Plasma Etching

An Introduction

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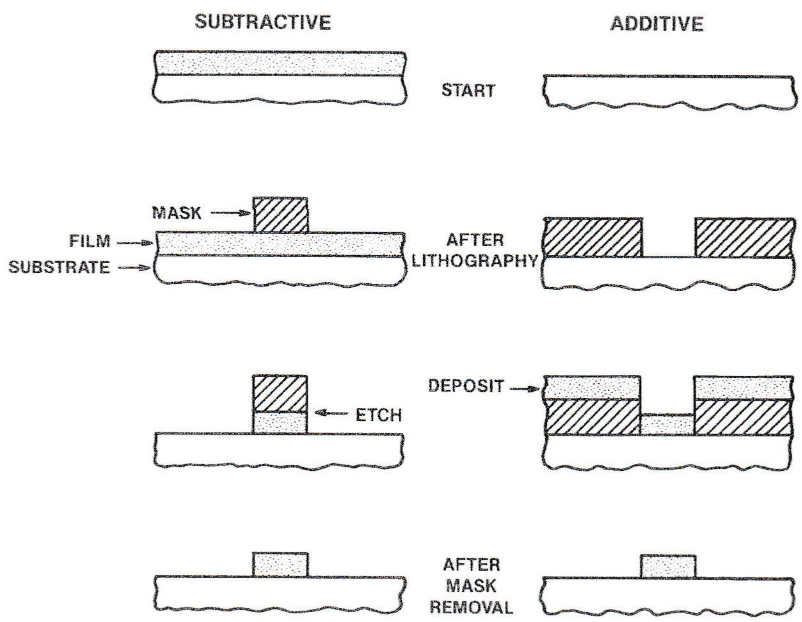

FIGURE 7. The two basic methods of pattern transfer are: subtractive, where the planar film is removed from areas not protected by the mask; and additive, where the film is deposited over the mask pattern and the mask with undesired film deposits is later removed.

In the additive process, the pattern is formed at the same time the film is deposited. A resist pattern-mask is first formed on the base substrate and afterwards, a film material is deposited over the mask and onto uncovered substrate areas, thus creating the desired pattern. When deposition is complete, the resist is swelled by a strong solvent and dissolves away, lifting off unwanted deposits from the masked areas of the pattern.

The subtractive process dominates production pattern transfer. The additive method is mainly used for masking laboratory prototype devices. Plasma etching can be applied to steps in both processes.

E. ISOTROPIC AND ANISOTROPIC ETCHING

Differences in etching mechanisms have an immediate effect on the profiles of features in both "wet" chemical and "dry" plasma chemical etching. *Purely chemical* etching usually has no preferential direction. This leads to isotropic circular profiles, which undercut a mask [14] (see Fig. 8). As

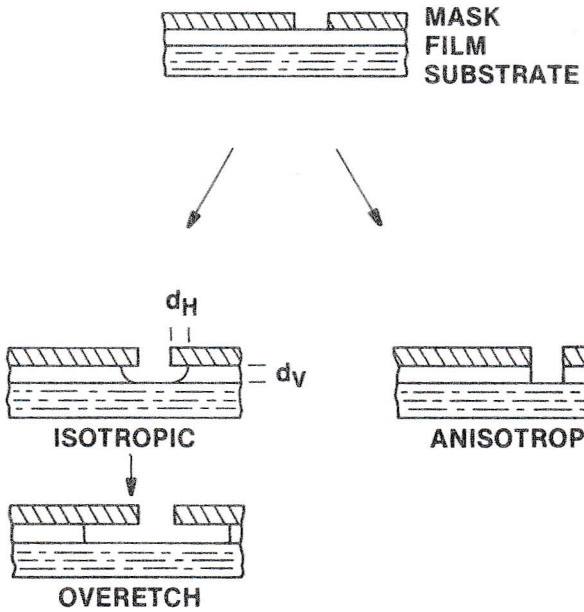

FIGURE 8. Replicating the pattern from a mask stencil into a film depends on the ability to control horizontal etching. Left: Isotropic etching; the horizontal and vertical etch rates are equal, creating an undercut, d_H, in the film beneath the mask, equal to the film thickness, d_V. If etching is continued, this lateral attack will continue and the etched film edge profile will become almost vertical. Right: Anisotropic etching; the horizontal etch component is very small, resulting in faithful pattern transfer.

shown, the thickness etched (d_V) equals the undercut (d_H) until etching reaches the film-substrate boundary. Overetching past the point where the underlying substrate is just exposed increases the undercut and radius of the undercut cross section. At large degrees of overetching the walls are essentially vertical. In practice, overetching is necessary because of wafer surface topography, nonuniform film thicknesses and variations in etch rate in the reactor (see Section IV.C.2). Moreover, in isotropic plasma etching it is difficult to control the degree of overetching beyond the endpoint because *the rate of undercut may accelerate at the end point* where (unfortunately) control is needed most. This loading effect is discussed further in Chapter 2.

Ideal *ion enhanced* plasma etching, on the other hand, produces an anisotropic profile (see Fig. 8). When the mean free path of ions in a plasma is long compared to feature depth, electrical fields (the sheath field) make ions strike horizontal surfaces almost exclusively at normal incidence. This ion bombardment preferentially accelerates the chemical reaction in the

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vertical direction so that vertical sidewalls are formed along the edges of masked features at right angles to the substrate. In practice, tapered profiles can also be produced (see Sections IV.C.1, IV.C.2) because of ion scattering and superimposed isotropic chemical etching effects.

It is important to add that the formation of vertical walls on etched features does not necessarily mean that etching was ion enhanced. Vertical profiles are formed in isotropic chemical etching during severe undercutting (as noted before), and can also be produced when there is preferential etching along specific crystal planes. Such crystallographic attack is more common in wet chemical etching [15], but it also occurs in plasmas, for instance when III-V compound semiconductors are etched by gaseous halogen radicals. Dry crystallographic etching can be used to form vertical or tapered walls with only a small undercut (see Chapter 2). While undercutting is usually obvious when the mask is compared to the feature, in practice the edges of a mask may be tapered rather than vertical, and mask erosion (e.g., by sputtering, or chemical attack) leads to a more complex profile. If the mask erodes at an appropriate rate relative to the undercutting, it is possible to attain features in which the edge of the mask aligns with the walls of etched features, even though the etching is isotropic.

F. THE TRANSITION FROM WET TO PLASMA ETCHING

Plasma etching was explored as a cheaper alternative to wet solvent resist stripping [16] for integrated circuit manufacture in the late 1960s and early 1970s. By the early 1970s, CF_4/O_2 plasma etching was widely adopted for patterning silicon nitride passivation of its selectivity over resist masks and underlying metalization. The wet chemical alternatives were complicated and indirect. Around the same time, oxygen plasma resist stripping, or ashing in oxygen plasmas, was finally integrated into many manufacturing lines. Production plasma etch processes were next developed for polysilicon and a host of other materials. These initial dry plasma-assisted etching processes were purely chemical and isotropic. At first, their advantages seemed to lie in unique processing sequences, substitution of safe nontoxic gases such as O_2 and CF_4 for corrosive liquids, easily discharged waste products and simple automation. By the late 1970s, however, it was widely recognized that plasma etching offered the possibility of a vertical etch rate that greatly exceeded the horizontal rate (e.g., anisotropic etching).

Because of the isotropic undercut, wet etching a 1 μm thick film through a 1 μm mask opening at best yields a cross-sectional profile that measures