Development of an Aspherical Bimorph PZT Mirror Bender with Thin Film Resistor Electrode

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Abstract

A bimorph PZT mirror bender was designed for active optics. This bender was to be constructed with two pairs of Si and PZT plates and glue bonded as Si-PZT-PZT-Si structure. Each PZT was coated with silver(Ag) thin film as the ground electrode and titanium nitride(TiN) thin film as the control electrode. The TiN film performs as a resistor layer and different voltages can be applied at both sides to linearly distribute the voltage difference. When interactive with the ground electrode, an adjustable third order polynomial surface profile can be achieved. This paper describes the TiN electrode fabrication processes and the testing results of a single bimorph PZT mirror prototype (Si-PZT bounded structure).

Keywords: bimorph PZT; mirror bender; active optics; thin film, TiN; electrode

1. Introduction

Bendable mirror is now a wildly research topic in synchrotron radiation and laser applications [1-4]. An important approach is the bimorph PZT type active/adaptive optics which possess the benefits of compact, low cost, large stroke and versatile [5,6]. There were multi-electrode segmented mirrors developed and installed in ESRF. A multi-electrode segmented aspherical bimorph PZT bendable mirror prototype had also developed in SRRC for active optics [7]. A complex power supply system with multiple channels and contact mechanisms is requested if the bimorph PZT optics with multiple control electrodes can be dynamically adjusted to a high order polynomial surface profile.

It is possible to simplify the power supply system and contact mechanisms if a linear distributed voltage can be applied to the bimorph PZT mirror on both ends of the control electrode through a two channel controllable power supplier. By applying the beam theory and FEM to construct and analyze the numerical simulation, based on the piezoelectric property and mechanics of materials, the relationship between the polynomial surface profile $Z=C_2y^2+C_3y^3$ and the voltages applied V_1 and V_2 can be derived as:

$$Z = \alpha \frac{d_{31}(V_2+V_1)}{4t^2} y^2 + \alpha \frac{d_{31}(V_2-V_1)}{2lt^2} y^3 \quad (1)$$

$$V_1 = \frac{t^2}{\alpha . d_{31}}(2C_2 - C_3 l) \text{ and } V_2 = \frac{t^2}{\alpha . d_{31}}(2C_2 + C_3 l) \ . \quad (2)$$

Where l is the length of optics, t is the thickness, d_{31} is the piezoelectric constant and α is a constant based on the geometrical and material.

The control electrode of the PZT plate has to be of resistor type in order to linearly distribute the voltages applied on both ends. Then, the mirror can be dynamically adjusted to obtain the third-order-polynomial surface profile in order to eliminate the defocus and coma aberrations.

2. Resistor Electrode Construction

The major issue of the aspherical bimorph PZT mirror bender is the construction of the resistor electrode layer that linearly distributed the applied voltage difference between the two ends of the control electrode. Considering the generated heat and current limitation of the power supplier, the resistance of the electrode should be larger than 30 KΩ and less than a few hundred KΩ. Determination of the electrode material and processes to meet these requirements is the key problem and it took lots of work before the TiN had settled.

2.1 Primary Trial

At first, the thick film process was adopted. The resistor layer was screen printed on the PZT plate and then sintered to solid layer. Since the sintering temperature (800^{o}C) is higher than the curing temperature (300-350^{o}C), the PZT plate had to be polarized afterward and it became unable to polarize the PZT plate from original parameters. Besides, there are small cracks in the resistor layer after sintered and the resistance is unstable to measure. The thick film process was then dropt.

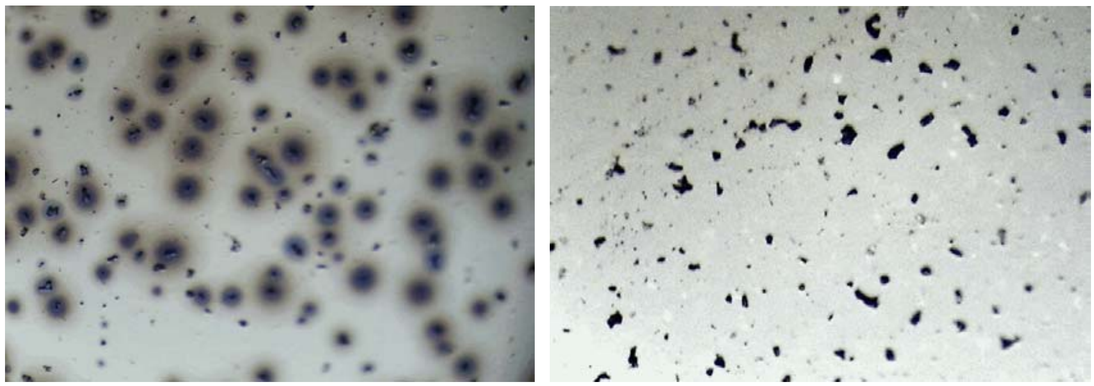
Thin film process was considered due to the low temperature processes. The commercially available polarized PZT plate can be adopted and don’t have to re-polarize it. Since the local thin film resistor vendor adopted metal material, we still can’t get reliable layer before a coater was constructed in SRRC.

The resistivity of thin film metal resistor is still too low to form an uniform layer with resistance higher than 30KΩ. Then TiN with suitable resistivity became a feasible candidate.

2.2 TiN Electrode Construction

TiN coatings have been used successfully as hard and decorative coatings and also diffuse barriers in semiconductor technology. But the properties of TiN are wildly changed by different sputtering conditions [8,9]. There are no reports about TiN being used as the electrode of PZT actuators. The sputtering conditions had to be tried out before the electrode to be coated.

The coater in SRRC had been setup for mirror coating and it consists of a linear stage to carry the mirror body for long ranged coating (1.4 m). In order to get uniform coating, a moving speed of 5 mm/sec and 180 W for DC relative magnetron sputtering were chosen. The PZT plate has to be cleaned before coating and pre-baking to expire the moisture inside since the PZT plate is made by particles sintered and is porous. Figure 1(a) shows the spots around the porous PZT surface after coating without pre-baking and (b) shows no spots after a 10 min. of 100^oC pre-baking.



(a) (b)

Fig. 1: (a) Spots around the porous PZT surface after coating without pre-baking.
(b) The coating layer on PZT plate after a 10 min. of 100^oC pre-baking.

The coating time was counted by the traveling loops of the stage due to the low yielding of TiN film. A total 30 loops sputtering time were chosen and every 5 loops stop for 10 minutes to avoid the temperature being too high to depolarize the PZT plate. Varies of conditions had been tested to find the feasible sputtering parameters for electrode and the results are listed as in Table 1.

Table 1: TiN Electrode Coating Conditions and Results

Type	**Condition (mbar)**	**Resistance/squire**
Polished surface	Ar:3×10^{-3} ,N_2:1×10^{-3}	3.2 KΩ
	Ar:3×10^{-3} ,N_2:3×10^{-3}	12 KΩ
	Ar:3×10^{-3} ,N_2:6×10^{-3}	80 KΩ
Unpolished surface	Ar:3×10^{-3} ,N_2:3×10^{-3}	>120 MΩ*

* Larger than the measurement capacity of the multi-meter.

The size of the PZT plate to be electrode coated is of 180 mm long, 40 mm wide and 3 mm thick. The parameters to coating the PZT control electrode were determined based on the above test to be Ar:3×10^{-3} ,N_2:3×10^{-3} mbar partial pressure. The PZT plate has to be surface polished (50 angstrom RMS) at first to get a better coating rate and also remove the warp phenomena due to polarizing. In addition, the resistance will be double after a few days aging and then become stable. The prototype with TiN control electrode as in Fig. 2 was also coated with Al layer on both ends for voltages applied connecting. The other side was coated with Ag layer as the ground electrode. The resistance of the control electrode was about 60 KΩ after coated and then aged to 120 KΩ.

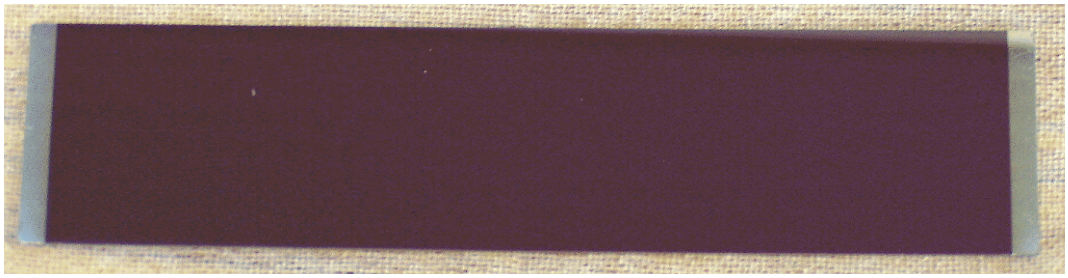


Fig. 2: The PZT plate coated with TiN control electrode and Al layers on both ends for voltages applied connecting.

The TiN electrode was applied with 100 V voltage difference on both ends to examine the linear distribution characteristic. As in Fig. 3, the standard deviation is about 0.55 V and it indicate an about 0.6% error during the 800~900 V usage range. The piezoelectric properties also examined by using a HP 4194 A impedance/gain-phase analyzer and showed a decay about 30% after coating.

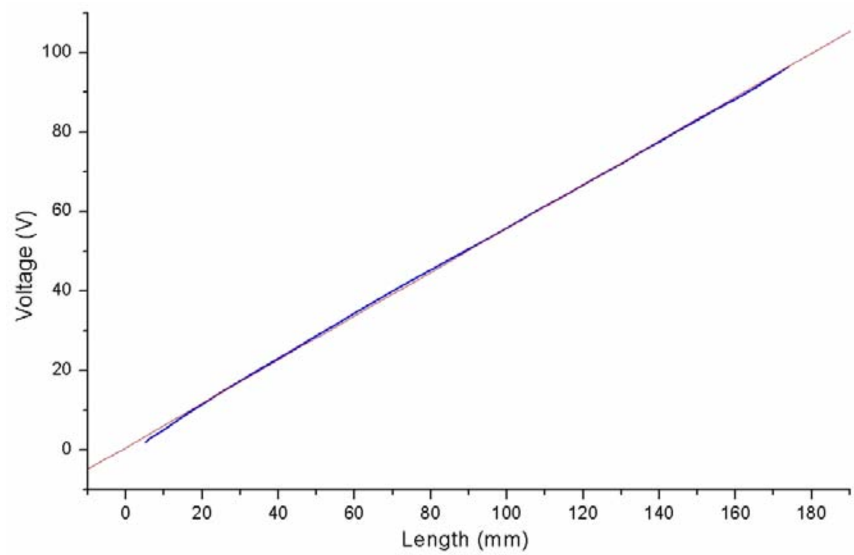


Fig. 3: Voltage distribution test on the TiN control electrode of the PZT plate.

3. Bimorph PZT Mirror Fabrication and Tests

Though there occurred a decay of piezoelectric property due to electrode coating, a bimorph PZT mirror prototype could still be fabricated for a test. The electrode coated PZT plated was glued with a Si plate (170 mm long) to form a bimorph mirror prototype. The glue adopted is 3M DP-460EG. After gluing, the control electrode were found to electrically conducting with the Si plate and the resistance is down to about 13 KΩ. Tests could still be carried out to examine the bimorph PZT mirror prototype for future reference and the prototype was setup for testing as in Fig. 4. The Ag coated ground electrode was used as the surface to be measured by the Long Trace Profiler (LTP). The voltages were applied by using contacting probes. Since the surface was not perfectly polished, the testing data were the differences between voltages applied and without voltages applied.

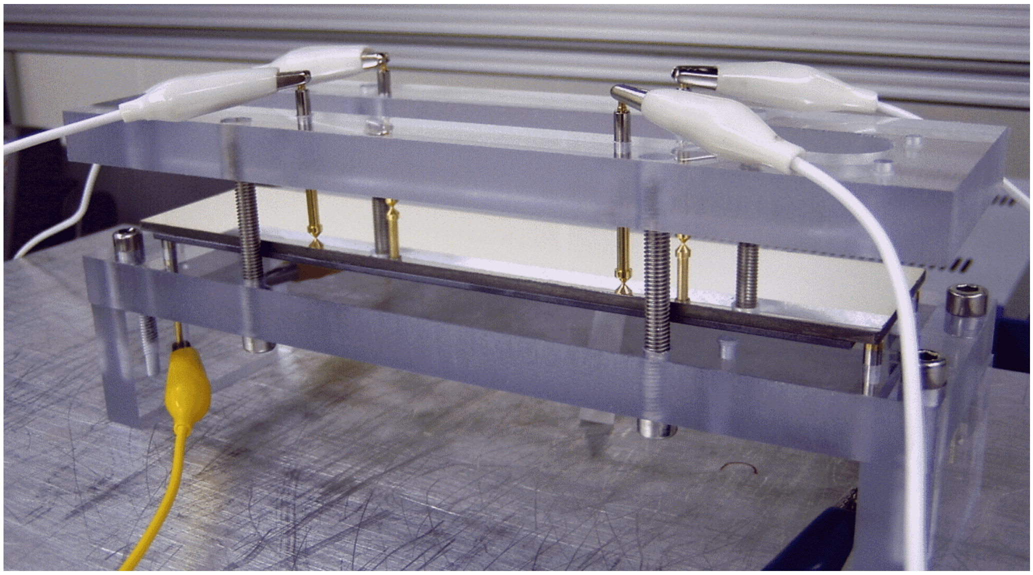


Fig. 4: Bimorph PZT mirror prototype setup for testing.

3.1 Voltage Cycling Test

The mirror prototype was applied with a 900 V amplitude sinusoidal cycling test first to examine the gluing strength and also release the stress due to gluing. With a 0.1 Hz frequency and 3 days lasting, more than 25,000 cycles proved the good gluing strength.

3.2 Curvature Test

The mirror prototype was applied with different voltages for curvature test and the curvature changed quit proportional to the voltage applied as in Fig. 5. With 900 V applied on the control electrode, the curvature is about 45 m and meet the requirement.

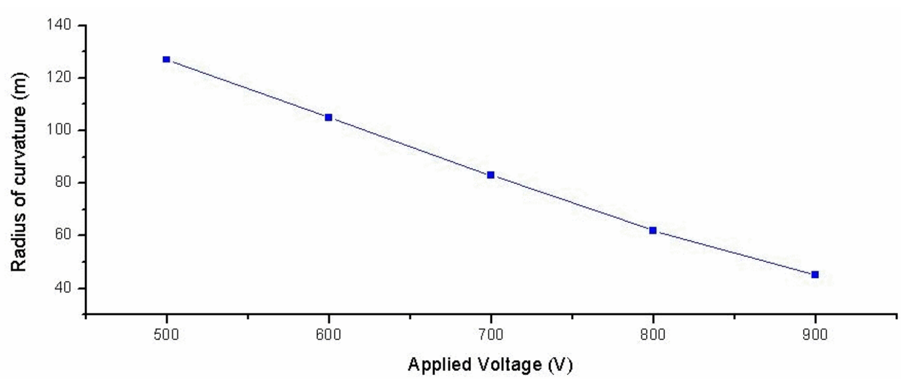


Fig. 5: The radius of curvature measured at different voltages applied.

The slope error is about 5 μrad RMS as in Fig. 6 and it could be the influence of the conducting with the Si plate.

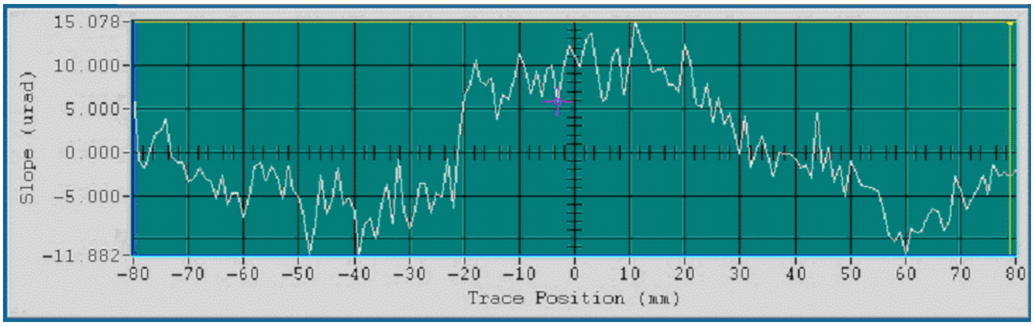


Fig. 6: The slope error of curvature fitting for a 900 V voltage applied.

3.3 Stability Test

The stability test was carried out with a 900 V voltage applied on the control electrode for a 150minute. The radius of curvature changed from 45 m to 41 m as in the Fig. 7. It is mainly due to the hysteresis and creep phenomena of the PZT plate. This shows a feedback control system to compensate the above phenomena is essential for future applications.

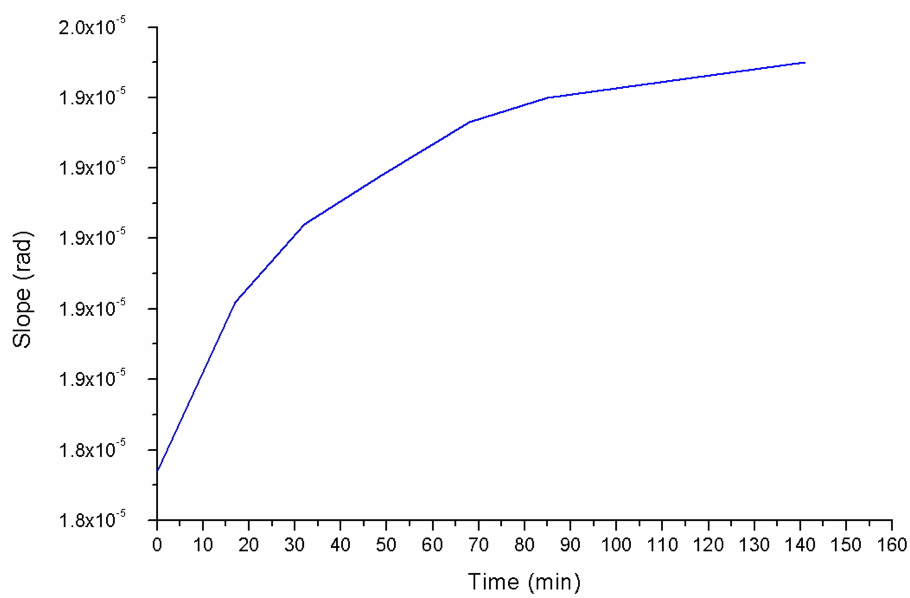


Fig. 7: Slope changes for time lasting at steady voltage (900 V) applied.

3.4 Range Test

The range meet the requirement is the most important criteria for the bimorph mirror development. Since the control electrode is electrically conducted with the Si plate and the low resistance restricts the voltage difference at both ends of the control electrode to only 50V. The adjusting range between 850 V and 900 V was measured as in Fig. 8 and still meet the application requirement in SRRC. The poor symmetry phenomena is also possibly due to the hysteresis and creep of the PZT plate.

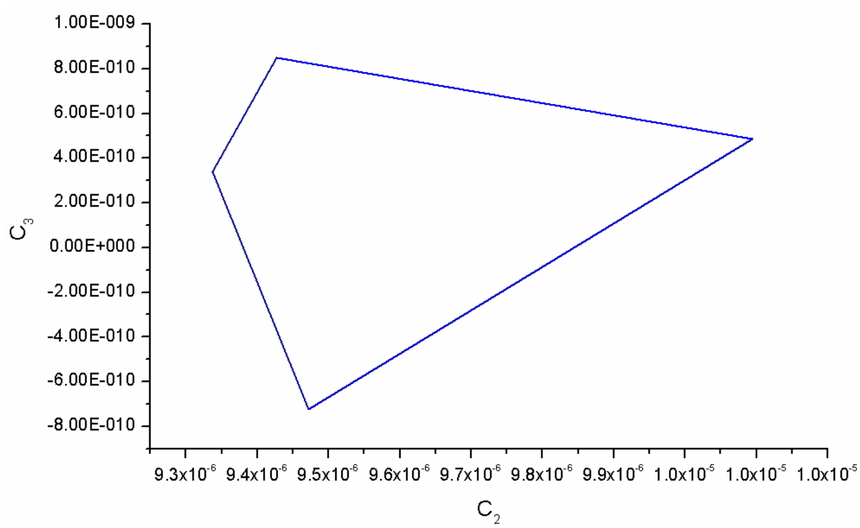


Fig. 8: The adjusting range of C_2 and C_3 for the polynomial surface profile $y=C_2x^2+C_3x^3$, unit:mm.

4. Conclusion and Discussion

The concept to simplify the power supply system and contact mechanisms for an aspherical bimorph PZT mirror demands a resistor type control electrode which linearly distributes the voltage difference applied on the both ends of the electrode. From series of testing, TiN thin film proves to be a promising candidate. It shows good uniformity, stable electrical property and high adhesion strength with PZT.

The bimorph PZT mirror prototype also showed that the controllable aspherical surface profile can be achieved by a resistor type electrode. The poor stability may be because the PZT plate we used is suit for high dynamic motion transducer (Channel Ind. Inc. C5800). The type for static motion transducer (C5500) with feedback system should be a good solution and will be the next work to do.

A new problem arising is the electrically conducting between the TiN electrode and the Si plate since a pressure system was adopted to insure firm and uniform adhesion between them. The imperfect slope error and restricted adjusting range should be blamed on this. The problem will be solved by using an insulating material as the mirror plate such as ULE or to oxidize the Si plate to from an insulting SiO_2 layer.

Another problem is the decay of piezoelectric properties due to TiN electrode sputtering. A lower power (150 W) and fewer coating loops with longer suspend period will be adopted to avoid it. After all, the bender with Si-PZT-PZT-Si structure will be fabricated.

5. References

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