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13. ABSTRACT (Maximum 200 words)

In very fine-line VLSI photolithography, alignment and overlay errors due to distortion in the projected image of a photomask relative to an existing pattern on a silicon wafer are becoming such serious problems that product-yield is beginning to drop precipitously. We propose to solve these problems by deliberately deforming a mask with a system of piezoelectric actuators in such a way that its induced deformations precisely match those of the wafer and so that all of the alignment marks at each chip site can be pulled into registration simultaneously during exposure.

The centerpiece of our program is a proof-of-concept demonstration of inducing predictable distortions in a photomask by means of piezoelectric transducers in a deformable mask holder. In this report, we outline our program and provide a status report of the ongoing work. We have constructed and tested the deformable mask holder for the proof-of concept demonstration and performed measurements of mask distortions as a function of applied force.

14. SUBJECT TERMS
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(1) List of Papers submitted or published – "Adaptive Alignment of Photomasks for Overlay Improvement", C. Chen, R. Englestad, E. Lovell, D. White, O. Wood, M. Smith, and L. Harriott, J. Vac. Sci. Technol B, Vol. 20, 3099 (2002).

(2) Scientific Personnel – Lloyd R. Harriott, Professor Electrical and Computer Engineering, University of Virginia, Megan K. Smith, Graduate Student, ECE, UVA, MS 5/03.

(3) Report of Inventions – none

(4) Scientific Progress and Accomplishments

In very fine-line VLSI photolithography, alignment and overlay errors due to distortion in the projected image of a photomask relative to an existing pattern on a silicon wafer are becoming such serious problems that product-yield is beginning to drop precipitously as a result. We propose to solve these problems by deliberately deforming a mask with a system of piezoelectric actuators in such a way that its induced deformations precisely match those of the wafer and so that all of the alignment marks at each chip site can be pulled into registration simultaneously during exposure.

According to the 2001 International Technology Roadmap for Semiconductors, fulfilling overlay requirements is one of the most difficult technical challenges in lithography. Current estimates of the ultimately achievable overlay value, about 30 nm (mean + 3 sigma), is a major concern for sub-100-nm lithography. In fact, the overlay requirement for DRAMs at the 70 nm technology node is an unimaginably-small 25 nm (mean + 3 sigma).

The overall goal of this program was to investigate the use of mechanical means to compensate for overlay errors in nanolithography. The application considered is imprint lithography but may be extensible to other lithographies such as advanced photolithography, and EUV lithography. Imprint lithography uses a master or mold to impart patterns to a substrate. This master is frequently constructed from a quartz substrate such as those used for photomasks. In this program we used a photomask as the test vehicle for the research.

The goal of our experimental program was to demonstrate the effect of applied mechanical forces on positions of alignment marks on a photomask. This data was collected by fabricating a photomask with an array of alignment marks and measuring the positions of the marks with and without variable applied forces. The measurements were made on an LMS IPRO located at IBM in Burlington, VT. The mask holder included a piezoelectric transducer to apply variable force to the mask and a force measurement transducer to read the applied forces (see figure 1). The setup is designed such that external electrical connections are maintained to the mask holder during the measurements in the IPRO tool. When the mask was loaded into the tool, a pre-load force was applied via a set-screw to maintain contact between the force transducers and mask during the measurements. Position measurements were performed on an 11 x 11 array of alignment marks on the mask with the pre-load condition as a baseline. Measurements were then made at various additional applied forces from zero to about five pounds. Measurements were repeated at least three times for each condition to average the data. Force measurements were performed with increasing and decreasing schedules to check for hysteresis that could result from frictional binding forces. The data shows the expected qualitative behavior with displacements on the order of 50 nm or more in along the edges of the mask nearest the force application points (see figure 2).

In the initial set of experiments, force measurement transducer failed and made it difficult to make a quantitative correspondence between applied voltage and force. This set of measurements was compared to finite element calculations done by Prof. Englestad's group at U of Wisconsin and found to disagree by about a factor of two in the direction of the applied force. Other minor discrepancies were also found.

The set of measurements was repeated with a functional force measurement transducer so that a direct *in-situ* force measurement was performed for each applied voltage. Multiple measurements were made at each applied voltage. Each set of measurements determined the positions of the marks in an 11 x 11 array across the mask. Comparisons of these experimental data and finite element model results are shown in Figures 2-6. The correspondence between measured and calculated displacement was within experimental error in the force direction (x) but the agreement was not as good in the perpendicular direction (y).

The next step in the program was to fabricate a mask holder with eight sets of force transducers. In that way, positional adjustments corresponding to 3 alignment points as would be used in lithography can be measured. We could emulate the lithography conditions by bringing 3 alignment marks on the mask into concidence with theoretical positions and then measuring the effect on the rest of the alignment mark array. In this way, various algorithms for alignment correction can be tested. In principle, with three alignment marks, six data points (x and y for each) are measured. A minimum of six actuators would allow these three marks to be brought into exact coincidence with the desired positions by mathematical inversion. The question is then how to do this without making the alignments in the rest of the pattern worse. Various schemes have been developed by Prof. Englestad's group at U of Wisconsin. Finite element calculations performed by Prof. Englestadt's group showed that the results could be improved by using eight transducers. Measurements made with this mask holder could be used to experimentally verify these models. The results of this investigation are applicable to advanced photolithography and imprint lithography. The results also apply for EUV since a fused silica or like substrate will be used for masks.

A design and fabrication of a mask holder with eight force/measurement transducer pairs has been completed as shown below in figures 7-10. This design will enable more sophisticated mask distortions necessary to achieve simultaneous alignment of three alignment marks.

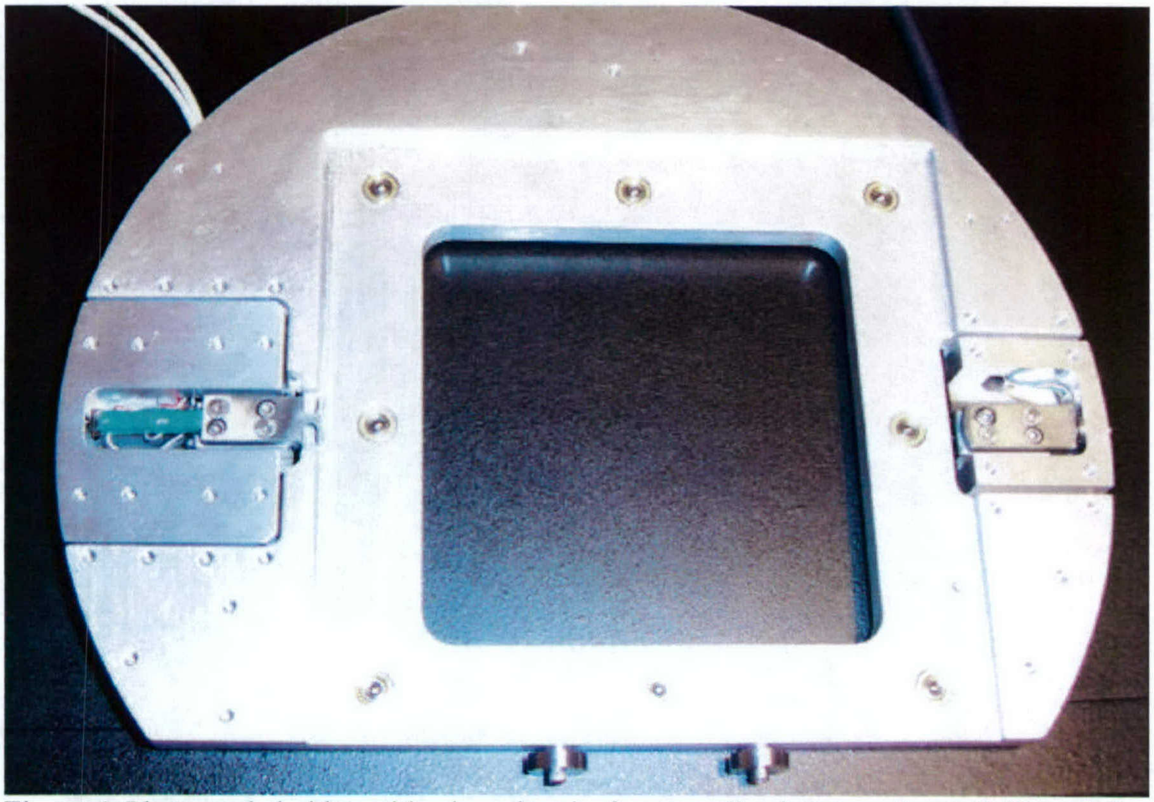

Figure 1 Photomask holder with piezoelectric force application transducer (left) and force measurement transducer (right). The holder is compatible with Leica coordinate measurement machines such as LMS IPRO.

Page #1

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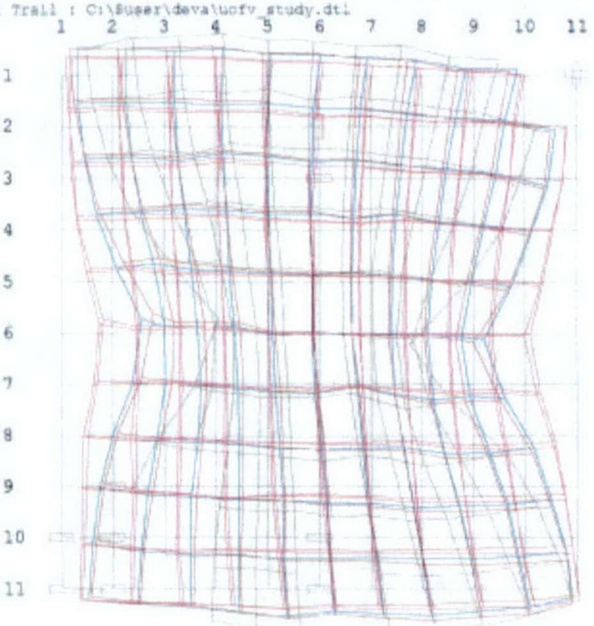
LEICA LMS IPRO Registration

5"MeganSmith mask on AMH orient 00, ⊣, Stress load @ 0 VOLTS

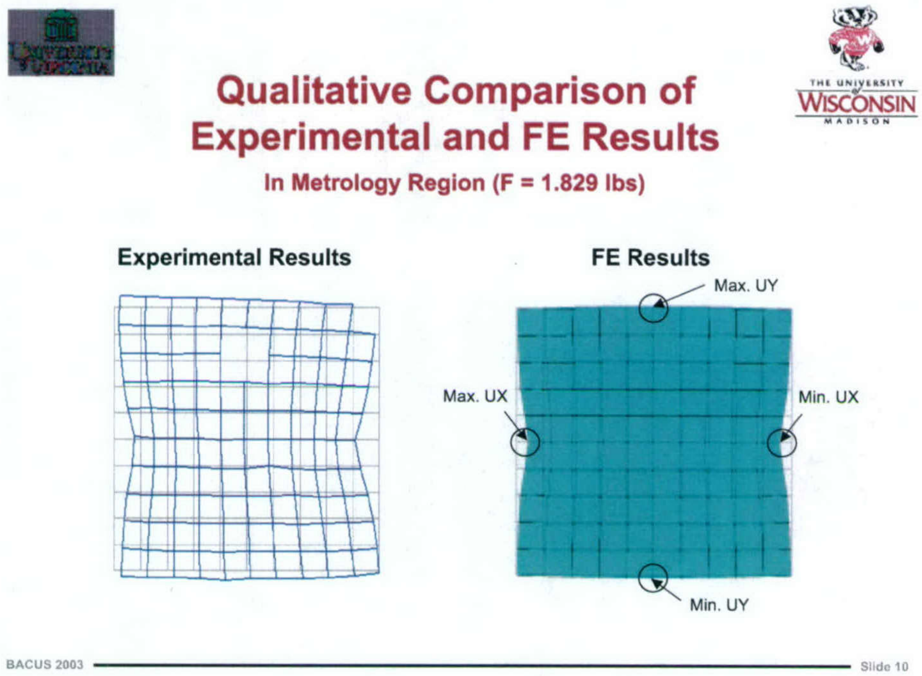


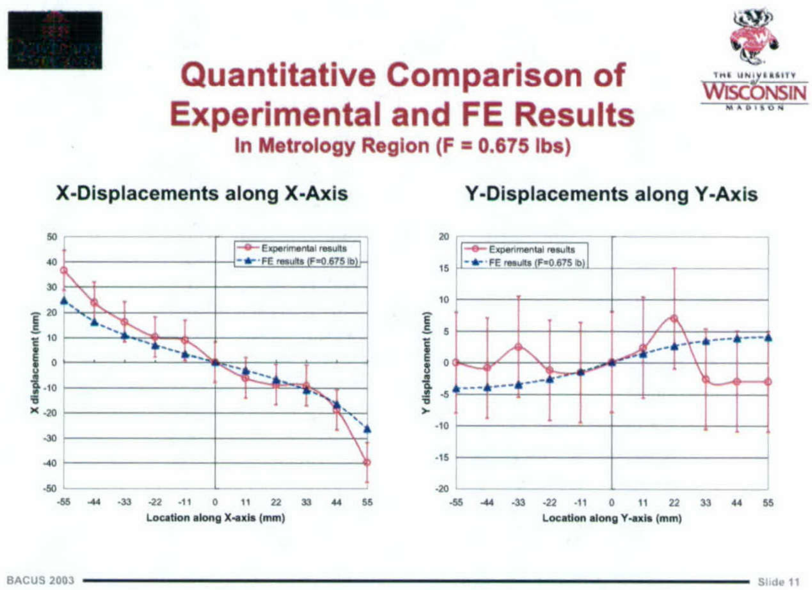
Processing
⇒ ▯ Missed Measurements
Alignment : ALL
Ref.: Average, 2 files : (MS030730.NA2)
1 : Average, 3 files : (M0307315.NA2)
2 : Average, 3 files : (M0307375.NA2)
3 : Average, 3 files : (M0307330.NA2)
4 : Average, 3 files : (M0307315.NB2)
5 : Average, 3 files : (M0307375.NB0)

50 [nm]

Summary	X [nm]	Y [nm]
Mean	-0.04	-0.67
Max 3 S.D.	380.44	173.96
Min	-392.67	-108.41
Max	370.51	98.87

Figure 2. Data obtained using the mask holder in Fig. 1. The voltage on the force transducer was varied and positions of an 11x11 array of alignment (cross) marks was measured. The data show the qualitative behavior that is expected with a pinching in the direction of the applied force and some bulging in the perpendicular direction.

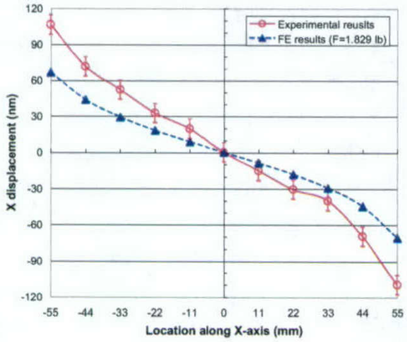




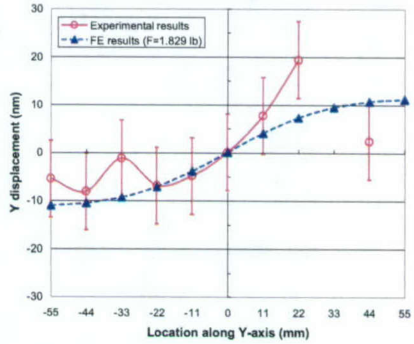
Figures 3 and 4 showing repeated measurements using the mask holder in Fig. 1 with a working in-situ force measurement transducer. Figure 3 shows the overall comparison of the measured and calculated displacements. Figure 4 shows comparisons of measured and calculated displacements along the major (x and y) axes. The force is applied in the x-direction.

Quantitative Comparison of Experimental and FE Results
In Metrology Region (F = 1.829 lbs)

X-Displacements along X-Axis

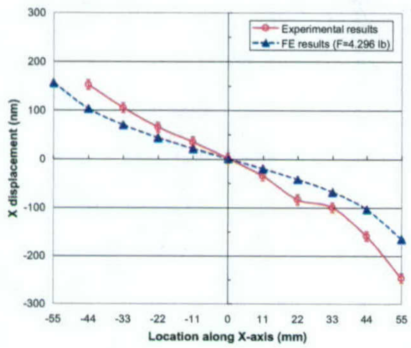


Y-Displacements along Y-Axis

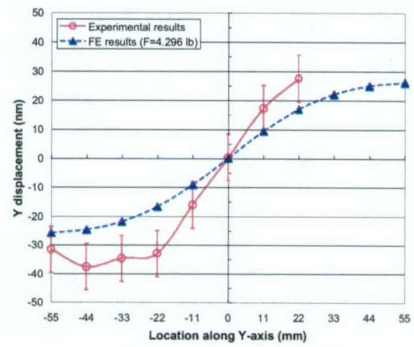


Quantitative Comparison of Experimental and FE Results
In Metrology Region (F = 4.296 lbs)

X-Displacements along X-Axis



Y-Displacements along Y-Axis



Figures 5 and 6 showing repeated measurements using the mask holder in Fig. 1 with a working in-situ force measurement transducer. Figure 5 shows comparisons of measured and calculated displacements along the major (x and y) axes for an applied force of about 1.9 pounds and Figure 6 for a larger applied force of about 4.3 pounds. The force is applied in the x-direction.

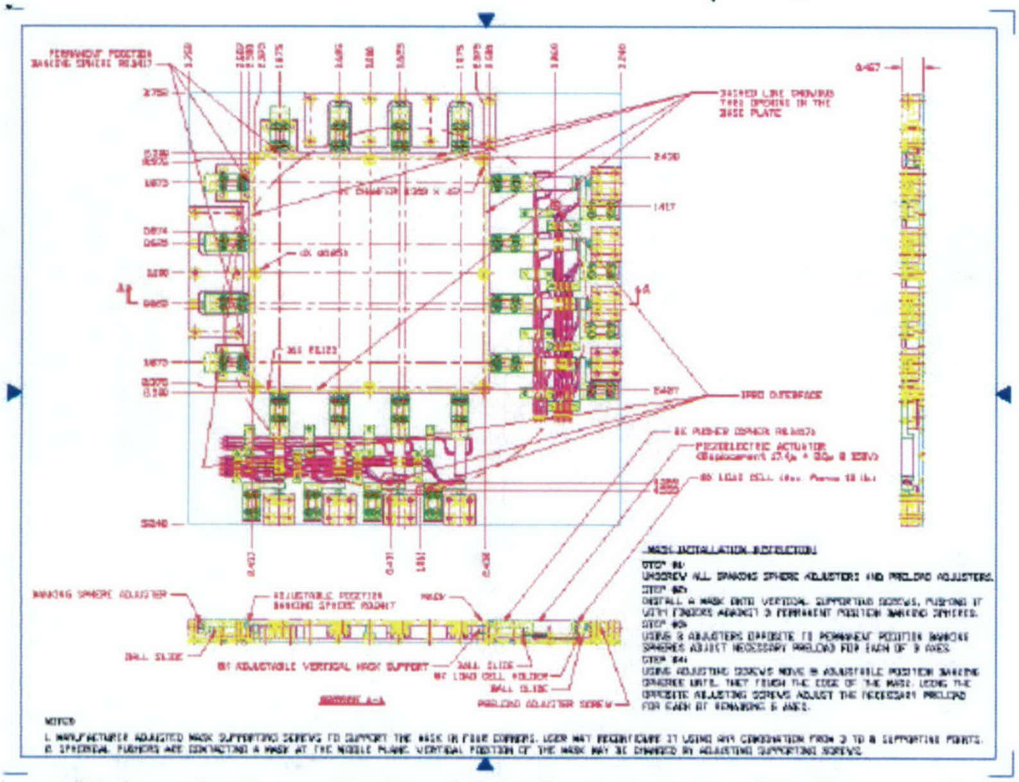


Figure 7 Schematic diagram for the mask holder design using eight force transducer pairs. There are four transducers along the x-direction and four along the y-direction.

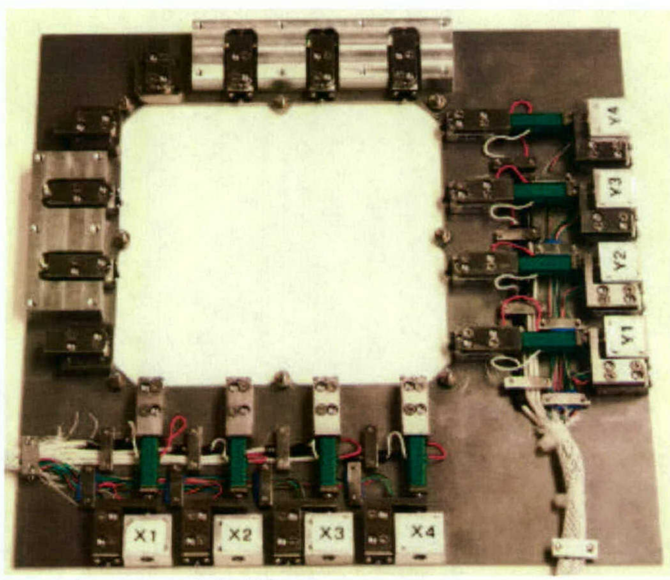


Figure 8 Photograph of eight-transducer mask holder.

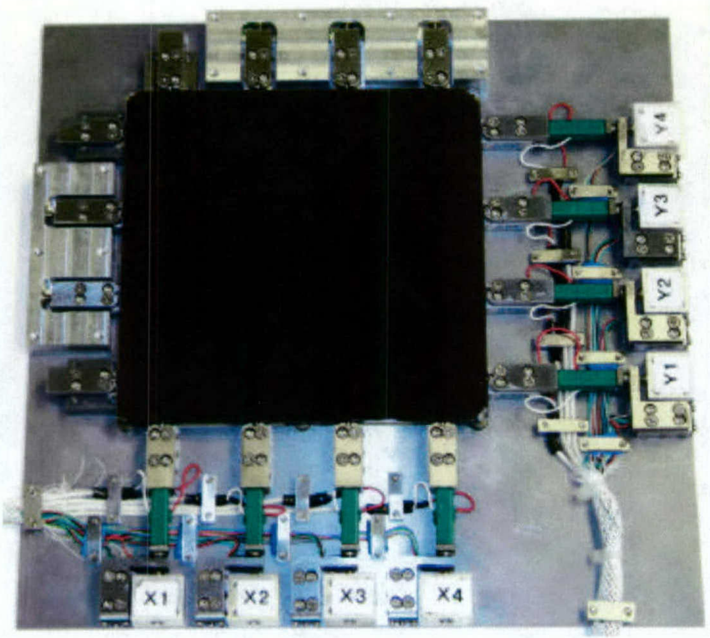


Figure 9 Photograph of eight-transducer mask holder with a photomask mounted.

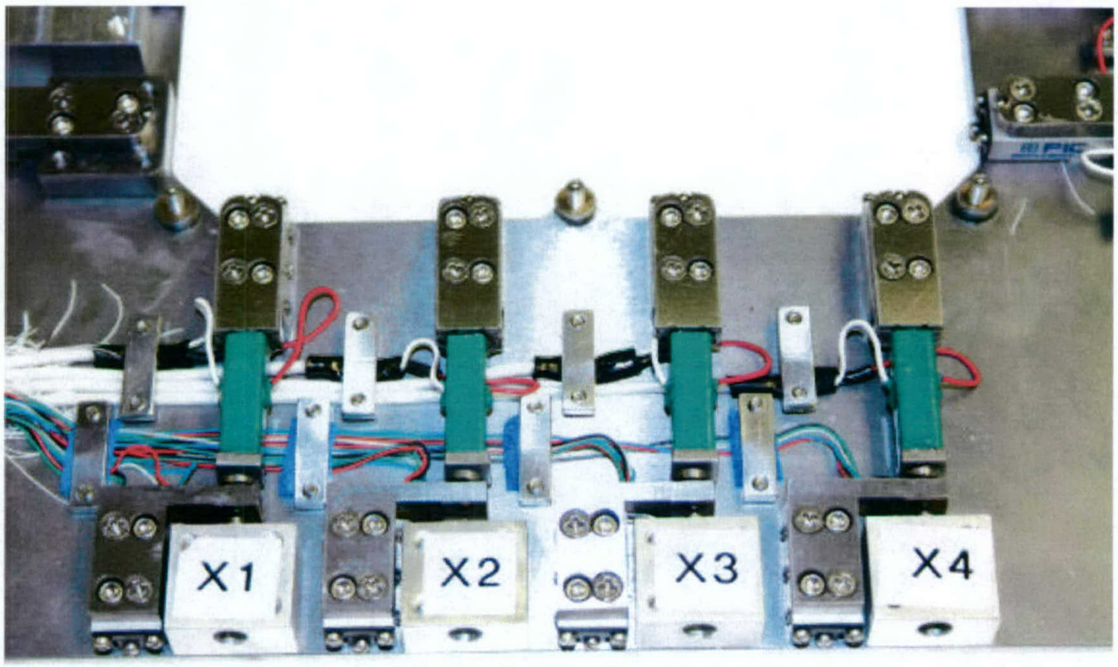


Figure 10 Close-up photograph of the mask holder in Figs. 8 and 9 showing the piezoelectric force application transducers.

(5) Technology Transfer none