Modeling and Scheduling Stepper Operations in the Photolithography Process in Wafer Fabrication

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Increase in the use of computers and hi-tech gadgetry have boosted the semiconductor manufacturing industry tremendously over the past decade. At the same time, exponential rates of growth and innovation combined with cutthroat competition are putting tremendous pressure on the industry to improve manufacturing practices and reduce costs. With considerable existing work in the modeling, simulation and optimization of actual physicochemical operations, it has been estimated that major improvements in the productivity of semiconductor industry lay in the higher-level systems engineering research involving the planning, scheduling, and optimization of semiconductor manufacturing processes. However, the semiconductor industry is quite different from the more traditional manufacturing operations such as assembly lines or job shops. Features such as re-entrancy, resource constraints, and uncertainties make this industry a highly complex process system that is difficult to schedule.

The wafer fabrication process, wafer fab in short, dominates the economics of IC production and it is the most technologically-complex and capital-intensive stage in semiconductor manufacturing. In the wafer fab, the wafers are processed in order to build up layers of patterns to produce the required circuitry. This involves a complex sequence of processing steps with a number of operations that require different kinds of equipment. Modeling the entire suite of operations is still a daunted task, and we have been trying to focus on some specific, most critical, and bottle-neck steps. One such step is the photolithography. In this process, the wafer is exposed to a light source that passes through the reticle (or mask) which holds the pattern of the circuitry for a particular layer. Steppers are the equipment used for this process and form the most expensive bottleneck station in the wafer fab. One third of the total work-in-process competes at the steppers. Therefore, it is critical to allocate the wafer lots to the steppers in an efficient manner to manage the overall flow of the wafer lots through the fab. Wafer lots visit the stepper machines for different layers several times which makes the flow of the lots through the steppers re-entrant. Masks are used in the photo process to align layers and their availability can be limited imposing a constraint on the process.

Optimal allocation of steppers to different types of lots, while minimizing the setup or changeover times and costs, is essential for maximizing the productivity and hence profits. Allocation of a large number of lots waiting before the steppers, the re-entrant flow of lots, and the resource constraints in the form of limited masks make the scheduling of photolithography process very difficult. Even though the photolithography process is a semi-continuous operation, the wafers are generally processed in lots. Hence, we treat the stepper machines as batch units. In this paper, we model the photolithography process as a single stage, multi-product batch process with non-identical, parallel units.

Past scheduling work on such a process addressed the problem in terms of individual batches. The problem with such an approach is that it becomes impossible to schedule large numbers of lots waiting before the steppers. Thus, there is a need to develop a mathematical

model that addresses the problem in terms of batches of integral lots suitable for similar machines. In this paper, we develop such a mathematical model to schedule lots using slot-based continuous-time representation. Our model allows the scheduling of multiple lots of the same type of product/device in a single slot and hence is able to handle larger problems. Although our model introduces integer variables, it reduces the binary variables considerably, and hence solves faster. Numerical tests show that the integer variables as opposed to binary variables have much less effect on the model performance. At this time, we have considered two scheduling objectives in our work, maximizing throughput and minimizing the delay in fulfilling the production targets. We have been able to schedule as many as 30000 wafers on steppers in about 20 s, while the batch-based models existing in literature fail to get an optimum solution in a reasonable amount of time.

Keywords: scheduling, steppers, photolithography, batch, wafer fabrication

References:

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