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A General Simulation Method for Etching and Deposition Processes

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Abstract

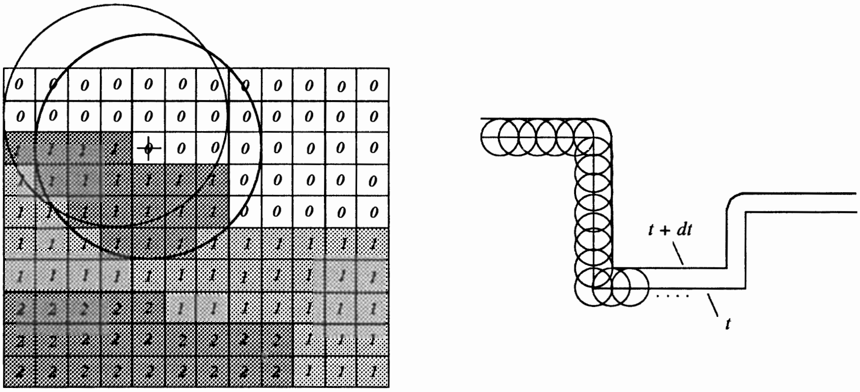
A new method for simulation of etching and deposition processes has been developed. This method is based on a cellular material representation and on morphological filter operations for surface movement. In this paper we describe theory and application of our approach. Simulation results both in two and three dimensions demonstrate the simulation capabilities of this new method.

1. Introduction

Accurate simulation of pattern transfer processes such as wet and dry etching, chemical vapor deposition, evaporation and sputtering requires three-dimensional models and algorithms for wafer topography evaluation. A variety of surface evolution algorithms has been studied to build three-dimensional topography simulators. Among them many algorithms have been reported for lithography simulation [1], [2], [3]. A few methods have been applied to three-dimensional simulation of etching and deposition processes [4], [5]. Surface advancement algorithms offer highly accurate results but with potential topological instabilities such as erroneous surface loops resulting from a growing or etching surface intersecting with itself. Cell removal methods allow the simulation of arbitrary structures, but suffer from inherent inaccuracy. Our new method is based on spatial adaptive filter operations for advancing the etch front. These filter operations are based on Minkowski algebra which makes it possible to simulate topography processes by use of the fundamental morphological operations of erosion and dilation, as they are termed in image processing [6]. Our method allows the accurate and absolutely stable simulation of three-dimensional arbitrary structures.

2. Simulation Method

The morphological approach is a general method in image processing used for many purposes including edge detection and segmentation of images. Several fundamental morphological operations provide a well defined methodology for altering an given image in terms of some predetermined geometric shape [6]. If we consider the simulation geometry as a black and white image (material or vacuum) these operations can be applied to the etching and deposition problem. We use an array of square or



(a) (b)

Figure 1: Simulation method

cubic cells for geometry representation, where each cell is characterized as etched or unetched. A material identifier is defined for each cell, therefore material boundaries need not be explicitly represented. To advance the etch front adaptive spatial filter operations are performed along the surface boundary as shown in Fig. 1. During etching, all cells within a filter are etched away, while cells outside stay unchanged. In general, for anisotropic simulation filters are ellipsoids, for isotropic movement of surface points filters are spheres. The spatial filter dimension is related to the simulation time step and to the local etch rates. The etch front at a given time step is obtained by the envelope of filtered cells. With our method we avoid the inherent inaccuracy of the original cell algorithm [7] which in two dimensions produces an octagon instead of a circle during uniform etching from a single point [8].

Filter operations at material boundaries are performed using composite filters. In general, interfaces lead to an abrupt change in etch rates. For this reason, on both sides of the interface a filter operation has to be performed selectively to the actual material. Filters which extend over a material boundary demand an additional filter operation for this time step. The etch rate for those filters depend on the etch rates on both sides of the interface and on how far a filter reaches into the other material.

3. Simulation Results

Fig. 2 shows a deposition from a hemispherical vapor source. The growth rate of the evaporated film at each point depends strongly on the surface topology. The growth rate varies along the surface as a result of shadowing. The side wall deposition depends on the solid angle visibility of surface points. Fig. 3 shows the simulation of reactive ion etching. The flux arrives with an angle of twenty degrees. This etching process is modeled regarding an isotropic and a directional etch rate component. The isotropic component models the chemically reactive gas. It produces profiles with large undercut and circular cross sections. The directional component correspond to the ion-enhanced surface etching effects due to ionic species. The flux can be shadowed and has a local $cos\phi$ rate dependences (where ϕ denotes the angle between incident flux and local surface normal).

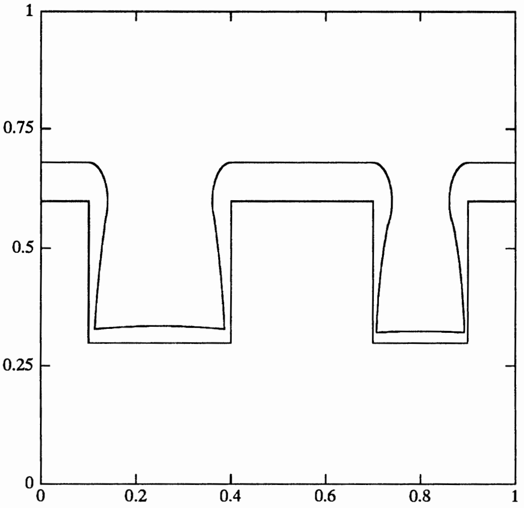


Figure 2: Sputter deposition simulation

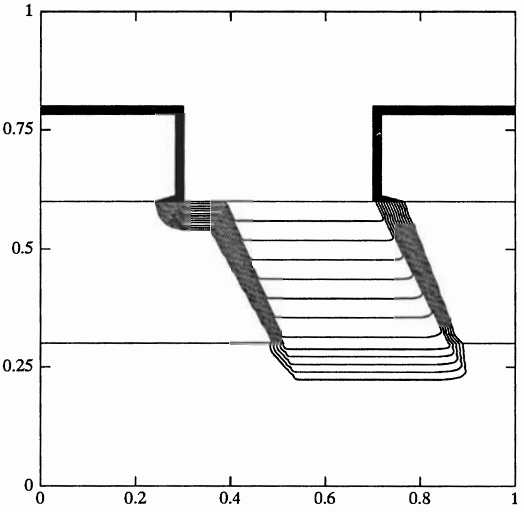


Figure 3: Simulation of reactive ion etching

Fig. 4 shows the result of sequential etching processes to simulate contact hole etching. The simulation for this example starts with a circular mask opening of 1 μm diameter. The first isotropic etching process etches the substrate to a depth of 0.5 μm. This was followed by a directional etch simulation for 0.5 μm additional material removal.

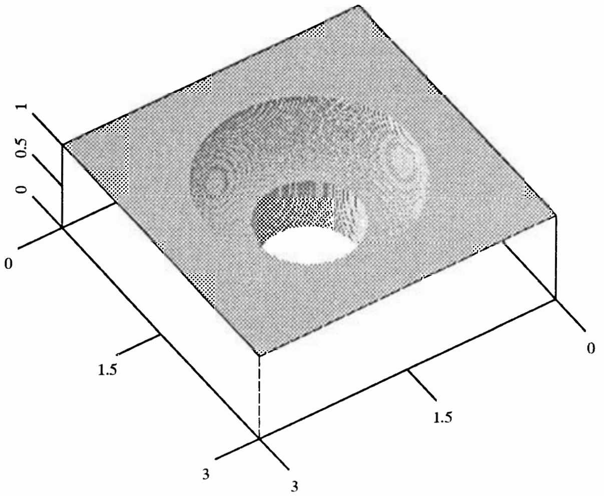


Figure 4: Simulation of contact hole etching

4. Conclusion

A new method for simulation of etching and deposition processes was introduced. Based on a cellular material representation and spatial filter operations for surface movement this method allows accurate and stable simulation of arbitrary structures.

Acknowledgements

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