CHAPTER CONTENTS

"Chance favors the trained mind."

Louis Pasteur

2300 Exelan® dielectric-etch system. Photograph courtesy of Lam Research Corporation.

CHAPTER **22**

DRY-ETCHING FOR ULSI

Wet-chemical etching (Chap. 21) was the standard pattern-transfer technique in early generations of ICs for several reasons. First, it was well known from its long-use in the printing-industry. Second, liquid-etchants can selectively remove materials being etched without affecting those beneath. Third, most do not attack photoresist (the most common etch-mask). However, such etching typically occurs in all directions at the same rate (*isotropically*). Thus, if the thickness of the film being etched is comparable to the minimum lateral pattern-dimension, the undercutting due to such isotropic-etching is unacceptable (see Fig. 22-2). Since many films used in ULSI-devices are 0.5–1.0-μm-thick, reproducible and controllable transfer of patterns by wet-etching becomes difficult at 1–2-μm,

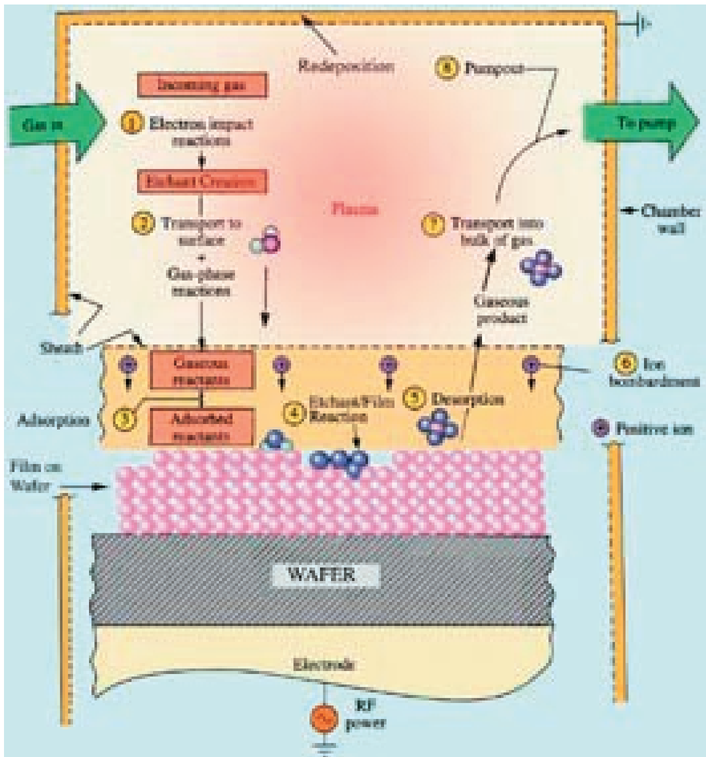

Fig. 22-1 Schematic view of the microscopic processes that occur during the *dry-etching* of a silicon wafer.

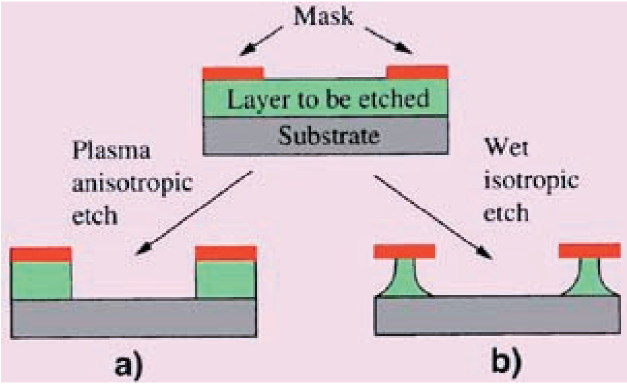

Fig. 22-2 Comparison between: (a) *completely anisotropic-etching*; and (b) *isotropic-etching*.

and impossible for submicron structures. Alternative pattern-transfer processes must thus be used to fabricate devices with such dimensions.

Dry-etching is an alternative method that offers the capability of non-isotropic (or *anisotropic*) etching. Dry-etch processes have been developed that can successfully serve as replacements for wet-etch processes (Fig. 22-1). Dry-etching also provides the important manufacturing-advantage of eliminating the handling, consumption, and disposal of the relatively-large quantities of dangerous acids and solvents used in wet-etching. Dry-etching and dry resist-stripping operations utilize comparatively small quantities of chemicals (although, some of those used are also quite toxic or corrosive, and must therefore be safely disposed). This chapter deals with the technology of dry-etch processes for ULSI fabrication. More details about dry-etching are found in References 1 thru 8.

22.1 TYPES OF DRY-ETCHING PROCESSES

Figure 22-3 shows that there are many types of dry-etch processes. Also indicated is the mechanism of etching that each such-type can have: **1**) a *physical-basis* (e.g., in glow-discharge sputtering [Chap. 15], or ion milling); **2**) *a chemical-basis* (e.g., in plasma-etching); or **3**) a combination of the two (termed *reactive-ion-etching* [*RIE*], or *ion-enhanced-etching*).

In processes that rely predominantly on the physical mechanism of sputtering, the strongly directional nature of the incident energetic-ions allows substrate material to be removed in a highly-anisotropic manner (essentially vertical-etch-profiles can be produced). Unfortunately, such material-removal mechanisms are also quite non-selective against both the masking-material and the materials underlying the layers being etched. The selectivity depends largely on sputter-yield differences between materials. Since sputter-yields for most materials are within a factor of three of each other, selectivities are typically not adequate. Furthermore, since the ejected-species are frequently non-volatile, redeposition and trenching can occur. Because of these issues, dry-etch processes for pattern-transfer based purely on *physical-removal-mechanisms* are not widely used in ULSI fabrication.

On the other hand, dry-processes relying *strictly on chemical-mechanisms for etching* can exhibit very-high-selectivities against both mask and underlying substrate-layers. Such purely chemical-etching mechanisms, however, typically etch in an isotropic-fashion. Some applications in ULSI fabrication which do not require anisotropic-etching, utilize such processes (e.g., photoresist stripping in oxygen-plasmas). However, etch-processes that rely primarily on chemical-reactions, are unable to solve the problem of undercutting associated with isotropic-etching, and thus are not used to etch features smaller than 1-μm.

However, by adding a physical-component to a purely chemical-etching mechanism, the shortcom-

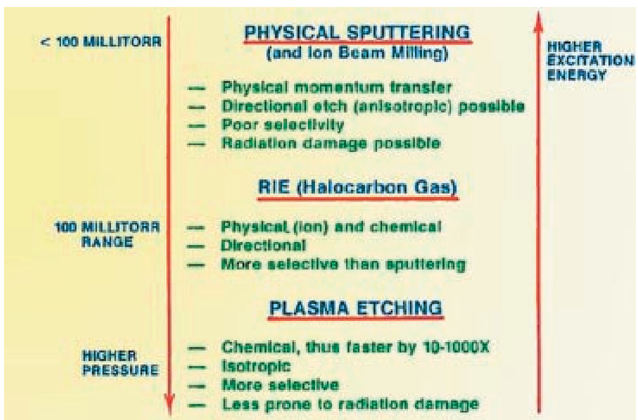

Fig. 22-3 The dry-etching spectrum.