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High-Accuracy Z Actuator Relying on a 3-dof Flexural Elements-Based Concept

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Abstract
This paper is concerned with the design of an actuator meant to accurately position a wafer. The actuator controls the wafer in the Z direction and moves in the XY plane. The design relies on a 3-dof flexural elements concept. It provides a long stroke combined with a high-accuracy in the Z direction as well as a very high dynamical performance during XY motions. The paper presents the selected architecture, the product design and its performance.

Flexures-based actuator, 3-dof, high-accuracy, wafer placement

1. Introduction

High-accuracy actuators are required for the placement of silicon wafers out of the horizontal plane. It may be either to have the wafer within a narrow focus depth (for the sake of wafer inspection) or to have it finely aligned with a mask (for the sake of lithography). A Z-actuator with a long stroke (e.g. 4 mm) is desired to deal with a greater variety of optics and processes. In addition, for the process to access any point onto the wafer surface, the actuator moves in the XY plane. During such XY motions, the actuator must offer a repeatable behavior and a fast settling.

In this paper, we present a piezo-like resolution and repeatability actuator offering accuracy thanks to a mapping of the repeatable errors. The concept is based on flexural elements with 4 mm stroke in the vertical direction (Z) as well as a ±0.1 ° rotation out of the horizontal plane (R_x and R_y). Possible alternative solutions are considered in section 2. Section 3 details the proposed architecture, its advantages are listed in section 4 and the Z3TM module relying on this architecture is shown in section 5. Some key performances (section 6) obtained on prototypes are then illustrated.

2. Review of possible architectures

Standard piezo-actuation is a possible solution offering a very stiff actuator for in plane motions [1]. However, such actuators have a limited stroke, typically below 100 µm. Longer strokes up to 1 mm can be reached thanks to the use of amplified piezo-actuators [2,5]. However the stiffness of the assembly drops which goes against a fast settling after XY motions. Longer strokes up to 20 mm can be reached while keeping the stiffness by making use of stepping piezo-actuators [3,4] even though the resulting maximum speed remains generally low (e.g. 20 mm/s).

In another approach, mechanical bearings are selected to guide the motion in Z. This is for instance the case for wedge actuators. 4 mm stroke are feasible and stiffness may be obtained. Nevertheless during XY motions, a load will be applied to the mechanical bearings. This results in a non repeatable behavior of the Z actuator during XY motions which is not suitable for some applications.

Using two layers of flexural elements for the bearing function allows to get rid of non-repeatable behaviour of the bearing. This architecture (sketched in 2D in Figure 1) has the advantage of the simplicity and is very stiff except in the Z direction where it is controlled thanks to two actuators and one encoder head located on the side. The design can meet the desired 4 mm stroke and is also very repeatable during horizontal motion.

Figure 1. 1-dof architecture relying on flexural elements

However, such a straightforward approach suffers from some drawbacks

- Unbalanced forces (due to imperfection in the actuators) create a residual angle R_y that hampers the accuracy in Z over the wafer surface.
- The out-of-plane settling is poorly damped by the structure which results in long settling.

3. Proposed architecture

The previous limitations may be overcome with a single layer of flexural elements and an additional set of encoder head and scale. A schematic representation of the proposed architecture is given in Figure 2. Note that the center of mass cannot be aligned with the flexural elements for technological reasons explained in section 4.

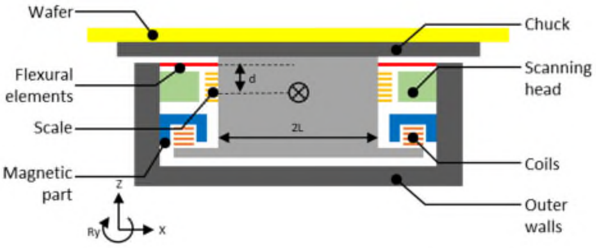

Figure 2. Schematic view of the proposed architecture

The flexural elements taken individually have a few orders of magnitude difference in their stiffness in and out of plane. The coupling of two of them as shown in Figure 2 allows the chuck to have a very smooth motion in Z and R_y over significant strokes, i.e. up to few millimetres and tenths of degrees.

Two linear incremental encoders are used to reconstruct the position Z and the angle R_y of the chuck. The scales are moving up and down with the chuck along the measuring length and they are also tilting with reference to the scanning heads. In order to keep a reasonable signal quality, the possible stroke in R_y must be limited according to the encoder specifications. In the proposed solution, an additional mechanism (not represented in Figure 2) limits R_y to ±0.1 °.

The moving part is actuated thanks to two voice coils featuring a built-in gravity compensation. Figure 2 shows that the magnets are attached to the walls while the coils are moving with the chuck. The complete mass of the moving part is passively compensated by a specific magnetic design which can deal with chucks ranging from 1 kg to 5 kg. This allows to limit the heat generated and preserve accuracy via a limited deformation of the path going from the encoders to the chuck.

4. Benefits of the proposed architecture

First, in comparison to Figure 1, the repeatability in Z is enhanced over the wafer surface thanks to the additional degree of freedom controlled with an additional encoder. The wafer tilt angle allows to keep the repeatability for any point onto the wafer. Note that this can also be used to compensate error in Z and R_y while moving in X.

Second, the center of mass of the moving part in Z cannot be kept aligned with the flexural elements for the following reasons

- The actuator is meant to accommodate a range of chucks from 1 kg to 5 kg making the position of the center of mass not constant from one application to another.
- For dynamical performance, it is desired to keep the center of mass below the flexural elements for any payload and for any position in Z over the 4 mm stroke.
- 10 mm is a typical value of the distance d in Figure 2.

Nevertheless, with the proposed architecture, during XY accelerations, the control scheme compensates for cross-talk effects on the R_y dynamics. The target is to have less than 100 nm residual error in Z after a motion at 0.6 G acceleration. In addition, during settling, the damping obtained by the control electronics is much better than the natural damping of the structure.

Figure 3. Picture of the Z3TM with electronics

5. Z3TM description

The so-called Z3TM shown in Figure 3 relies on the concept sketched in Figure 2. It actually comprises 3 flexural elements, 3 sets of scale and head and 3 actuators in a 120 degree arrangement. The same advantages remain and it offers the R_x rotation. The chuck can translate in Z and rotate around X and Y. The central part connected to the chuck comprises a rotary axis with infinite revolution around Z and a pins lift mechanism.

6. Performance

With an encoder-based reference equipment mounted in the center of the chuck interface, the accuracy and repeatability in the Z direction are evaluated according to the ISO-230-2 standard and displayed over 3mm in Figure 4. The Z3TM is ±45 nm accurate and also shows repeatability of ±22 nm (±2σ).

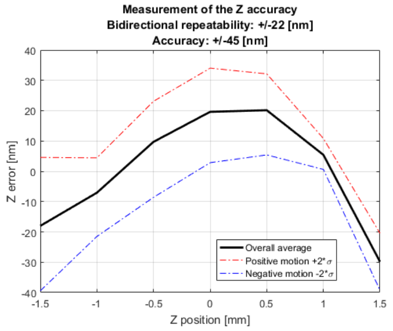

Figure 4. Illustration of the typical accuracy after 100 µm motions in Z

Figure 5 shows a ±2 nm position stability at the center of the chuck interface and after settling in XY and Z when mounted on ETEL isolation system. This compares to piezo-based actuators.

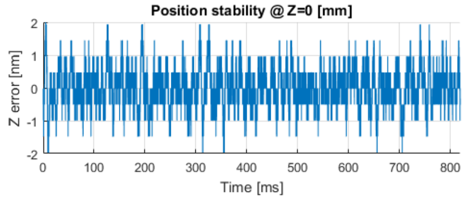

Figure 5. Illustration of the typical stability in Z

Figure 6 illustrates the residual error in Z after a 25 mm motion performed at 0.6 G. It is below 100 nm everywhere onto the wafer (within the red circle).

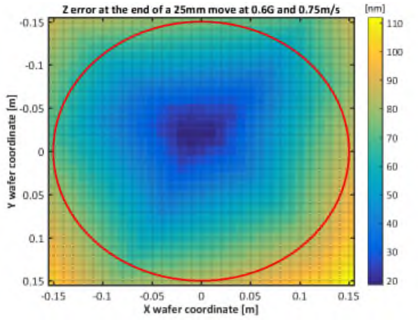

Figure 6. Illustration of the error in Z after a motion at 0.6 G

7. Conclusion

The derived architecture provides piezo-like resolution, repeatability and position stability but now combined with a 4mm stroke and it ensures a fast out-of-plane settling. The key design factor is the control of all the out-of-plane degrees of freedom (i.e. Z, R_x and R_y) with built-in gravity compensation voice coils and high resolution linear encoders. In addition, the desired stiffness and repeatability when moving a wafer in XY comes with the flexural elements.

References

[1] C. Mangeot (2012), High resolution and repeatability of a linear drive through the use of Piezo Actuator Drive (PAD), *In Proc. of EUSPEN*

[2] J. Juuti, K. Kordás, R. Lonnakko, V.-P. Moilanen, S. Leppävuori (2005), Mechanically amplified large displacement piezoelectric actuators, *In Sensors and Actuators A : Journal, **120,** p225-231*

[3] F. Claeyssen, A. Ducamp, F. Barillot, R. Le Letty, T. Porchez, O. Sosnicki, C. Belly (2008). Stepping piezoelectric actuators based on APAs, *Actuator*

[4] Daegab Gweon, Dongwoo Kang, Hyo Kim (2012), 6-DOF Parallel Nano-Positioning System with flexure joints and Piezoelectric Stepping Motors, *In Proc. of EUSPEN*

[5] E. Ahearne, G. Byrne, J. Liu, W. Connor (2013), Parameter Determination for an Electromechanical Model of a Displacement-Amplified Piezoelectric Actuator, *In Proc. of EUSPEN*