DESIGN AND CONTROL OF A NANO-PRECISION MULTI-AXIS VERTICAL MASK ALIGNER

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INTRODUCTION
The semiconductor industry is a higher value-added business. In addition the semiconductor manufacturing techniques are required high technological process. Now the techniques come at dozens nanometer units. Among other semiconductor manufacturing equipments, mask aligner is one of the most important equipment. It makes mask to align on the wafer surface precisely. It must have three degree of freedom, one translation and two rotational motions. In addition the precision of mask aligner is dozens nanometer units. In these days, there are many precision mask aligners. The majority of them have a horizontal framework type. It means that mask and wafer are parallel with ground. Those types have the merit of simple construction and stabilities. But recently they reach uppermost limit. That is the gravity. As time went on, the mask and wafer were getting bigger. In addition their precision rates were getting more important. But gravity makes mask to warp. Consequently in the future, it will be nearly impossible to manufacturing ultra precision (nanometer-unit) semiconductor

VERTICAL MASK ALIGNER DESIGN
Lately, because of these problems, their framework types are changed to perpendicular to ground. Therefore the wafer and mask are vertical to ground, too. It overcomes a handicap of the horizontal type. Because mask surface and wafer parallel to gravity force. Therefore, there is not curved phenomenon at the mask surface. It is possible to make bigger mask and wafer with a nanometer-precision. Therefore, in these days many semiconductor manufacturing corporations have researched this type equipment. But, up to present, they all work in the lab, and cannot be deployed on a commercial scale. This study covers vertical type mask aligner stage system. Especially, it analyzes 3-DOF guide hinge. It is called rotational symmetric leaf spring type hinge. For using this guide hinge, it needs to analysis of 6-DOF stiffness of the guide hinge. And it is driven by PZT Actuator. The PZT has very small moving range. Therefore it needs motion amplification mechanism. The motion amplification mechanism consists of 12-flexure hinges. Total system uses three guide hinges and three PZT amplification mechanisms and one moving plate. The moving plate is where the make is fixed on. Total system consists of 39-flexure hinges and 31-rigid bodies, and it carries out optimal design process totally. Using optimal design value, it was simulated by FEM tool. To prove validity of the analysis of 6-DOF stiffness, it is compared an analytic model with a FEM model. The error is below the 10%.

Amplification Mechanism
The vertical mask aligner stage consists of three piezoelectric actuators. PZT actuator has short transport distance. Therefore, it will need amplification equipment. The displacement generated by a piezoelectric actuator is 50um. Amplified by the amplification equipment are 200 micro-meters displacement amplification.

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Guide Mechanism
The mask aligner needs three degree of freedom, one translation and two rotational motions. Therefore, the guide hinge needs to three degree of freedom, too. The rotationally symmetric hinge [1] has 3-DOF, one translation and two rotational motions. It connects with the shaft coupler was used to. However, it is also easy to use as a mask aligner guide.
CONCEPT DESIGN
Total system uses three guide hinges and three PZT amplification mechanisms and one moving plate. The moving plate is where the make is fixed on. Total system consists of 39-flexure hinges and 31-rigid bodies. The system is compared FEM simulation tool. The error is below the 10%.

FEM SIMULATION RESULTS

1. Static result

<table>
<thead>
<tr>
<th></th>
<th>PZT 1</th>
<th>PZT 2</th>
<th>PZT3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force</td>
<td>10 N</td>
<td>100 N</td>
<td>100 N</td>
</tr>
<tr>
<td>direction</td>
<td>Modeling</td>
<td>FEM</td>
<td>Error</td>
</tr>
<tr>
<td>Z direction</td>
<td>$-2.09 \times 10^{-3}m$</td>
<td>$-1.92 \times 10^{-3}m$</td>
<td>$-8.85%$</td>
</tr>
<tr>
<td>$\theta_x$ direction</td>
<td>$1.42 \times 10^{-4}rad$</td>
<td>$1.44 \times 10^{-4}rad$</td>
<td>$1.40%$</td>
</tr>
<tr>
<td>$\theta_y$ direction</td>
<td>0 radian</td>
<td>0 radian</td>
<td>0 %</td>
</tr>
</tbody>
</table>

2. Dynamic results

<table>
<thead>
<tr>
<th>Mode</th>
<th>Modeling</th>
<th>FEM</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 mode</td>
<td>161 Hz</td>
<td>155 Hz</td>
<td>4.3%</td>
</tr>
<tr>
<td>2 mode</td>
<td>170 Hz</td>
<td>169 Hz</td>
<td>0.5%</td>
</tr>
<tr>
<td>3 mode</td>
<td>171 Hz</td>
<td>170 Hz</td>
<td>0.5%</td>
</tr>
</tbody>
</table>

CONTROL OF THE STAGE
The proposed stage is parallel mechanism in which three PZT actuators are coupled. Therefore, the kinematic relationship between input voltage of each actuator and motion of moving part must be examined. Since three sensors are also coupled, the same operation between sensor output and motion of moving part must be conducted [2].

\[
F = TV_{in} \quad (1)
\]

\[
X = T^*V_{out} \quad (2)
\]

In above equations F is the force vector by PZT actuator, X is the displacement vector of moving part expressed by rectangular coordinate, T and $T^*$ is the transpose matrix containing the kinematics of actuators and sensors, $V_{in}$ is actuator input voltage vector and $V_{out}$ is sensor output voltage vector.
EXPERIMENTAL VERIFICATION

FIGURE 6. Developed Vertical Mask Aligner

FIGURE 7. Hardware components of the control system.

The experiment result as follows. The stroke of translation movement is 190 micrometer, and the stroke of rotation movement is 0.5 mrad. And in-position stability is ±2 nm, ±30 nrad, and resolution is 6 nm, 80 nrad. The settling time is below the 50 msec.

REFERENCES