The following exam is open book and open notes. You may use any source of information that you find useful except consulting with other students, faculty, staff, or other experts.

At times you may find that it is necessary to make approximations or assumptions. When you do so, please indicate that an assumption was made and justify its use in writing.
Problem 1 (30 pts)

Polysilicon is to be deposited at low temperature using PECVD. To prevent gas-phase nucleation of silicon particles due to heterogeneous reaction paths, the feed gas (SiH₄) is greatly diluted with argon.

Flow of SiH₄ = 1 sccm
Flow of Ar = 100 sccm

Use a simplified set of reactions for this problem consisting of dissociation of SiH₄ and ionization of argon (Tₑ in eV).

\[
\begin{align*}
\text{Ar} + e & \rightarrow \text{Ar}^+ + 2e \quad k_1 = 1.23E-7 \text{exp}(-18.68/T_e) \text{ cm}^3 \text{s}^{-1} \\
\text{SiH}_4 + e & \rightarrow \text{SiH}_3 + \text{H} + e \quad k_2 = 1.5E-8 \text{exp}(-10/T_e) \text{ cm}^3 \text{s}^{-1} \\
\text{SiH}_4 + e & \rightarrow \text{SiH}_2 + 2\text{H} + e \quad k_3 = 1.5E-9 \text{exp}(-10/T_e) \text{ cm}^3 \text{s}^{-1}
\end{align*}
\]

The sticking coefficients for the silane-related molecules to both the chamber walls and the wafer surface are:

\[
\begin{align*}
\gamma_{\text{SiH}_4} &= 0.054 \text{ exp } (-0.86 \text{ eV/ kT}) \\
\gamma_{\text{SiH}_3} &= \gamma_{\text{SiH}_2} = 1
\end{align*}
\]

The plasma chamber consists of two parallel plates that are energized by radio frequency power at 50 W. Each plate has an area of 250 cm² and the separation between plates is 8 cm. You may estimate that the sheath potential is 100 volts. The chamber is pumped by a 500 liter per second turbomolecular pump connected to the chamber by a 30 cm long by 10 cm diameter pumping port.

a) Determine the approximate pressure within the chamber

b) Find the electron density and electron temperature within the plasma assuming that the presence of SiH₅ is a negligible perturbation.

c) Determine the time required to deposit a 1 μm thick film of polysilicon (ignore any hydrogen that may be incorporated in the film)
Problem 2 (10 pts)

Spatially coherent EUV radiation ($\lambda = 12$ nm) is used in a lithographic system with a numerical aperture of 0.1. What is the minimum feature size that can be resolved if the CMTF of the resist is 0.7? Repeat if the CMTF is 2.0. List reasons why it would be undesirable to use an optical system with NA = 0.8.

Problem 3 (30 pts)

Rather than the usual Gaussian profiles obtained by ion implantation, a certain process requires that a more uniform density of phosphorus dopant be implanted throughout the n-type region. The region begins at the wafer surface and extends 1.0 µm into the surface.

One method of obtaining a more uniform implant profile is by performing multiple ion implantations with varying dose and energy.

Design a 3-step implant (and activation anneal) to achieve a nearly uniform doping level of $10^{18}$ cm$^{-3}$ throughout the first 1 µm of the surface.

When completed, use SUPREM to confirm that your process is correct (Note: DO NOT use SUPREM to design the process by trial and error. Develop the process analytically first, then simulate it.)

Problem 4. (10 pts)

a) Chromium is sputtered from a target biased at $-400$V and 1 ampere. Find the deposition rate on a 100 mm diameter wafer if 25% of the sputtered Cr reaches the wafer. The density of Cr is 7.2 grams per cm$^3$ and the atomic weight is 52 a.m.u.

b) The electrical resistivity of the Cr film in (a) is measured by four-point probe and found to be 20 $\mu\Omega$-cm but text references indicate that it should be 12.9 $\mu\Omega$-cm. Make suggestions to improve the resistivity of the Cr.
Problem 5 (20 pts)

Answer the following questions with a brief written paragraph:

a) Explain *when* it is appropriate to use PECVD rather than LPCVD in a CMOS process.
b) When depositing a LTO (low temperature oxide), is the deposition rate most-likely *reaction-rate limited* or *mass-transfer limited*? Explain.
c) Describe the advantages and disadvantages of “hot” sputter deposition (T\textsubscript{wafer} \sim 500\textdegree C).
d) Why is cobalt replacing titanium in salicide processes?
e) Why is the minimum linewidth produced by e-beam lithography much greater than the wavelength of an electron?
f) The electron temperature in an argon plasma is 3 eV at 10 mtorr. What is the electron temperature at 1 mtorr?
g) A LPCVD furnace is evacuated by a pump located below the cleanroom floor to minimize vibration. The minimum pressure in the furnace is 3 torr. It has been suggested that a pump with a higher gas throughput should be purchased such that a lower pressure can be achieved. Do you agree? Explain.
h) A plasma etch process has A<<1 due to a collisional plasma sheath above the wafer. List three process changes you could make to improve the anisotropy.