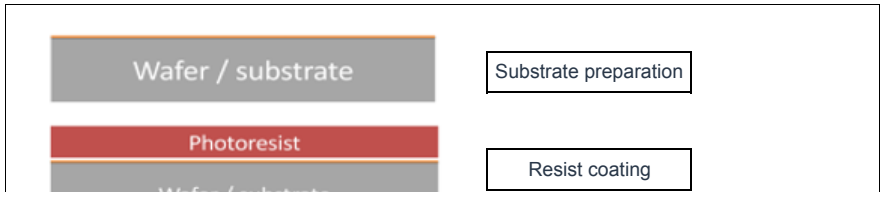
Question **7**

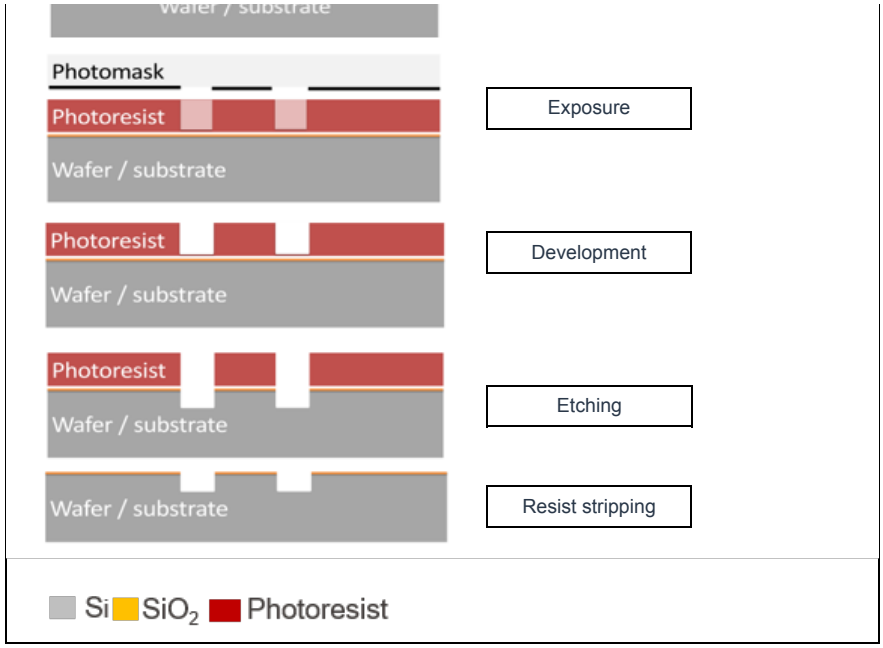
Correct

Mark 1.00 out of 1.00

The image below shows a schematic drawing of a typical process flow for a photolithographic process.

Drag and drop the text items to the right side of the corresponding image to name each step. Beware of the distractors.





Your answer is correct.

The process flow for lithography consists of substrate preparation, resist coating, resist exposure, resist development, patter transfer and resist stripping. In the case of this schematic drawing the pattern transfer is performed by etching as shown in the fifth step.

Question **8**

Correct

Mark 1.00 out of 1.00

Mask-based versus direct write photolithography

Mask-based lithography is a better-suited method compared to direct writing when the design [has already been] ✔ optimised and the structures need to be fabricated [many times] ✔ .

a few times

still has to be

Your answer is correct.

. Direct laser writing should mainly be considered when it comes to fabricating masks, or when we are doing some prototyping.

The correct answer is:

Mask-based versus direct write photolithography

Mask-based lithography is a better-suited method compared to direct writing when the design [has already been] optimised and the structures need to be fabricated [many times].

Question **9**

Correct

Mark 1.00 out of 1.00

Resolution in EBL is limited by forward scattering of the electrons in the resist.

Which of the following measures favour higher resolution?

- [ ] Use a thicker resist layer
- [x] Use a thinner resist layer ✔
- [x] Apply higher electron-beam accelerating voltage ✔
- [ ] Increase the size of the electron source

- [ ] Increase the size of the electron source
- [ ] Apply lower electron-beam accelerating voltage

Your answer is correct.

When hitting the resist, the electron beam broadens because of forward scattering. The thinner the resist layer, the smaller the impact of this broadening in the final structures. On the contrary, the acceleration voltage needs to be increased to decrease the forward scattering.

You can refer the formula $diameter_{forwardScattering} = 0.9*(resist_{thickness} / voltage_{acceleration}$ in video “Electron beam lithography: electron-sample interactions” slide “Electron-sample (resist) interactions”.

The correct answers are:
Apply higher electron-beam accelerating voltage ,

Use a thinner resist layer

Question **10**

Partially correct

Mark 0.67 out of 1.00

In which case is direct write laser a better-suited lithographic method than mask-based photolithography?

- [ ] A resolution of 10 microns is required, but the resist on the wafer should not be touched.
- [x] The design is in the prototyping phase and still needs to be optimized. ✔
- [ ] Test exposure of different shapes are required for the target pattern.
- [x] The structures need to be fabricated only once or twice. ✔

Your answer is partially correct.

You have correctly selected 2.
Mask-based photolithography is the most common exposure method. Direct laser writing should mainly be considered when it comes to fabricating masks, or when we are doing some prototyping. A resolution of 5 microns can be achieved with a mask aligner without being in contact.

The correct answers are:
The design is in the prototyping phase and still needs to be optimized.,

Test exposure of different shapes are required for the target pattern.,

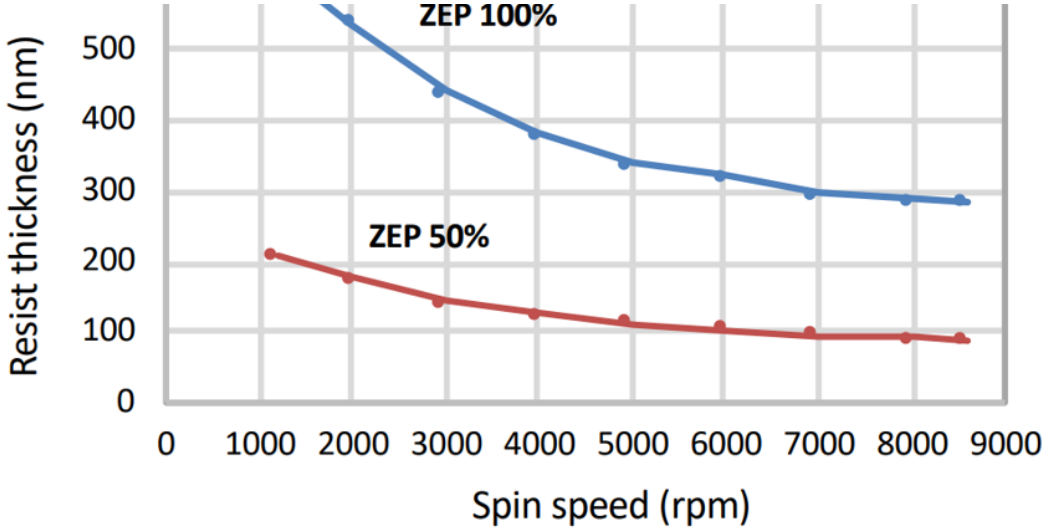
The structures need to be fabricated only once or twice.

Question **11**

Correct

Mark 1.00 out of 1.00

The spin curve for photoresists shows the relationship between spin speed and resist thickness.
Two typical spin curves for the EBL resist ZEP in two variations are shown below.
According to this graphic, in order to obtain a resist thickness of 300 nm the chosen resist should be ZEP 100% ✔ and the spin speed should be around 7000 ✔ rpm.



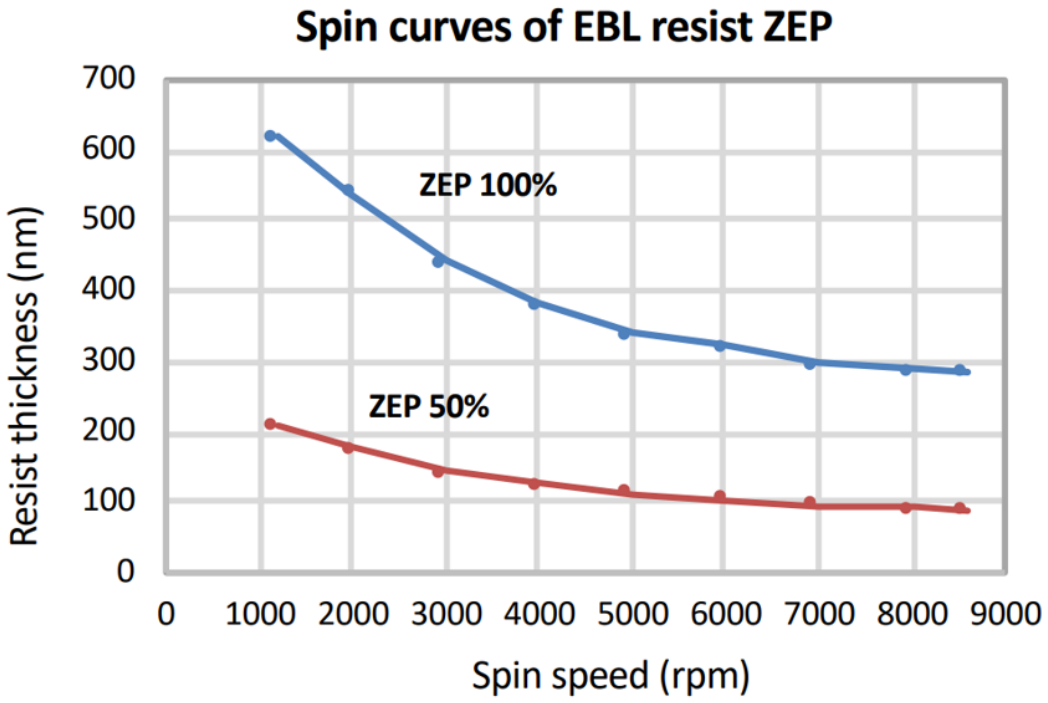
5000	ZEP 50%	2000	6000

Your answer is correct.

The spin curve shows the resist thickness versus the spin speed. To obtain a thickness of 300 nm in this case one needs to choose ZEP 100% as ZEP 50% would lead to thinner resist at any of the possible speeds. By looking at the ZEP 100% spin curve one can see that 300 nm are obtained at a spin speed between 7000 and 8000 rpm and 7000 rpm is the only possible answer that fits.

The correct answer is:

The spin curve for photoresists shows the relationship between spin speed and resist thickness.
Two typical spin curves for the EBL resist ZEP in two variations are shown below.
According to this graphic, in order to obtain a resist thickness of 300 nm the chosen resist should be [ZEP 100%] and the spin speed should be around [7000] rpm.



Question **12**

Partially correct

Mark 0.75 out of 1.00

Which of the following statements about photolithography and electron-beam lithography, is/are correct?

Multiple answers are possible.

- [ ] UV lithography can be performed without a photomask as a serial writing method using a laser
- [x] Electron-beam lithography can be used without an electron-mask as a serial beam writing method ✔
- [x] UV photolithography can be used to expose a full wafer through a photomask ✔
- [ ] Photolithography can generate smaller features than electron-beam writing
- [x] Electron-beam writing can generate smaller features than UV photolithography ✔

Your answer is partially correct.

You have correctly selected 3.
Electron-beam lithography is an inherently serial writing method. The beam has to scan the sample to locally expose the electron-sensitive resist.. Photolithography is not limited to serial writing. Serial photolithography can be achieved with direct laser writers and photomask are used to expose the whole mask design on the photoresist. This is what is called a flood exposure. Finally, contrary to photolithography, electron-lithography is not limited by diffraction. With electron-beam tools, higher resolutions can be achieved.

The correct answers are:
UV photolithography can be used to expose a full wafer through a photomask ,

Electron-beam writing can generate smaller features than UV photolithography,
UV lithography can be performed without a photomask as a serial writing method using a laser,

Electron-beam lithography can be used without an electron-mask as a serial beam writing method

Question **13**

Correct

Mark 1.00 out of 1.00

In UV-lithography we typically use a photomask, which is made of a transparent glass plate coated with a structured chromium film. What is the process flow to fabricate such a mask, assuming that the chromium layer is already added on the glass plate?

- ○ Laser writing, etching, resist coating, development, resist stripping, drying
- ◉ Resist coating, laser writing, development, etching, resist stripping, drying ✔
- ○ Development, etching, resist coating, resist stripping, laser writing, drying
- ○ Resist coating, development, laser writing, etching, resist stripping, drying
- ○ Laser writing, resist coating, development, etching, resist stripping, drying

Your answer is correct.

See “UV lithography: direct writing and mask writing” lecture notes, correct order may be deduced from the mask fabrication explanations.

The correct answer is:
Resist coating, laser writing, development, etching, resist stripping, drying

Question **14**

Correct

Mark 1.00 out of 1.00

Lithography using UV illumination can be done either through a photomask or by a scanning laser beam.

Contrary to direct laser writing, using a mask enables higher throughput (wafer/hour) in production.

Select one:

- True ✔
- False

Photomasks are used in production as they allow for a much higher throughput compared to direct write laser which is a serial writing process.

The correct answer is 'True'.

Question **15**

Correct

Mark 1.00 out of 1.00

Influence of gap between mask and resist in photolithography resolution

Consider a photolithographic process in proximity mode in which the thickness of the resist is 1.8 µm and the wavelength of the UV lamp is 405 nm. Calculate the maximum gap (in µm) possible to obtain a minimum feature size of 1.3 µm.

Answer: 2.37 ✔

The required gap can be found from the formula approximating the MFS in proximity mode $MFS \approx \sqrt{\lambda(d+g)}$, where d is the resist thickness and g the gap.

The correct answer is: 2.37

Question **16**

Correct

Mark 1.00 out of 1.00

Photolithography processes rely strongly on the relation of light intensity and resist dose and exposure.

A UV lamp can deliver a power of 6 mW/cm^2 to a wafer. Calculate the exposure time in s needed to expose the wafer with a dose of 55 mJ/cm^2

Answer: 9.17 ✔

The correct exposure time to deliver a certain dose given the value of the lamp power can be found by inverting the formula relating power and energy E=Pt.

The correct answer is: 9.17

Question **17**

Correct

Mark 1.00 out of 1.00

Shape corrections in illumination (mask versus DWL)

Shape correction methods (such as serifs) can be applied when writing the photomask in order to improve lithography performance. Such shape correction can in fact be applied on the photomask and also directly on the wafer when exposing resist. True or wrong?

Select one:

- True ✔

False

Shape corrections can be applied in both cases.

The correct answer is 'True'.

Question **18**

Correct

Mark 1.00 out of 1.00

In thermal scanning probe lithography (t-SPL), which of the following statements are true?

- [x] Tip wear limits the lifetime of the probes. ✔
- [x] The tip apex size limits the maximum achievable resolution. ✔
- [x] An atomic force microscopy tip is heated and scanned over the substrate to remove or modify a material. ✔
- [ ] An atomic force microscope tip is scanned over a hot substrate to modify a resist.

Your answer is correct.

One of the options is wrong as the tip is heated and not the substrate.

The correct answers are:
An atomic force microscopy tip is heated and scanned over the substrate to remove or modify a material.,

Tip wear limits the lifetime of the probes.,

The tip apex size limits the maximum achievable resolution.

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