Finite Element Analysis of the Upsurge of Bifurcation during the Thinning Process of Large Semiconductor Wafers

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Article

Finite Element Analysis of the Upsurge of Bifurcation during the Thinning Process of Large Semiconductor Wafers

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Abstract During the thinning process, in the semiconductor industry, residual stress from thin films can cause severe warpage in wafers, which can compromise their processability and packaging. This warpage can lead to bifurcation or buckling, making it important to understand this phenomenon for the manufacturing of large semiconductor wafers. We conducted a finite element analysis of the thinning process using ANSYS mechanical enterprise 2023/R2 to investigate the asymmetric curvatures resulting from bifurcation in a standard 300 mm Si (001) wafer. We induced an asymmetry in the system by applying a slight force on a point of the circumferential region perpendicularly to the substrate. We also simulated the compressive stress from the damaged layer formed during the thinning process and considered its influence on warpage and bifurcation in both linear and non-linear cases. We also included the influence of Earth's gravity induced deflection (GID) and investigated the influence of the compressive stress damaged layer on the grinding process of the whole wafer by adding a metal front layer to the ground back damaged wafer.

Keywords: thinning process; bifurcation; buckling; wafer; warpage; curvature; finite element analysis (FEA); simulations

I. Introduction

Because of the residual stress determined by thin films manufactured within the large-scale integration process of the semiconductor industry, during the thinning process, a severe warpage degeneration can compromise the upcoming processes required for the packaging of a die. Indeed, as the thickness of the wafer gets reduced by thinning, the upsurge of the warpage can result in the phenomenon of bifurcation or buckling [1–4], which can further compromise the processability of a wafer. For this reason, a deeper comprehension of the phenomenon of bifurcation in relation to the thinning process can be of help in the manufacturing of large semiconductor wafers. In this work, a finite element analysis of the thinning process is presented. We implemented a finite element analysis method by using ANSYS mechanical enterprise 2023/R2 to investigate the phenomenon of bifurcation in a standard 300 mm Si (001) wafer subjected to a simulated thinning process such that the asymmetric curvatures of the wafer resulting from the bifurcation can be investigated. To investigate the bifurcation, an asymmetry was induced in the system, by applying a slight force on a point of the circumferential region perpendicularly to the substrate. To take into account of the phenomenology of the grinding process, we simulated the compressive stress determined by the damaged layer which forms during the thinning stress, and we determined the influence on the warpage after thinning of the residual stress generated by this bottom layer in the linear case, in the non-linear case and hence considered its influence on the bifurcation. To complete the investigation, we also included the influence of Earth's gravity induced deflection (GID) in relation to the grinding process. Lastly, we added a metal front layer to the ground back damaged wafer and investigated the influence of the compressive stress damaged layer on the grinding process of the whole wafer.

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II. Background

Previously we investigated the warpage and bifurcation of large semiconductor wafers [5–14] by using ANSYS® Mechanical Static Structural. Given a certain thickness, we showed as by increasing the stress of the metal layer the phenomenon of bifurcation can emerge. In this work, what we have done is to investigate the upsurge of bifurcation by simulating the thinning process. In particular, we fixed the properties of the metal layer stressing the wafer and investigated the warpage and its degeneration to bifurcation as the thickness of the wafer decreases continuously. As it is well known, thinning occurs by grinding, consequently, to properly take into account of the grinding process we considered the presence of an equivalent layer that can simulate the compressive stress of the damaged layer placed at the back of the ground wafer.

III. Methodology

Simulations were developed by using ANSYS® Mechanical Enterprise 2023/R2 for a back damaged ground 200 mm silicon wafer. The properties of the damaged layer were setup to generate a well determined compressive stress because of the mismatch of the coefficient of thermal expansions (CTEs). A thermal load was applied to the whole system and the resulting warpage and emergence of the bifurcation phenomenon was monitored as a function of the thickness of the wafer. Warpage and bifurcation were monitored also in the presence of Earth's gravity if the wafer is oriented with the back damaged layer on the top and if the damaged layer is on the back. Finally, the effect of the damaged layer on the bifurcation has been combined with the presence of a metal layer on the top of the wafer.

IV. Results

In Figure 1. we report the schematic of a semiconductor wafer. the ground damaged layer lies on the back of the wafer. The damaged layer having a thickness t_f of 6 μm is simulated as a compressive stress layer, whose Young modulus and Poisson coefficient are 126 GPa and 0.26, respectively. while the coefficient of thermal expansion (CTE) was tuned to $5 \times 10^{-6}\,°C^{-1}$. The semiconductor substrate was set as a silicon anisotropic substrate (001) oriented.

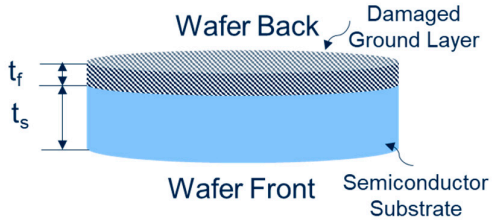

Figure 1. Schematic of a semiconductor wafer reporting the ground damaged layer on the back of the wafer. The damaged layer having a thickness t_f of 6 μm is simulated as a compressive stress layer, whose Young modulus and Poisson coefficient are 126 GPa and 0.26, respectively. while the coefficient of thermal expansion (CTE) was tuned to $5 \times 10^{-6}\,°C^{-1}$. The semiconductor substrate was set as a silicon anisotropic substrate (001) oriented.

In Figure 2. we reported the bifurcation diagram of the thinning process. The curvature of a 300 mm wafer is reported as a function of the wafer thickness for the case of damaged layer generating a compressive stress of 65 MPa as an example. The bifurcation of the wafer occurs at a thickness of 355 μm. In the linear approximation (large deflection off) the simulated wafer does not bifurcates. The behaviour is compared with the standard theory determined by the Stoney equation. It is worth to observe as the theory approximate well the behaviour of the principal curvature far from the bifurcation point. According to the theory the stress determined by the damaged layer is of 60 MPa.

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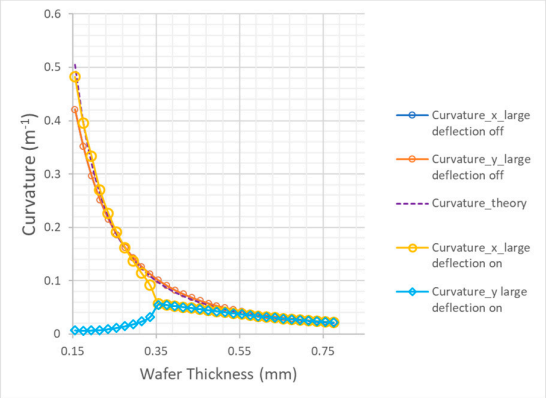

Figure 2. Bifurcation Diagrams of the thinning process. The curvature of a 300 mm wafer is reported as a function of the wafer thickness for the case of damaged layer generating a compressive stress of 65 MPa as an example. The bifurcation of the wafer occurs at a thickness of 355 μm. In the linear approximation (large deflection off) the simulated wafer doesn't bifurcates. The behaviour is compared with the standard theory determined by the Stoney equation. It is worth to observe as the theory approximate well the behaviour of the principal curvature far from the bifurcation point. According to the theory the stress determined by the damaged layer is of 60 MPa.

In Figure 3, we report a snapshot of a bifurcated 300 mm back-ground Si (001) wafer. The damaged layer, on the back of the wafer, determines a compressive stress of about 60 MPa.

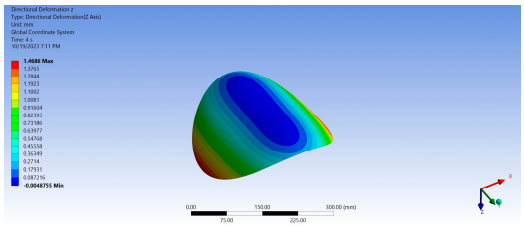

Figure 3. Bifurcation of a 300 mm back-ground Si (001) wafer. The damaged layer, on the back of the wafer, determines a compressive stress of about 60 MPa.

A. Results: Gravity Induced Deflection and Thinning

The presence of Earth's gravity can determine some modifications in the upsurge of the bifurcation in the thinning process. We investigated these effects. In Figure 4a we report the schematic of the 12" wafer subject to the Earth's gravity oriented such that the back ground surface of the wafer is upward. Whereas in Figure 4b the orientation is reversed.

Simulations have been repeated by adding the gravity force and the results are reported in Figure 5 for the two cases. It resulted that, as the thinning process occurs, if the damaged layer of the wafer is on the top, Earth's gravity will shift the bifurcation point at higher values of the thickness of the wafer. If the damaged layer is down, Earth's gravity will determine a mitigation of the bifurcation.

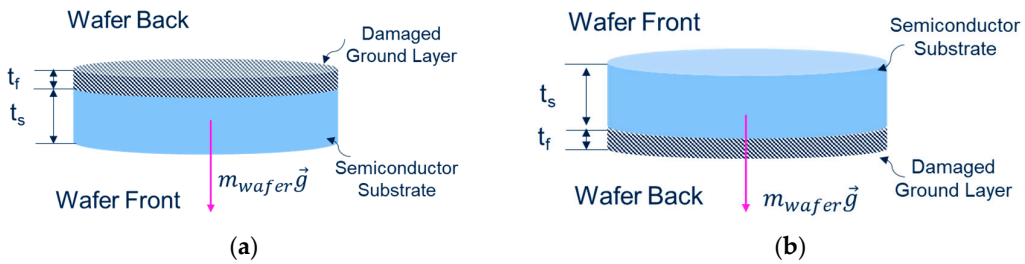

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Figure 4. a. Wafer orientation with respect to the force of gravity, with the wafer back on the top. b. Wafer orientation with respect to the force of gravity, with the wafer back on the bottom.

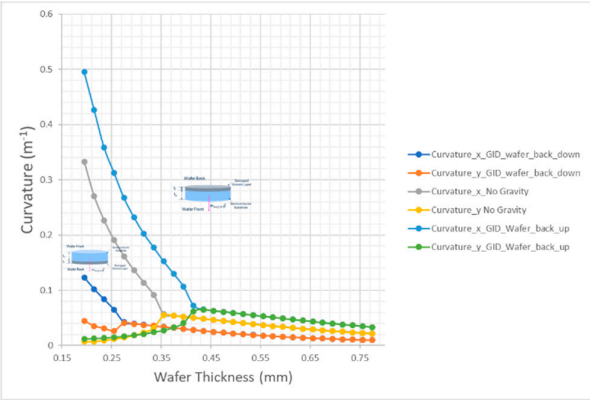

Figure 5. The effect of Earh's Gravity (Gravity induced deflection (GID)) on the bifurcation determined by thinning of the wafer. If the damaged layer of the wafer is on the top, Earth's gravity will shift the bifurcation point at higher values of the thickness of the wafer. If the damaged layer is down, Earth's gravity will determine a mitigation of the bifurcation.

B. Results: Bifurcaiton Induced by a Damaged Layer and Metal Layer durign the Thinning Process

What happens if the thinning process occurs when at the top of the wafer there's a metal layer? In Figure 6 the schematic of a semiconductor wafer reporting the ground damaged layer on the back of the wafer and a metal layer added on the top is reported. By simulating the thinning process, it resulted that bifurcation onset by reducing the thickness of the wafer for an Al front side metal layer in presence of the investigated damaged layer and its comparison with the bifurcation determined only by the damaged layer. It results that the bifurcation point occurs well before for the front side metalized back damaged ground wafer.

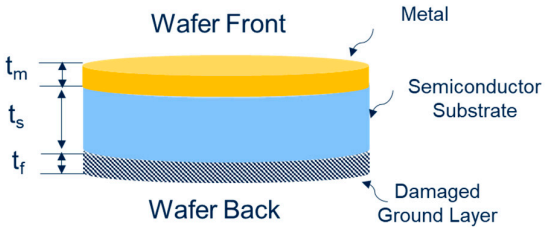

Figure 6. Schematic of a semiconductor wafer reporting the ground damaged layer on the back of the wafer and a metal layer added on the top.

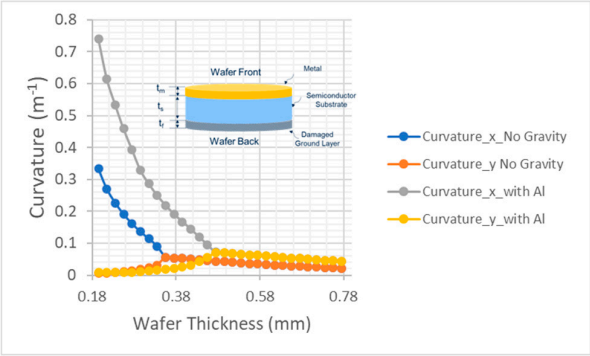

Figure 7. Bifurcation onset by reducing the thickness of the wafer for an Al front side metal layer in presence of the investigated damaged layer and its comparison with the bifurcation determined only

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by the damaged layer. It results that the bifurcation point occurs well before for the front side metalized back damaged ground wafer.

V. Conclusions

In conclusion, we have investigated the influence on warpage and bifurcation of a compressive damaged layer obtained after grinding during the thinning process. In particular, we investigated the upsurge of bifurcation as the thickness of the of the wafer is reduced. The effect of the gravity induced deflection has been also investigated once the ground bottom layer is oriented upward and downward with respect to the force of gravity. It results that the warpage and bifurcation is mitigated if the ground layer is oriented downward. Moreover, the combined influence of a damaged layer on the back of the wafer along with the presence of a metal layer, resulted in an upsurge of the bifurcation well before the metal free wafer. These investigations can be of use in order to investigate the influence of a compressive damaged layer during the thinning process.

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