be deposited by several techniques, but the most commonly used process is chemical vapor deposition (CVD), involving the reaction of silane gas and ammonia. Plasma-Enhanced Chemical Vapor Deposition (PECVD) is preferred to other CVD technologies (atmospheric pressure CVD or low pressure CVD) because it is a low temperature process ($T < 500°C$), and this means reducing complexity and preventing lifetime degradation.

But the most outstanding property of PECVD for mc-material is that it produces hydrogenation, and its benefits for silicon are well known [96, 97]. Atomic H interacts with impurities and defects in the bulk of Si, neutralizing their recombination properties to a certain extent, a phenomenon that is usually expressed as "bulk passivation". In the case of PECVD, amorphous silicon nitride films are produced with up to 40 atomic % of hydrogen (i.e. although these films are usually referred to as SiN_x they are really a-SiN_x:H). A subsequent thermal step is needed to activate hydrogenation, and in an industrial process the metal firing step fulfills this objective [98].

Additionally, surface passivation due to SiN_x deposition by PECVD has also been reported [99]. Achievable surface recombination velocity on a phosphorus-doped emitter is similar to that of a high-quality oxide passivated one, and a value as low as 4 $cm\,s^{-1}$ has been obtained on a polished 1.5 Ω·cm FZ *p*-type silicon wafer [100].

These three different properties (AR coating, bulk passivation and surface passivation) cannot be varied independently, an optimization of processing parameters (temperature, plasma excitation power and frequency, gas flow rate) is necessary, and a compromise should be reached [101, 102]. Furthermore, there are different PECVD techniques giving different results.

The state of the art of the industrial PECVD equipments today is the "direct" PECVD, schematized in Figure 7.11(a). The processing gasses are excited by means of an electromagnetic field, and the wafers are located within the plasma. Bulk is effectively passivated, but surface damage is sustained due to direct exposure of wafers to plasma, precluding the achievement of good surface passivation. Furthermore, surface passivation degrades with exposition to UV light.

There is a high frequency direct PECVD (13.56 MHz) and a low frequency one (in the range of 10–500 kHz), the former being better in terms of surface passivation and UV stability. On the other hand, it is more difficult to obtain uniform layers.

A different approach is the "remote" PECVD, where wafers are located outside the region in which the plasma is formed. Surface damage is avoided in this way, so that

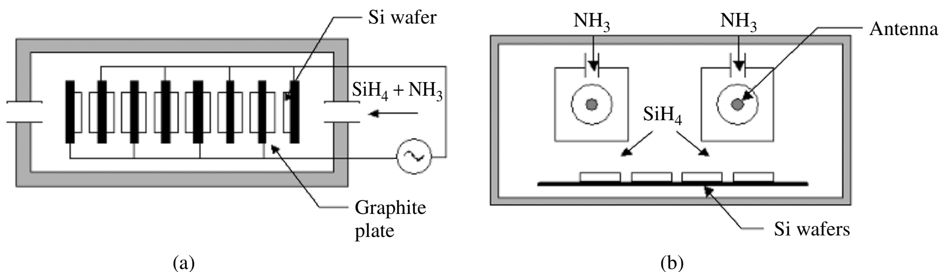

Figure 7.11 Industrial PECVD reactors: (a) direct-plasma reactor; and (b) remote-plasma system