Fast Marching Level Set Methods for Three-Dimensional Photolithography Development

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ABSTRACT

The *fast marching method*, introduced by Sethian in [23, 22], is a numerical technique for solving the Eikonal equation, and results from combining upwind schemes for viscosity solutions of Hamilton-Jacobi equations, narrow band level set methods, and a fast *min*-heap algorithm. On a rectangular grid of N total points, the fast marching level set method computes the solution to the Eikonal equation from given initial data in $O(N \log N)$ steps. In a series of papers, we have applied this technique to a wide collection of problems, including construction of geodesics on surfaces [10], computer vision [13], and shape-from-shading [23]. In this paper, we analyze the application of the fast marching method to photolithography development.

Our results show that application of this scheme results in three-dimensional photolithography development times of under 40 seconds on a Sparc 10 for rate functions defined on 150x150x150 grids. We provide studies of timings, accuracy, and examples of realistic applications to fully three-dimensional photoresist development.

KEYWORDS: Fast marching method, Level set techniques, Eikonal equation, Photoresist development

2. INTRODUCTION

In this paper, we analyze the application of the *fast marching method*, introduced by Sethian in [23, 22], to photolithography development, including development times for rate functions calculated from realistic patterns masks. The algorithm is an outgrowth of the general Osher-Sethian level set methodology [14], which has been applied to a wide collection of semi-conductor device simulations, including problems in three-dimensional etching and deposition in [3, 4]. Our fast marching version, which applies to the special case of the Eikonal equation and more general static Hamiltonians, is accurate, robust, extremely fast, and unbreakable. In particular,

- The algorithm is based on straightforward, upwind finite difference approximations
- The accuracy of the technique depends on the accuracy of the difference operators, and can be made of arbitrarily higher order of accuracy in smooth regions away from sharp corners.
- The storage required is essentially twice the size of the grid necessary to hold the rate function
- The algorithm is extremely fast; a 50×50×50 grid of rate values can be developed in less than one second on Sparc 10; on 150×150×150 grid, the development is less than 40 seconds.
- There is no time step in the calculation of the lithography profile; by converting the problem to a stationary one, the solution at all time levels may be directly constructed.
- The algorithm is less than 500 lines of code.

The outline of this paper is as follows. We begin with a formulation of the equations of motion for a lithographic development profile. We then discuss numerical approximations to these equations of motion, and review the level set approach to entropy/viscosity solutions of front propagation problems. This leads to the fast marching method presented in [23, 22], which we review. We then analyze the performance of the technique to photolithography simulations; finally, we show a series of simulations using our approach.

3. EQUATIONS OF MOTION

Consider a boundary, either a curve in two dimensions or a surface in three dimensions, separating one region from another. Imagine that this curve/surface moves in a direction normal to itself (where the normal direction is oriented with respect to an inside and an outside) with a known speed function F. Our goal is to track the motion of this interface as it evolves. We are only concerned with the motion of the interface in its normal direction; throughout,