Design of a passive micro-mechanism chuck to minimize the effect of backside particles on semiconductor wafer planarity

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Abstract

There are a number of factors affecting semiconductor wafer planarity, namely intrinsic factors such as warp, bow and non-linear thickness variation [2]; and extrinsic factors such as backside particles [3,4] and chuck flatness [5]. Of these non-planarity causing factors, backside particles are the most detrimental as they affect a large portion of the wafer real estate by causing out-of-plane distortion when they get lodged between the wafer and the wafer chuck [2]. Conventional pin type and groove type chucks correct for the non-planarity causing intrinsic factors sufficiently well but do not adequately address the extrinsic factors, especially that of backside particles. Previously [7], we introduced a chuck called the compliant pin chuck that can minimize the effect of backside particles. This chuck has micro-mechanism pins that react to the presence of particles in ways that eliminate the non-planarity introduced otherwise. In this paper, we discuss some key features related to the design of the compliant pin chuck.

1. Introduction

The increasing demand on lithography systems to transfer sub 100 nm features on semiconductor wafers to allow the production of faster and cheaper chips, has forced these systems to operate under extremely tight process tolerances. One such process parameter that is becoming crucial going forward to next generation pattern transfer (sub 100 nm) is substrate flatness. For example, in the case of optical lithography, an increase in resolution results in a decrease in depth of focus thus requiring an extremely flat substrate for distortion free pattern transfer [1].

There are a number of factors affecting semiconductor wafer planarity, namely intrinsic factors such as warp, bow and non-linear thickness variation [2]; and extrinsic factors such as backside particles [3,4] and chuck flatness [5]. Of these non-planarity causing factors backside particles are the most detrimental as they affect a large portion of the wafer real estate by causing out-of-plane distortion when they get lodged between the wafer and the wafer chuck [2]. Conventional pin type chucks provide only partial relief from the detrimental effects of backside particles by reducing the contact area between the chuck and the wafer. By doing so, they only reduce the probability of lodging particles. However, if particles get lodged between the pins and the wafer they result in producing the same detrimental effects. Moreover, further reducing the contact area is not an adequate solution as it results in weaker pins increasing the chances of pin failure. Also, reducing contact area between the wafer chuck and the wafer results in poor heat transfer by conduction through the chuck which is undesirable in most lithography systems.

Previously [7], we introduced a chuck called the compliant pin chuck (CPC) that can correct for the effects of backside particles on wafer planarity. Unlike the pin type chuck, which has microstructures to support the wafer, the CPC has three-dimensional micro-mechanisms that support the wafer and in the presence of a particle these passive micro-mechanisms react in a way that minimizes the non-planarity introduced otherwise. The present paper explains some key features related to the design and fabrication of the CPC. For further information one may refer [6].
2. The compliant pin - structure

The primary distinguishing feature of the CPC is in the design of its pins. The pins of the CPC are micro-mechanisms which in their most simplistic form can be thought of as a 'T' structure with two raised areas called contact lands (see Figure 1 for illustration). Contact lands serve two purposes: 1.) They are the equivalent to a single pin of a conventional pin type chuck and reduce the contact area between the chuck and the wafer. 2.) They ensure that a bending moment is always applied about the stem of the 'T' structure, which is the flexure element of the mechanism and is referred to as the ‘flexure stem’.

![Figure 1. Compliant pins and their principle of operation](image)

3. Design features of the CPC

Some key design features of the CPC are explained in the following section.

3.1 Dual stiffness character of the compliant pin

In order for the CPC to be effective in correcting both the intrinsic and extrinsic non-planarity causing factors, the pins have to exhibit ‘dual stiffness character’. By this we mean that when no particles are present, the compliant pins have to be stiff to support the forces (produced by applying vacuum or static load to the wafer) required to correct the warp and bow in the wafer; conversely, in the presence of backside particles the compliant pins should exhibit low stiffness to accommodate the particle. This dual stiffness character is achieved by the proposed compliant pin chuck concept shown in Figure 1. When a wafer is placed on the compliant pins and no particles are present between the wafer and the wafer chuck, both the contact lands of each pin are equally loaded. This produces equal and opposite bending moments about the flexure stem that cancel each other and the compliant pin system is stable and supports the vertical load. In this case, the vertical stiffness of the compliant pin is defined by the bending stiffness of the flexure head and the vertical stiffness of the flexure stem. In case a particle gets lodged between the wafer and the contact land of a compliant pin, the force acting through the particle on a single contact land causes a bending moment to be produced about the flexure stem thereby causing the compliant pin to bend thus allowing the pin to accommodate the particle size. In this latter case, the vertical stiffness of the compliant pin is defined by the bending stiffness of the flexure stem (which is much lower than the vertical stiffness of the flexure stem).

![Figure 2. Compliant pin concept with improved lateral stiffness](image)

3.2 Lateral stiffness of the pins

It was observed through finite element analysis (FEA) of the compliant pins that with the ‘T’ structure design the lateral stiffness of the pins was very poor and there was a danger of the pins breaking at the flexure stem and hence a different design was developed that is shown in Figure 2.
flexure joints (the primary flexure joints) connect the support members to the flexure head. A second set of flexure joints (the secondary flexure joints) connects the support members to the bulk of the wafer chuck. This increases the lateral stiffness of the pins and still allows the bending behavior of the compliant pin.

3.3 Remote axis of rotation of the compliant pin

The location of the rotation axis of the pin is important as an improperly located rotation axis can cause the reaction end (i.e. the contact land opposite the contact land on which the particle is present) of the compliant pin to introduce non-planarity in the wafer. Figure 3 illustrates this concept. It is desired that the compliant pin rotates about a remote axis lying between the primary and the secondary flexure joints to ensure that no non-planarity is introduced in the wafer due to the parasitic motion of the reaction end of the compliant pin. This behavior was confirmed through FEA. Figure 4 shows the finite element simulation model of a single compliant pin in the undeformed and deformed configurations.

3.4 Multi-layer design of the CPC

To simplify fabrication of the CPC, the critical components of the chuck were distributed into multiple layers. Each layer was then fabricated using 2D lithography processing.

Figure 5 shows a schematic of the layers of Figure 6. Cross sectional view of the tri-layer stack of a single compliant pin

Once the layers were fabricated they were then aligned and bonded together to yield functional 3D micro-mechanisms. Figure 5 shows a schematic of the layers of
a single repeating unit cell of the CPC and Figure 6 shows the cross sectional view of a compliant pin. The pin layer consists of the contact lands and the primary and secondary flexure joints. The base layer consists of the flexure stem, vacuum channels and motion relief steps (see Figures 6). Motion relief steps are recesses of a defined depth (equal to the design limit of the compliant pin) in the top surface of the base layer that lie under the flexure head and the support members. They are an important feature of the compliant pin design and serve two functions: 1.) They provide the required clearance to allow the flexure head to move to accommodate particles (of sizes within the design limit). 2.) They act as a mechanical stop preventing catastrophic failure of the pins due to the presence of particles that are beyond the design limit of the compliant pin. Should a particle that is larger than the design limit of the compliant pin get lodged between the pin and the wafer the compliant pin would ‘ground out’ and will then behave like a rigid microstructure similar to a pin of a conventional pin type chuck.

Figure 7. Photograph of a single pin of the fabricated CPC prototype

The bottom-most layer is the foundation layer and its purpose is to provide bulk rigidity to the compliant pin chuck. The only feature it consists of is the vacuum supply hole in the case of a vacuum compliant pin chuck. A 4” CPC prototype was fabricated and showed to have a flatness of 120 nm (3 sigma standard deviation) over an area of 30 mm x 30 mm and demonstrated to be less sensitive to backside particles than a conventional wafer chuck [6,7]. Figure 7 shows a single pin of the fabricated CPC.

4. Summary

Previously [7], a novel chuck called the compliant pin chuck was introduced that can correct for non-planarity introduced by backside particles. In this paper, some key design features of the CPC are explained. The dual stiffness character of the compliant pins that allows the compliant pins to correct both the intrinsic and the extrinsic factors of non-planarity is explained. The modified design of the compliant pins is shown with the side members that increase the lateral stiffness of the compliant pins. Furthermore, the importance of the location of the rotation axis of the compliant pin is described and it is shown that the compliant pins do not introduce any non-planarity in the wafer during operation. Lastly, the multi-layer design of the chuck that simplifies fabrication is explained.

References