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An Application of Traveling-Salesman Models to Shot Sequence Generation for Scan Lithography

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ABSTRACT

The Scan Lithography (**SL**) transfers circuit patterns on a reticle onto a silicon wafer by laser projection. In a scan type projection exposure apparatus, the scanning direction of each shot affects the total time to expose all chips on a wafer. The **shot sequence** (*sequence*, in short) indicates the order of shots projected on a wafer under consideration of the direction. The cycle time (the time required for a sequence) reduction is an important factor to improve the productivity. We propose a new Traveling-Salesman Problem (**TSP**) model for finding an optimal sequence in this paper. Experimental results showed that our method generated the optimal sequences within a reasonable time.

Figure 1 shows an image of a silicon wafer. The problem of finding a sequence is formulated as a graph $G = (V, E)$ where V is a set of vertices and E is a set of arcs. In our problem setting, V is divided into n groups. Figure 1 uses 4 groups, called the *beginning node* B, the *alignment node* A, the *shot node* S and the *terminating node* T. Alignment nodes are used for identifying the position of a wafer and SL projects an circuit pattern on a shot node. Each possible sequence starts from a beginning node, then a laser head goes to an alignment node. After passing all alignment nodes at once, then it goes to a shot node. After passing all shot nodes at once, then it goes to a terminating node. We call this as the **group constraint**. We also call a route from the beginning to the terminating node as **shot sequence**. A cost between two vertices is pre-defined by the distance and the performance of SL. An optimal sequence is one where the sum of cost on the sequence is minimum. We call the problem of finding an optimal sequence as the **shot sequence generation problem**.

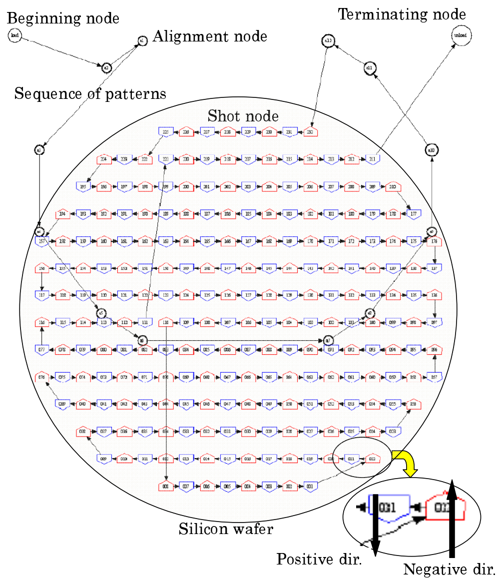

Figure 1: A Production Image

The passing direction on shot nodes affects the cost between two vertices in SL. We introduce the positive direction $P(v)$ and the negative direction $N(v)$ for

each shot node v (see Figure 1). We define the cost $c(v_1, v_2)$ from a vertex v_1 to v_2 below:
(1) $c(v_1, v_2)$,$v_1 \in B, v_2 \in A$. **(2)** $c(v_1, v_2)$,$v_1 \in A, v_2 \in A$.
(3) $c(v_1, P(v_2)), c(v_1, N(v_2))$,$v_1 \in A, v_2 \in S$.
(4) $c(P(v_1), P(v_2)), c(P(v_1), N(v_2)), c(N(v_1), P(v_2)), c(N(v_1), N(v_2))$,$v_1 \in A, v_2 \in S$.
For simplicity, we assume that the cost is symmetric such as $c(P(v_1), N(v_2)) = c(P(v_2), N(v_1))$.
(5) $c(P(v_1), v_2), c(N(v_1), v_2)$,$v_1 \in S, v_2 \in T$. **(6)** $c(v_1, v_2)$,$v_1 \in T, v_2 \in B$.
(7) Other costs are infinite.

The shot sequence generation problem with costs defined above is naturally identified with the asymmetric TSP (**ATSP**). We convert the ATSP model to the symmetric TSP (**STSP**) model, since the high-performance solvers can be available for STSP. Therefore, we introduce 3-node expression to express the passing direction on the shot node on STSP. Figure 2 represents the conversion of an physical ATSP model to the STSP model. A shot node is expressed by 3 nodes in STSP model for representing the positive and the negative direction. For example, a sub-sequence $(a, P(s1), N(s2))$ is represented by $(a, s1u, s1m, s1l, s2l, s2m, s2u)$ in the STSP model. An appropriate M added to costs between alignment nodes and shot nodes is for selecting just one arc. By using an appropriate M, only a sequence satisfying the group constraint are generated. The total cost obtained from the STSP model is $c(a, P(s1)) + c(P(s1), N(s2)) + M$. The true total cost is obtained, by taking M off from the total cost.

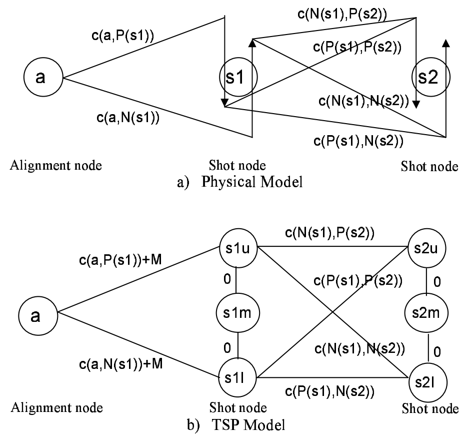

Figure 2: Converting Models

Our translated instances for the shot sequence generation problem can be solved by the Concord TSP solver. We compared our method with several ATSP methods such as the truncated branch-and-bound method[1], the mixed-integer linear programming approach with minimum-cut solved by CPLEX, and the generic 2-node and the 3-node expression model for converting ATSP into STSP[2]. The experimental results for three real problems are summarized in Table 1 which shows the cycle time of sequence and the run time. Table 1 and results from other real or randomly-generated examples showed that:
(1) The optimal solution improved the cycle time of SL faster than human-made sequences.
These differences are meaningful in the actual production process.
(2) Our model solved the problems faster than other methods.
It is expected that the actual production process becomes adaptive for various requests.

Table 1: Experimental Results (the cycle time and the run time)

$Prob.$	$size$A	$size$S	$HumanExpert$	$Trunc.B\&B$	$MILP$	$2-Node$	$3-Node$	$Proposed$
$Pr1$	4	64	23.16	22.64(27s)	22.39(19s)	22.39(59s)	22.39(147s)	22.39(6s)
$Pr2$	12	232	44.65	45.49(190m)	44.06(29m)	–	–	44.06(34s)
$Pr3$	48	232	49.08	49.57(463m)	48.35(281m)	–	–	48.35(34s)

REFERENCES

[1] W. Zhang. “Truncated branch-and-bound: A case study on the asymmetric tsp”. *In Working Node of AAAI 1993 Spring Symposium: AI and NP-Hard Problems*, 160-166, 1993.

[2] G. Gutin and A. P. Punnen (eds.). “The Traveling Salesman Problem and its Variation”. Kluwer Academic. 2002.