Solution 9

Exercise 1:

	CVD	PECVD	PVD (sputtering)
Deposition	conformal	conformal	Directional
	Heated substrate required (normally > 200 °C)	Room temperature deposition possible (higher temperatures are optional).	
	Soft (no particle bombardment)	Possible particle bombardment.	particle bombardment
Deposition rate	Higher than PVD (exception: ALD)		>1 nm/s
Materials that can be deposited	Depend on availability of precursors		Virtually all materials
Sticking coefficient	< 1	<1	Close to 1
Cost	Less expensive than PVD (less vacuum, no electrical needs)	Higher cost	Higher cost
Up-scalability	Possible and demonstrated in all cases		

Exercise 2:

a) The energy distribution of an argon plasma at the ground electrode was measured with a mass spectrometer and compared to simulations. The energy distribution of ions hitting the substrate is important, as ions with too high energy sputter, while low energetic ions help to organize the layer structure.

While Ar^+ ions show a wide energy distribution with a peak at very low energies, ArH^+ ions show a single peak at high energies. This difference is explained the following way:

In contrast to the much lighter electrons that follow in their movements the alternating electric field, the ions "see" only the time-averaged potential, which is the time-averaged sheath voltage. For both Ar^+ and ArH^+ ions, crossing the sheath takes several rf or VHF cycles. In that time, Ar^+ ions usually pass several symmetric charge exchange interactions with neutral Ar atoms ($Ar^+ + Ar \rightarrow Ar + Ar^+$), where the kinetic energy is not transferred. Therefore, the Ar^+ ions hitting the substrate are typically not the same as the ones that started carrying the charges through the sheath; The energies they carry depend mainly on the number of charge exchange interactions of the charges which is different for each charge carried through the sheath. This leads to a wide energy distribution of the Ar^+ ions.

This is not the case for ArH^+ ion. As its neutral counterpart ArH does not exist, the charge exchange interaction $ArH^+ + ArH' \rightarrow ArH + ArH'^+$ can not take place.

Therefore the ArH^+ ions hitting the substrate surface travelled through the whole sheath and carry the energy $e\overline{V_p}^t$, where $\overline{V_p}^t$ is the time-averaged sheath voltage and e the elementary charge.

b) Advantages of VHF PE-CVD compared to PE-CVD are:

- Higher deposition rates possible (more power does not automatically lead to more powder formation in the plasma, as it is the case for rf)
- Reduced internal stress of the deposited films
- Thinner sheaths
- Higher ion flux but less energetic ions on the substrate surface

The applications of VHF PE-CVD are principally the same as for rf PE-CVD. Where the deposition rate plays a crucial role for the total costs (as e.g. for the production of TFT screens or for thin-film photovoltaics), VHF is of special interest due to the higher deposition rate.

Exercise 3:

a)
- Atomic shadowing due to oblique deposition
- low working pressure (no scattering of particles)
- low substrate temperature (no surface diffusion)

b)
- Formation of nanostructures (nanowires, metamaterials).
- Co-sputtering deposition from combinatorial screening of new materials

c) Advantages of sputtering deposition over evaporation:

- Better step coverage (evaporation is directional)
- larger range of materials that can be deposited (from metals to dielectrics and alloys)
- large area deposition (production processes-e.g. roll to roll deposition)