

- **What is NFC film and how can it be deposited?**

  NFC stands for Near-frictionless Carbon. NFC films/coatings were developed at the Argonne National Laboratory (Chicago, USA) by plasma enhanced chemical vapor deposition (PECVD). A source gas of either pure methane or a mixture of methane (CH_4) and hydrogen (H_2) at 10-40 mtorr pressure at room temperature with an RF bias of 300-400 V was used to prepare super low friction carbon films in the thickness range 1-10 micrometers. It was published by **Erdemir, Ali** *et al* in the Journal of Vacuum Science and Technology (J. Vac. Sci. Technol. A 18(4), Jul/Aug 2000 1987-1992).

- **Expand XRR. What can it be used for?**

  XRR stands for X-ray Reflectivity. It is also called as X-ray Reflectometry or X-ray Specular Reflectivity. In thin films science, this technique is used to characterize density, roughness, and thickness of thin coatings. In general this technique has been used to study a variety of solid and liquid interfaces since its inception in 1954. The central concept behind this technique is the deviation in the intensity of the reflected x-rays, which is then used for characterization.

- **What is the typical hydrogen content in a-C:H films? What does the hydrogen content strongly depend on?**

  The typical hydrogen content in a-C:H films is from 30% to more than 50%. The hydrogen content strongly depends on the kinetic energy of the impinging ions during plasma-enhanced chemical vapor deposition process.

- **How can one control the hydrogen content in a-C:H films?**

  The hydrogen content in a-C:H films can be controlled by controlling the impinging ion energy during plasma-enhanced chemical vapor deposition. The hydrogen content increases with decreasing impinging ion energy.

- **How is the hydrogen content related to carbon bonding in a-C:H films?**

  The more the hydrogen content, the more the sp^3 hybridized carbon atoms. Carbon films made at low impinging ion energies with about ~50% hydrogen atom concentration are soft in nature, and are termed as **polymer-like amorphous carbon films**.

- **What kind of carbon bonding will be observed at high ion energies (> 50 eV)?**

  At high ion energies (say, > 50 eV), the hydrogen content decreases in the carbon film which increases the amount of sp_2 hybridized carbon atoms.

- **What are polymer-like amorphous carbon films?**

  Polymer-like amorphous carbon films are carbon films made at low energies with almost all the carbon atoms in sp^3 hybridized state. Polymer-like amorphous carbon films are very soft in nature.

- **What is the effect of energy of impinging ions on film composition?**

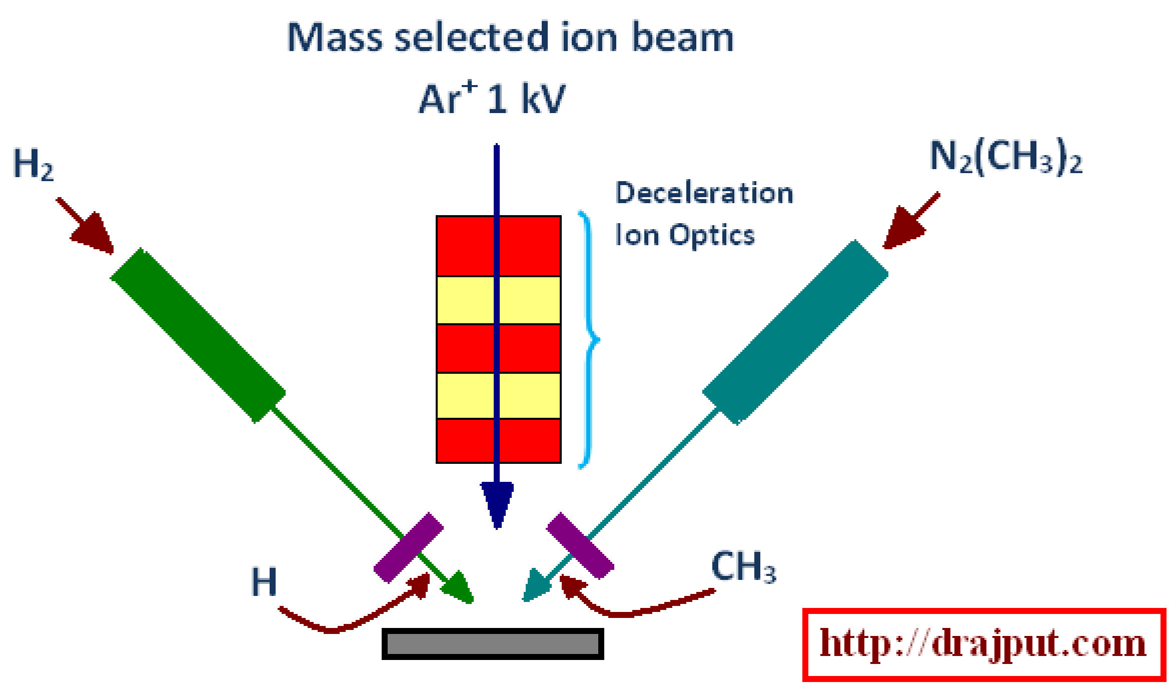
  The more the energy of impinging ions, the lower the amount of hydrogen atom concentration, the more the sp^2 hybridized carbon atoms in the carbon film, and vice versa. (always remember: the more the hydrogen, the more the sp3 carbon atoms)

- **What is surface loss probability, and what are its values for sp^1-, sp^2-, and sp^3- hybridized precursors?**

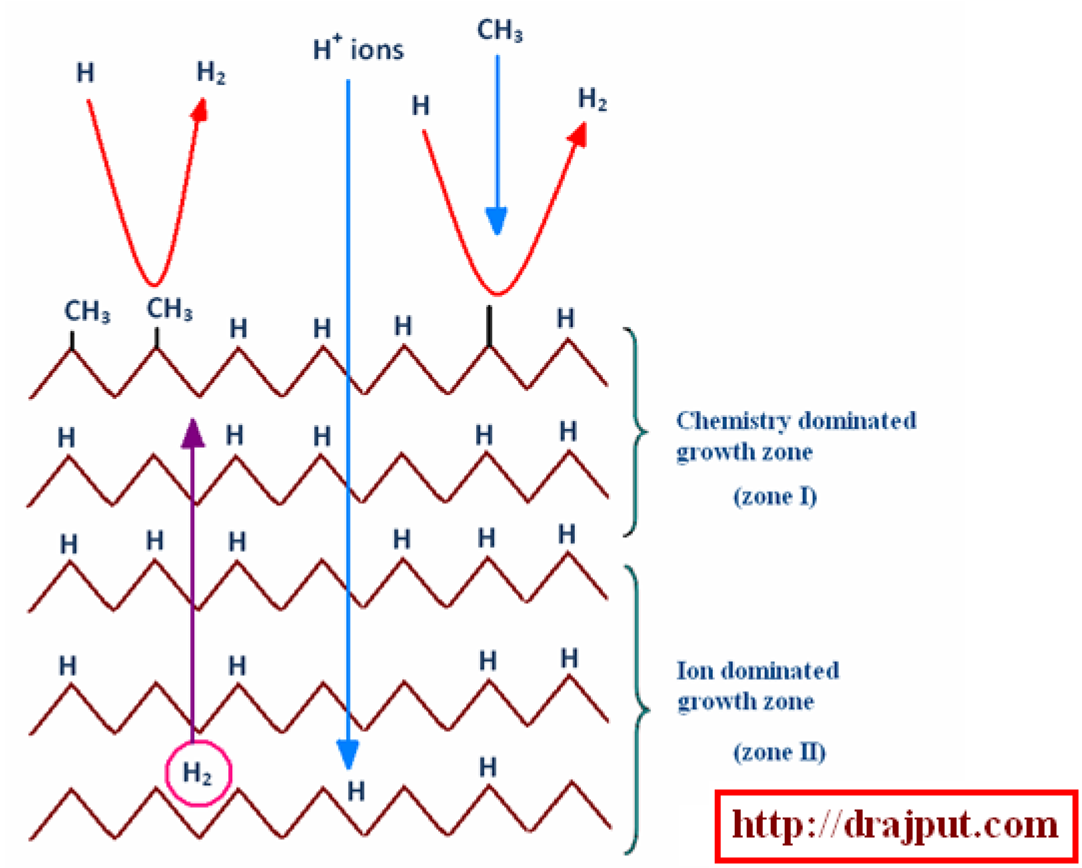
  Surface loss probability is the probability that the impinging source ions stick to the surface of the growing film (i.e., 1 minus reflection coefficient) (read more). Its values for sp^1-, sp^2-, and sp^3-hybridized precursors are 0.9, 0.35, and < 0.01, respectively.

- **Explain the growth mechanism of a-C:H films with schematics.**

  The energy of impinging ions and the surface loss probability have been found to determine the structure of carbon films. However, the growth mechanism of a-C:H films is not fully understood, and is based entirely on plasma experiments. In plasma experiments, the effect of various process parameters (viz. substrate temperature, plasma power, bias voltage, etc.) as a function of growth rate is studied. A simplified pictorial description of the particle beam experiment is shown below (inspired by Hopf, C. *et al*).



In this experiment, the very first step is the creation of dangling bonds at the film surface. Dangling bonds are created by abstraction of surface-bonded hydrogen by impinging H and CH_3 radicals. Chemisorption of CH_3 radicals at dangling bonds at the C:H film surface results in film growth. H and CH_3radicals interact with the C:H film surface simultaneously, which leads to a growth synergy. Schematic of the growth mechanism is shown below.



There are two zones during film growth: (1) chemistry dominated zone, and (2) ion dominated zone. The chemistry dominated zone extends approximately 2 nm from the surface into the film. In this zone, impinging H radical activates the surface by abstracting hydrogen, which creates chemisorption sites for incident CH_3 radicals. In the ion dominated zone, the distribution of bonded hydrogen in the film is altered in consecutive cascades. Displaced H atoms recombine during such a distribution to form hydrogen molecules (H_2), which eventually desorb, and decrease the hydrogen content in the film permanently. However, displaced H atoms may also occupy dangling bonds inside the film in a lattice defect or at the film surface (chemisorption sites).