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Conceptual Design of Planar Retainer Mechanisms for Bottom-Opening SMIF Environment

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Abstract: This paper presents an efficient and systematic methodology for the conceptual design of planar retainer mechanism. The mechanism is used to hold wafers in a wafer container and prevent wafers from collision and scrape during transportation. At the request of high cleanliness, the mechanism is required to have least frictional motion to avoid generating particles inside the wafer container. These conceptual functions of retainer mechanism are embodied as functional requirements for the motions of mechanism's key links. From the functional requirements, it is possible to construct the admissible key-links chain. The key-links chain is then assigned into feasible graphs existing in the atlas. In addition to the key-links chain in the feasible graphs, the remaining links and joints confining the mechanism motion to the specific mobility and nature of motion can be identified. Admissible retainer mechanisms can be finally obtained by assigning appropriate specifications of the remaining joints.

Keywords: Retainer mechanism, SMIF, Wafer container

1 Introduction

The cleanliness request for semiconductor processing equipment is unceasingly increased due to the enhancement of integrated circuit's integration. With a view to ensuring wafers against contamination, standard mechanical interface (SMIF) environment [1, 2] is constructed to interface a clean wafer transport container to the port on semiconductor processing equipment. This technique reduces the cost and difficulty in maintenance and production in an integrated-circuit manufacturing factory. Two classes of interfaces are provided for the SMIF environment, one as the bottom-opening interface [1] that is arranged in the bottom of the wafer transport container, and another as the front-opening interface [2] arranged in the front side of the container. The former interface is used in 100, 125, 150, 200 and 300 mm wafer size versions of the SMIF port, and the latter in 300 mm port. In this paper, we focus on the bottom-opening SMIF environment, which is shown in Fig. 1. The wafer transport container creates a particle-free and airtight mini-environment such that wafers can be prevented from contamination by abraded particles during the transportation or storage. In the bottom-opening container, wafers are stationed in a cassette located on the container door. While operating, the container is first mated to the port of processing equipment, and the container door is then released from the container and delivers wafers into the processing equipment. For safety reason, the retainer mechanism is used to retain wafers from collision and scrape in the container. An existing design of retainer mechanism [3] with a referenced coordinate system attached to the lower left corner is shown in Fig. 2. This retainer mechanism inside the container is constructed by a parallelogram four-bar linkage comprising the retaining link (link 3), two cranks (links 2, 4) and the container case as ground link (link 1). As the container door engages with the container in its engaging direction y, the retaining link serves as an input link and is driven by the upward push of the container door. Followed by the door engaging motion, the retaining link slides in direction x with respect to the container door to retain the wafers in the cassette. Various designs of retainer mechanisms can be found in the industrial applications [3, 14-24]. Since the retainer mechanism is directly exposed inside the clean mini-environment of the container, it is possible to contaminate wafers due to the abraded particles by the mechanism motions. The way to reduce the contamination possibility is to adopt the mechanism design, with a reduction of relative motions among objects for the sake of eliminating contact abrasion. For example, the mechanism acts without relative motions between the retaining link and wafers, or between the input link and

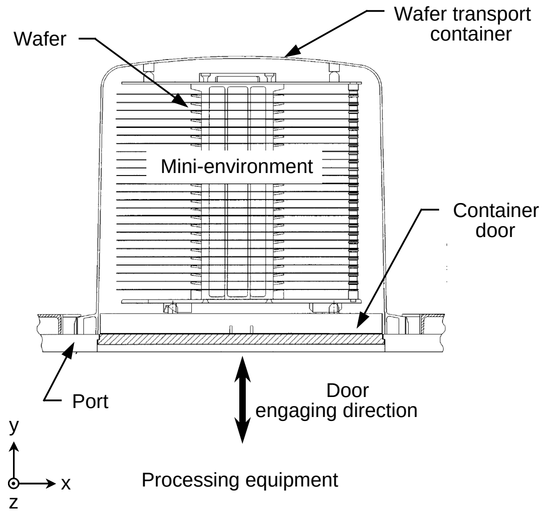


Figure 1: Bottom-opening SMIF environment.

container door.

In recent decades, the application of graph theory has played an important role in the pursuit of systematic approach of mechanism design [4-8]. From that point on, the mechanism design was able to evolve in a relatively more systematic manner and be applied to a variety of industrial applications [9-13]. The objective of this paper is to conceive a systematic methodology for the design of planar retainer mechanisms for the bottom-opening SMIF environment [1] with an aid of graph theory. It will be shown that the key-links chain in the retainer mechanism performs the desired functions, and the remaining links and joints constrain the mechanism to fulfill the structural requirements for the specific mobility and nature of motion. In accordance with the functional requirements embodied from the desired functions of mechanism, admissible key-links chain is constructed. Then, feasible graphs are determined by applying the structural requirements. The design of mechanisms can then be performed by assigning the admissible key-links chain into feasible graphs followed by determining the remaining joints.

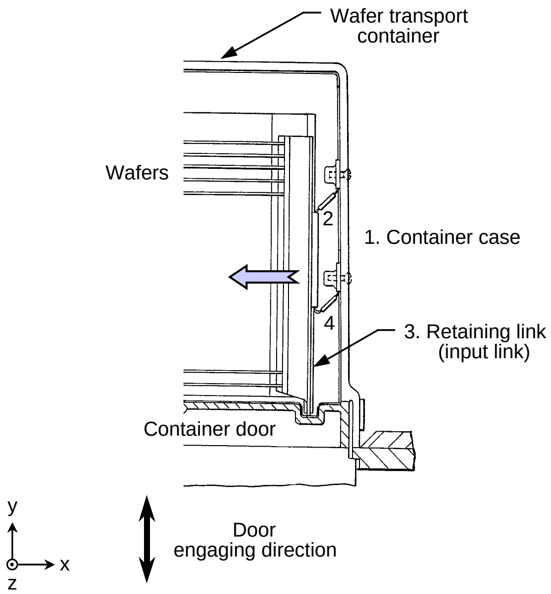


Figure 2: An existing retainer mechanism design.

2 Functional Requirements of Retainer Mechanism

It is shown that the primary function of retainer mechanism is to hold and support wafers, upon condition that relative motions of contacting links to wafers and the container door are eliminated. In this paper, the input link and retaining link are designated as different links. In view of Fig. 2, the input link of retainer mechanism is actuated by the upward motion of the container door in direction *y*. In order to avoid the abrasion between the input link and the actuating container door, it is desirable to have no relative motions in direction *x*. Hence, the input link is expected to move along the same path with the door engaging motion, i.e. a linear motion along direction *y*. Therefore, the first functional requirement of retainer mechanism can be characterized as follows, always assuming the engaging direction of the container door is oriented in direction *y*:

R1. *The input link must move linearly in direction y with respect to the ground link to avoid abrading with the actuating container door.*

As shown in Fig. 2, wafers are to be retained by the retaining link moving along direction *x*. Similarly, it is desirable to avoid the abrasion between the retaining link and wafers. Hence, relative motions between the retaining link and wafers in direction *y* are expected to be eliminated. In the SEMI standards for the bottom-opening container [1], wafers are placed in a cassette located on the container door, and hence they can be regarded as the same body of the container door. As a result, another functional requirement of retainer mechanism can be characterized as follows.

R2. *The retaining link must move linearly in direction x with respect to the container door in order not to abrade wafers.*

3 Construction of Key-links Chain

From **R1** and **R2**, it can be seen that the functional requirements characterize the motions of the input link and retaining link. The input link, retaining link and ground link are designated as the key links of the retainer mechanism that perform required motions to achieve the functions. In order to achieve the required motions in **R1** and **R2** in a convenient manner, the input link is set adjacent to the ground link and the retaining link is set adjacent to the input link. Accordingly, the key-links chain of the retainer mechanism is sequentially formed by the ground link, input link and retaining link as the graph representation [4] shown in Fig. 3(a) where links are denoted by vertices and joints by edges. In this figure, the ground link is denoted by double circles, the input link by a gray vertex and the retaining link by a solid vertex. The joint between the ground link and input link is called the input joint, while the joint between the input link and retaining link is called the retaining joint.

The functional requirements **R1** and **R2** can be realized by assigning the joint types and orientations of the input and retaining joints into the key-links chain. In view of **R1**, the required linear motion of input link in direction *y* with respect to the ground link can be produced through assigning the input joint as a prismatic joint in direction *y*. Thus, we have the following functional characteristic:

C1. *The input joint of the key-links chain can be designated as a prismatic joint (P) in direction y to avoid the abrasion between the input link and the actuating container door.*

When characterized by **C1**, there will be no relative motion between the input link and the container door while operating. As for the functional requirement **R2**, the required linear motion of retaining link in direction *x* with respect to the container door can be thought of a motion with respect to the input link. Thus, it can be produced through assigning the retaining joint as a prismatic joint in direction *x*. We have the other functional characteristic as follows:

C2. *The retaining joint of the key-links chain can be designated as a prismatic joint (P) in direction x to avoid the abrasion between the retaining link and wafers.*

The functional characteristics **C1** and **C2** yield feasible designs for the input and retaining joints. Through the combination of these two joints, admissible key-links chain for the retainer mechanism can be obtained. The result is shown in Fig. 3(b) where the input and retaining joints are labeled according to joint type with the arrowed suffix indicating the direction of motion. The input joint is labeled as $P_{\vec{y}}$ and the retaining joint as $P_{\vec{x}}$. The admissible key-links chain constitutes the possible module in the retainer mechanism that can fulfill the functional requirements.

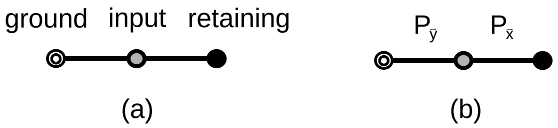


Figure 3: (a) Key-links chain of the retainer mechanism. (b) Admissible key-links chain.

4 Feasible Graphs with Assigned Key-links Chain

In this phase, the admissible key-links chain derived from the previous section is assigned into feasible graphs of kinematic structures. To determine the kinematic structure of mechanism, the first step is to find its numbers of links and joints. In this paper, the retainer mechanism is designated as a planar mechanism. Hence, the numbers of links and joints must follow the general degree-of-freedom (DOF) equations for the planar mechanism:

$$F = 3 \cdot (n-1) - 2 \cdot j_1 - j_2 \tag{1}$$

and

$$j = j_1 + j_2 \tag{2}$$

where F denotes the DOF of mechanism, n the number of links, j_i the number of i-DOF joints and j the number of joints.

In this paper, we intend to design the retainer mechanism in the simplest form. Therefore, the mechanism is assumed to have 1-DOF and up to 4 links. By substituting the number of links $n = 3$ or 4, and the DOF of mechanism $F = 1$ into Eq. (1), possible sets of integer j_1 and j_2 can be solved as shown in Table 1. Feasible numbers of links and joints (n, j) are then obtained accordingly. For the given sets of (n, j), feasible graphs of kinematic structures can be searched from the existing atlas [4, 25] and are shown in Table 1 where the lower pairs are denoted by thin edges and the higher pairs by heavy edges.

According to the compatibility of the joint DOF between the key-links chain and the feasible graphs, the assignment can be executed through placing the thin edges of key-links chain coincident with the thin edges of feasible graph, and heavy edges of key-links chain with those of feasible graph. Since the DOF of mechanism is set as one in this work, the 1-DOF loop of a multi-loops graph containing all the links of the key-links chain forms a functionally complete retainer mechanism. The remaining links in other loops shall become redundant. Therefore, the following rule for assigning the key-links chain can be made: *All the links of the key-links chain cannot be assigned into a 1-DOF loop of a multi-loop kinematic structure.*

By applying the above rule, the admissible key-links chain in Fig. 3(b) can then be assigned into the feasible graphs in Table 1. Let us take the No. 3 graph in Table 1 as an example. This graph is tagged as shown in Fig. 4(a). The two thin edges of the admissible key-links chain can be assigned coincident with two of the thin edges among e_1, e_2, e_3 of the graph. However, to let the input and retaining links stay in two separate loops, the two thin edges of the key-links chain can only be assigned into e_2 and e_3 of the graph in the path v_2-e_2-v_3-e_3-v_4 or the reverse, as shown in Fig. 4(b). The other assignments arranging the key-links chain in the path v_1-e_1-v_2-e_2-v_3 or the reverse make the input and retaining links in the same 1-DOF loop and thus violate the rule. Following this procedure, feasible graphs with assigned key-links chain, RM-1 to RM-5 can be enumerated as shown in Table 2.

Table 1: Feasible graphs of kinematic structures.

n	j_1	j_2	(n, j)	Graphs
3	2	1	(3, 3)	No. 1
4	4	0	(4, 4)	No. 2
	3	2	(4, 5)	No. 3, No. 4, No. 5

5 Admissible Retainer Mechanisms

As the results shown in Table 2, feasible graphs with assigned key-links chain are determined according to the functional requirements. Excluding the key-links chain from these graphs, the remaining links and joints provide the overall mechanism the specified DOF and nature of motion. The DOF of mechanism has been determined in the previous section by the numbers of links and joints. The nature of motion depends on the types and orientations of the remaining joints. In this phase, these specifications of the remaining joints are finally determined to yield admissible retainer mechanisms.

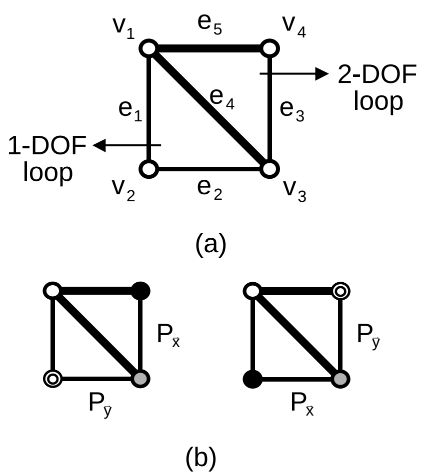
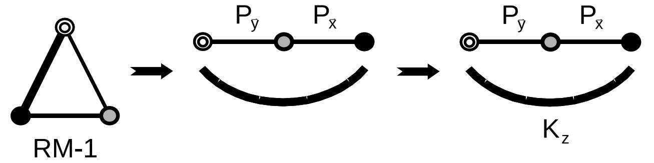
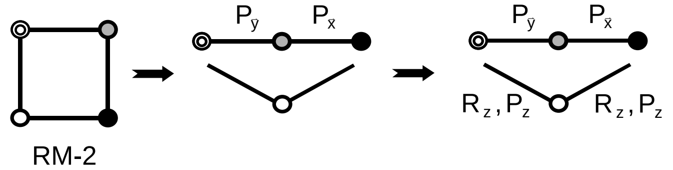
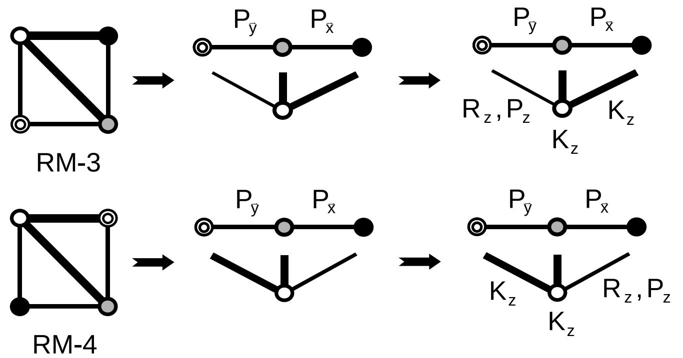
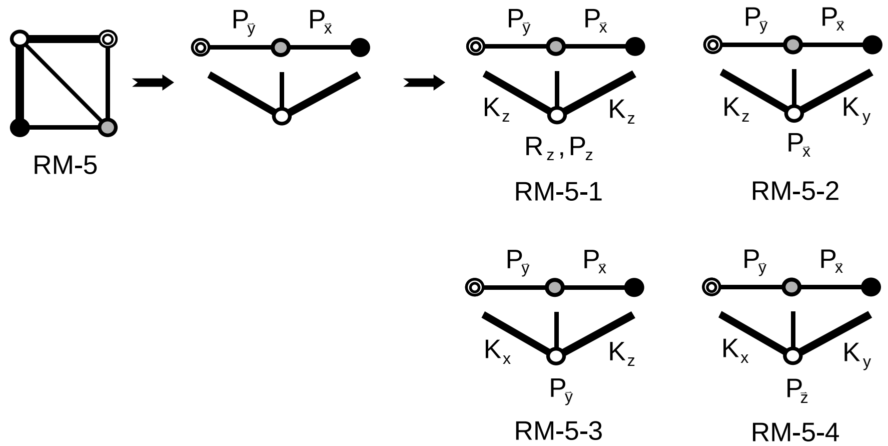


Figure 4: (a) No. 3 graph. (b) Feasible graphs with assigned key-links chain.

Table 2: Planar retainer mechanisms with up to 4 links.

No. of Graph	Feasible Retainer Mechanisms
1	
2	
3	
4	
5	None

For the planar mechanism, only the types of joints producing planar motions between the connected links can be adopted. The revolute joint (R), prismatic joint (P) and planar cam pair (K) are used in this paper. Furthermore, the types of joints are determined according to the joint DOF condition, that is, revolute or prismatic joint can be assigned for the 1-DOF joint (thin edge), and planar cam pair for the 2-DOF joint (heavy edge). As for the orientations of the remaining joints, they can be further determined according to the motion characteristics of the key-links chain. Since links in the same loop of a planar mechanism are constrained to move on the same plane, the orientations of joints in the mechanism can be arranged accordingly. As shown in Fig. 3(b), the input link of the key-links chain slides in direction *y* with respect to the ground link, while the retaining link slides in direction *x* with respect to the input link. These two links can be considered as moving on the same *xy* plane. Among the feasible graphs with assigned key-links chain in Table 2, as the input and retaining links are placed in the same loop such as RM-1 and RM-2, the motion plane of the loop is therefore arranged on *xy* plane. Hence, the remaining joints are oriented with the rotating axis about *z*-axis. As a result, the thin edges are labeled as R_z or P_z, and the heavy edges as K_z where the suffix indicates the rotating axis. The prismatic joint with suffix *z*, P_z represents that it can slide in arbitrary directions on *xy* plane, as it were to rotate about *z*-axis with an infinite radius of curvature. Note the difference between P_z and $P_{\vec{z}}$, where the latter arrowed suffix indicates the direction of motion.

As the input and retaining links are placed in distinct loops such as RM-3 to RM-5, they can be considered as moving on distinct planes. However, the common link connecting the two loops shall move linearly along the intersection of the two different planes. Since linear motions are produced by the prismatic joint, the common joint connecting the common links should be designated as a prismatic joint aligned in this intersection. Hence, only the graphs with the common joint as thin edge (prismatic joint) are feasible for the case of input and retaining links moving on distinct planes, such as RM-5. Hence, all links in RM-3 and RM-4 should also be constrained to move on the same *xy* plane, and the remaining joints are accordingly oriented with the rotating axis about *z*-axis. As for RM-5, the left-side loop containing the input joint $P_{\bar{y}}$ can be considered on *xy* or *yz* plane, and the remaining joints in this loop are oriented with the rotating axis about *z* or *x*-axis respectively. The right-side loop containing the retaining joint $P_{\bar{x}}$ can be considered on *xy* or *xz* plane, and the remaining joints in this loop are oriented with the rotating axis about *z* or *y*-axis. As a result, the heavy edge in the left-side loop can be K_z or K_x, and that in the right-side loop can be K_z or K_y, Through the combination of feasible options for the two heavy edges, four situations RM-5-1 to RM-5-4 are obtained as shown in Table 2. The mechanism RM-5-1 contains the same *xy* plane of motion, and the common joint is designated as R_z or P_z. The mechanisms from RM-5-2 to RM-5-4 contain two different planes of motion, and the common joint is designated as a prismatic joint aligned the intersection of the two planes. Feasible planar retainer mechanisms with up to 4 links are shown in Table 2.

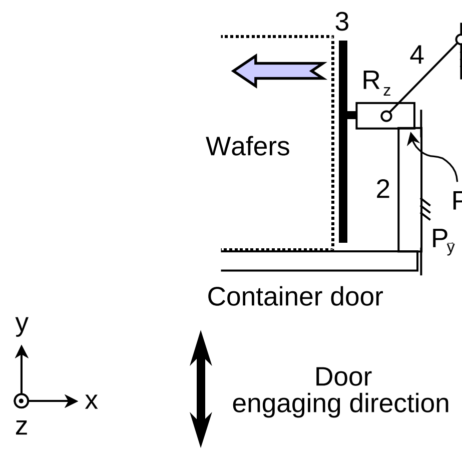


Figure 5: Functional schematic of RM-2 with all revolute remaining joints.

Figure 5 shows the functional schematic of RM-2 with all remaining joints selected as R_z. In the mechanism, all links move on the same *xy* plane. The input link, link 2, is actuated by the upward push of the container door in its engaging direction *y*. Following the door engaging motion, link 2 moves linearly along *y*-axis, since it is jointed with the ground link, link 1 by a prismatic joint $P_{\bar{y}}$. Because there is no relative motion between the container door and link 2 while operating, the abrasion between them is therefore avoided. Actuated by link 2, the retaining link, link 3 slides along direction *x* with respect to link 2, since it is jointed with link 2 by a prismatic joint $P_{\bar{x}}$. For this reason, link 3 can provide wafers a pure retaining action without generating relative motions between the two objects. The abrasion between link 3 and wafers is therefore avoided. In RM-1, link 3 is also paired with ground link by a planar cam pair K_z to constrain the mechanism mobility as one.

6. Conclusion

This paper describes a modular design methodology to synthesize planar retainer mechanisms in a systematic manner. The retainer mechanism is functionally and structurally decomposed into two modules, one as the key-links chain and another as the remaining links and joints. The design of retainer mechanisms is treated as an integration of the construction of admissible key-links chain, the search of feasible graphs with assigned key-links chain, and the determination of the remaining links and joints. Using this procedure, admissible planar retainer mechanisms with up to 4 links are obtained, and several innovative designs are therefore realized.

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