# THREE-DIMENSIONAL STATE-OF-THE-ART TOPOGRAPHY SIMULATION

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## KEYWORDS

Three-dimensional topography simulation, cell based algorithm, level set method

## ABSTRACT

Two major contenders in the field of topography simulation, the level set method [1] and an advanced cell based algorithm [2, 3] are compared. The focus of this comparison is placed on both accuracy and performance. Isotropic deposition using a realistic trench structure with non-orthogonal surfaces is employed for benchmarking the two methodologies. This simulation enables a very in depth analysis of the relative error, the simulation time and, the number of required discretization points. The calculations are performed using the simulators TOPO3D for the cellular algorithm and TOPO3D-II for the level set method. Both have been integrated into a process flow simulation.

## THE TWO TECHNIQUES

The cell based algorithm was originally derived from an algorithm used in image processing [3]. The degree of freedom is limited to a single direction perpendicular to the underlying orthogonal grid. This algorithm treats etching as an eroding operation, while deposition is described as a dilating process. One of these operations is chosen and is applied to the exposed cell elements. The interface is then propagated by adding or removing cell elements by the shaping elements enabling simple anisotropic modeling. The cellular algorithm at hand is called 'advanced hybrid cellular algorithm' [2] and represents an improved version of the classic algorithm. It compensates the loss of information inherent in simulations based on a cell based algorithm by utilizing polygonal data representation. During post-processing the surface is extracted, triangulated, smoothed and simplified [3].

The level set method [1] is implemented in the simulator TOPO3D-II. The propagating surface is implicitly represented by a distance function. It can be perceived as the evolution of the concept of the cell based algorithm to a far more general form. Three dimensional topography simulation is accomplished using both Narrow Band and Fast Marching techniques [4, 5]. Post-processing includes again surface extraction, triangulation, and simplification, but no smoothing of the extracted surface. The resulting surface has to be merged with the original structure by boolean operations. The resulting final structure is then saved in a discretized tetrahedral volume mesh [6].

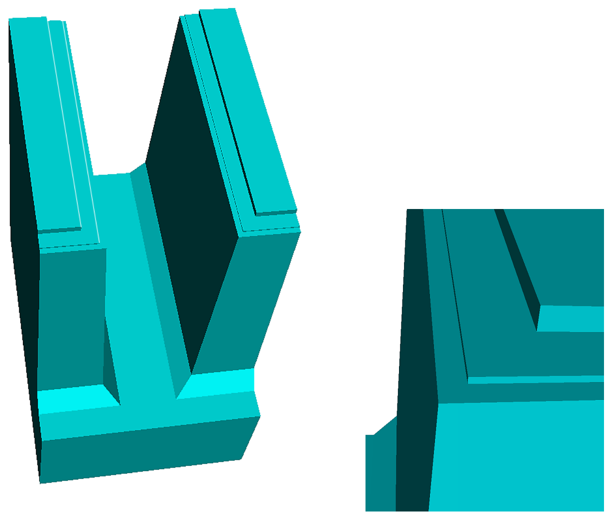

**Figure 1:** Initial geometry (left) and detailed view (right)

## THE COMPARISON

Figure 1 shows the initial three-dimensional trench geometry used for the comparison of the two topography simulation approaches. The presented geometry was chosen for several reasons: Many process steps are known to produce similar edges as well as non-orthogonal trench side walls. The proper treatment of the two including three-dimensional corners is very challenging.

The dimensions of the initial geometry are 4 $\mu$m $\times$ 5.8 $\mu$m $\times$ 6.525 $\mu$m. The performance is measured by the allocated CPU time as well as the number of points used for the surface representation. Accuracy is judged by the maximum amplitude of surface error as well as a measure for surface noise based on the curvature of the surface. Surface noise must not go unchecked as it may invalidate results at critical dimensions such as the bottom width of the trench.

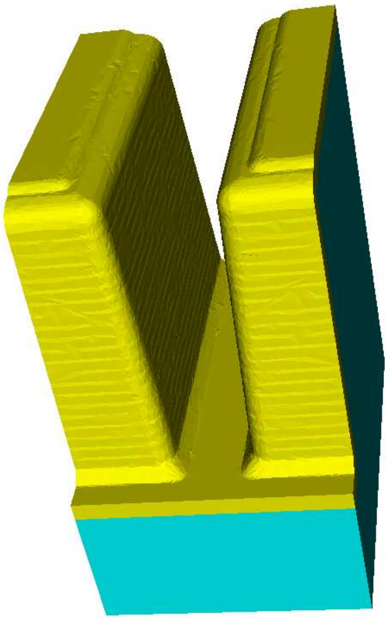

**Figure 2:** Isotropic deposition simulation with the advanced cellular algorithm

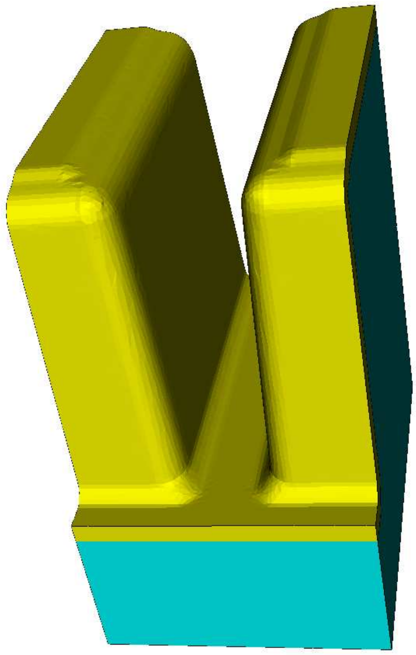

**Figure 4:** Isotropic deposition simulation with the advanced level set algorithm

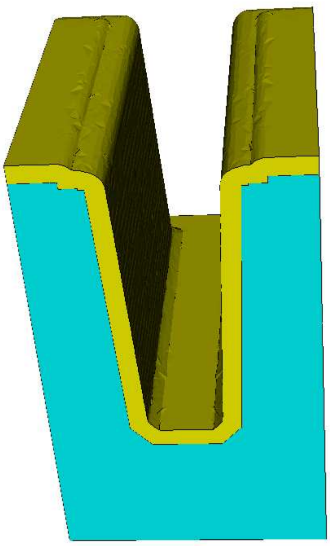

**Figure 3:** Isotropic deposition simulation with the advanced cellular algorithm, rear view

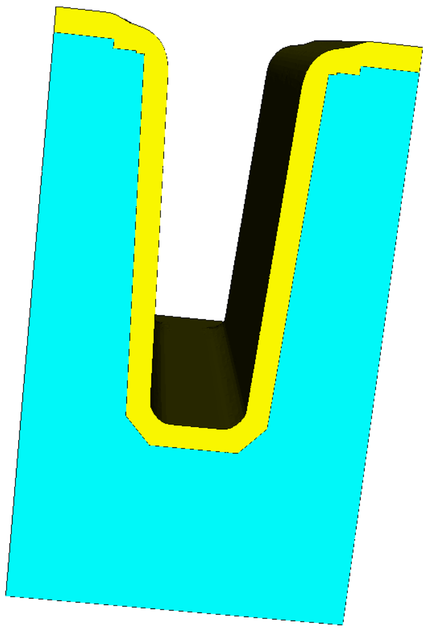

**Figure 5:** Isotropic deposition simulation with the advanced level set algorithm, rear view

Depostion simulations of a 0.27 $\mu$m thick layer were performed. Results of the calculations using the cellular algorithm can be seen in Figures 2 and 3. Even when the resolution of the simulation is increased and thereby the overall accuracy, a small periodic error cannot be avoided due to the nature of the algorithm. The surface is always modeled by the exposed facets of the cubic cells and therefore a non-orthogonal surface always results in the introduction of artefacts and an incorrect representation of the surface. The simulation has to be considered invalid as soon as this error is of the same order of magnitude as the critical dimension of the simulation. The results obtained by the level set based TOPO3D-II do not exhibit this error, as can be seen in Figures 4 and 5. Another important point is the time requirements of the computations, which are given along with the errors in the following tables. The first table describes the 0.27 $\mu$m deposition, while the second and the third tables give details of a 0.56 $\mu$m deposition:

| 0.27 $\mu$m depos. | Simulation time | Geometry points |
|---|---|---|
| initial | - | 1,162 |
| Cellular | 83m 6.2s | 27,240 |
| Level set | 31m 32.7s | 16,091 |

| 0.56 $\mu$m depos. | Simulation time | Geometry points |
|---|---|---|
| initial | - | 1,162 |
| Cellular | 105m 43.3s | 27,433 |
| Level set | 42m 0.1s | 16,147 |

| - | Simulation time | Relativ error |
|---|---|---|
| Cellular | 105m 43.3s | 9 |
| Level set | 42m 0.1s | 1 |

## CONCLUSION

A comparison of state-of-the-art topography algorithms found the level set algorithm to be superior to the cellular algorithm. In particular for surfaces that are not parallel to each other an error is unavoidable in the cellular algorithm, even when a high resolution is used. Only in case of negligible error the cell based algorithm will meet the needs of the simulation. The level set method, on the other hand, describes and evolves the surface implicitly and can thus easily describe surfaces which are not parallel to one of the principal axes. The simulation converges to the exact solution and is more than twice as fast as the cell based simulation.

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