Numerical and Experimental Study of an Al_2O_3-TiC Slider with a Piezoelectric Nanoactuator

Jia-Yang Juang, David B. Bogy

Computer Mechanics Laboratory
Department of Mechanical Engineering
University of California at Berkeley
Berkeley, CA 94720

C. Singh Bhatia

Hitachi GST
5600 Cottle Road
San Jose, CA 95193

ABSTRACT

A gap flying height (FH) of less than 5 nm between the read/write element and the surface of the disk is required for ultrahigh density recording. A stable and constant FH must also be sustained in the presence of altitude and temperature changes and manufacturing tolerance. A FH adjustment or controlled slider that is capable of adjusting its gap FH has been proposed previously. In this report, we demonstrate an inexpensive and low-temperature approach for integrating piezoelectric materials in the fabrication of current picosized Al_2O_3-TiC sliders. A bulk PZT sheet is bonded onto the back of row-bars and the sliders are separated by a standard dicing process. It requires no deep reactive-ion etching (DRIE) or high temperature processes and is suitable for mass production. The fabricated prototype slider has been tested by an optical profiler and a FH tester. A non-flying actuation stroke of 0.6 nm/V has been observed and a FH adjustment of 2 nm with sub-nanometer resolution was achieved, which also agreed well with the numerical analysis.

1. INTRODUCTION

As the spacing between the slider and the disk decreases in hard disk drives the linear bit spacing of the magnetic recording can decrease, resulting in a higher areal density. A gap flying height of less than 5 nm between the read/write element and the surface of the disk is required for ultrahigh density recording. A stable and constant FH must also be sustained in the presence of altitude and temperature changes, manufacturing tolerance, and track-seeking motion. Furthermore, the dynamic instability caused by FH modulations (FHMs) and nanoscale adhesion forces, such as electrostatic and intermolecular forces should be minimized. Those challenges make a conventional air bearing surface (ABS) slider an unlikely choice for an areal density of 1 $Tbit/in^2$. One potential solution is a FH adjustment or control slider that is capable of adjusting its gap FH with sub-nanometer resolution.

Due to its quick response and low power consumption piezoelectric materials have been proposed as active elements for adjusting the FH. Yeack-Scranton *et al.* [1] proposed an active slider for contact recording, where a piezoelectric material was inserted in a channel that ran across the full width of the slider at its top rear. They experimentally demonstrated movement of the read/write element from ~ 200 nm to contact, but the proposed structure of piezoelectric actuator was difficult to implement in the smaller currently used pico- or femto-sized sliders. Another approach is to bond a layer of piezoelectric material to one side of the suspension and change the FH by bending the suspension [2], [3]. The bandwidth of actuation is limited by that of the suspension dynamics, which is much lower than that of the air bearing. Khanna *et al*. [4] in 1991 and then Zhang *et al.* [5] in 2005 reported a method of FH adjustment by bonding a bulk piezoelectric material on the backside of a slider body. The FH was adjusted by applying a voltage to the piezoelectric material and thereby changing the crown and/or camber of the slider body. The structure of such sliders is simpler and it is relatively easy to fabricate but the fact that the FH is adjusted by changing the crown and/or camber contradicts the ABS design rule of reducing sensitivity of flying attitudes to these two parameters. Another approach is to utilize piezoelectrically actuated unimorph cantilever sliders. Several papers, such as Kurita *et al.* [6], [7], Tagawa *et al.* [8], Suzuki *et al.* [9], and Su *et al*. [10], have presented active sliders made of silicon with piezoelectric unimorph cantilevers. The slider structure was simpler and could be fabricated by silicon microfabrication technology. However, the use of silicon as the slider material and the requirement of high temperature processes make it difficult to integrate with current fabrication technology.

In this report we propose an approach for integrating piezoelectric materials in the fabrication of current picosized Al_2O_3-TiC sliders and conduct numerical and experimental analyses to investigate their performance.

2. DESIGN CONCEPT AND FABRICATION

A schematic diagram of the controlled-FH slider with an unimorph piezoelectric nanoactuator is shown in Fig. 1. The slider carries a layer of piezoelectric material, which is located between the slider body and the suspension flexure. The two slits near the trailing edge are created to form a cantilever. The read/write element is located near the end of the cantilever. When an electric voltage is applied to the middle portion of the piezoelectric material the cantilever bends down or up depending on the polarity of the induced electric field, resulting in a decrease or increase of the gap FH. There are two modes of operation. In the passive mode there is no external voltage so the active cantilever rests in the original position. The gap flying height in this case may be designed to be around 10 nm, depending on the ABS design. In the active mode the cantilever is bent into close proximity of the disk with the application of a DC voltage to the middle portion of the piezoelectric material.

Fig. 2 illustrates the fabrication process of Al_2O_3-TiC sliders with piezoelectric actuators. The process starts from dicing wafers into quads and cutting them into row-bars, followed by lapping of the row-bars to the desired slider thickness. The ABS is then defined and etched by photolithography and dry-etch processes such as ion-milling and reactive-ion etching. A thin layer of diamond-like carbon (DLC) is deposited on the entire ABS to protect the read/write element from corrosion and wear. The row-bars are then bonded with 127-μm thick commercially available lead-zirconate-titanate (PZT) sheets (Piezo Systems, Inc.) by silver epoxy (Transene Company, Inc.). Thin vacuum sputtered nickel electrodes have been deposited on both surfaces of the PZT sheets to produce extremely low current leakage and low magnetic permeability. A standard dicing process is used to separate the PZT and to cut the row-bars into individual sliders. Since there are no deep reactive-ion etching or high temperature processes involved, the cost introduced by these additional steps can be kept at a minimum and the previously deposited read/write element will not be damaged. The sliders are then mounted onto suspensions by the use of conductive and nonconductive glues to complete the suspension-gimbal assembly (HGA). The electrodes on the suspension flexure for read/write heads are used to apply voltages to the actuator. The prototype of a fabricated Al_2O_3-TiC slider with a layer of PZT and the completed HGA are shown in Fig. 3 and Fig. 4, respectively.

3. NUMERICAL AND EXPERIMENTAL ANALYSES

The CML Air Bearing Simulator, which solves the generalized Reynolds equation, is used to obtain the steady-state flying attitudes of a given ABS slider. Fig. 5 shows the picoslider ABS used in this study. The two white rectangles are slits through the entire thickness of the slider. The length and width of each slit are 550 μm and 65 μm, respectively. The FHs of the slider with and without the two deep slits are 44.8 nm and 10.7 nm, respectively. The presence of the slits reduces the negative pressure generated by the ABS and hence increases the FH. The effect of the actuation on the flying attitudes can be simulated by changing the relative height of the center trailing pad to the rest of ABS.

The non-flying actuated stroke at the pole-tip as a function of applied voltage was measured by a Wyko optical profiler (HD8000). It is shown in Fig. 6 that the actuation stroke is proportional to the applied voltage with a rate of about 0.6 nm per volt. We used an optical dynamic FH tester (PFHT4000) to measure the FH of the fabricated slider and the FH change with applied voltages ranging from 0 to 50 V. In the tests, the sliders were flown over a glass disk at a rotational speed of 15000 rpm and a radial position and a skew angle of 29.89 mm and 0 degree, respectively. The experimental results are compared with numerical ones simulated by using the CML Simulator with consideration of the actuation strokes obtained by the Wyko profiler as shown in Fig. 7. It is observed that both the experiment and simulation show a FH reduction of about 2 nm. In order to evaluate the actuation performance, we define actuation efficiency as the ratio of FH reduction to stroke. It is found that the actuation efficiency for this particular slider is only 7 %, which indicates a strong air bearing coupling with the actuation.

4. CONCLUSION AND FUTURE WORK

This report proposes a low-temperature and inexpensive process for fabricating and integrating Al_2O_3-TiC sliders with piezoelectric nanoactuators. The measured non-flying actuation stroke exhibits a linear relationship with the applied voltage with a rate of 0.6 nm per volt. In addition, the flying height measurements showed that FH adjustment with sub-nanometer resolution was achieved, which also agreed well with the numerical analysis. However, the actuation efficiency is found to be only 7 %, which indicates a strong air bearing coupling with the actuation. A properly designed ABS is required for further increasing the efficiency of FH control sliders. It is also desirable to reduce the applied voltage as well as the total thickness of the slider with PZT nanoactuator.

ACKNOWLEDGEMENT

This study is supported by the Computer Mechanics Laboratory (CML) at the University of California, Berkeley and Information Storage Industry Consortium (INSIC). J. Y. Juang has also been supported by The California State Nanotechnology Fellowship. The authors would like to thank T. Neumann, Y. Midori, N. Bach and V. Chow for the help on the fabrication, measurements and useful discussions.

REFERENCES

1. C. E. Yeack-Scranton, V. D. Khanna, K. F. Etzold, and A. P. Praino, “ An active slider for practical contact recording,” *IEEE Trans. Magn.*, vol. 26, pp. 2478-2483, 1990.
2. D. L. Good, J. E. Mason, and H. H. Ottesen, “Fly height servo control of read/write head suspension,” U.S. Patent 5,377,058, December 27, 1994.
3. X. Liu, A. Li, W. Clegg, D. F. L. Jenkins, and P. Davey, “Head-disk spacing variation suppression via active flying height control,” *IEEE Trans. Instrum. Meas.*, vol. 51, pp. 897-901, 2002.
4. V. D. Khanna, F. Hendriks, and A. P. Praino, “ Programmable air bearing sliders,” *IEEE Trans. Magn.*, vol. 27, pp. 5145-5147, 1991.
5. M. Zhang, S. Yu, J. Liu, and B. Liu, “Flying height adjustment by slider’s air bearing surface profile control,” *J. Applied Physics*, vol. 97, 10P309, 2005.
6. M. Kurita, T. Yamazaki, H. Kohira, M. Matsumoto, R. Tsuchiyama, J. Xu, T. Harada, Y. Inoue, L. Su, and K. Kato, “An active-head slider with a piezoelectric actuator for controlling flying height ,” *IEEE Trans. Magn.*, vol. 38, pp. 2102-2104, 2002.
7. M. Kurita and K. Suzuki, “Flying-height adjustment technologies of magnetic head sliders,” *IEEE Trans. Magn.*, vol. 40, pp. 332-336, 2004.
8. K. Suzuki, R. Maeda, J. Chu, T. Kato, and M. Kurita, “An active head slider using a piezoelectric cantilever for in situ flying-height control,” *IEEE Trans. Magn.*, vol. 39, pp. 826-831, 2003.
9. N. Tagawa, K.-I. Kitamura, and A. Mori, “Design and fabrication of MEMS-based active slider using double-layered composite PZT thin film in hard disk drives,” *IEEE Trans. Magn.*, vol. 39, pp. 926-931, 2003.

10. L. Su, M. Kurita, J. Xu, K. Kato, K. Adachi, and Y. Miyake, “Static and dynamic characteristics of active-head sliders,” *Tribol. Intl.,* vol. 38, pp. 717-723, 2005.

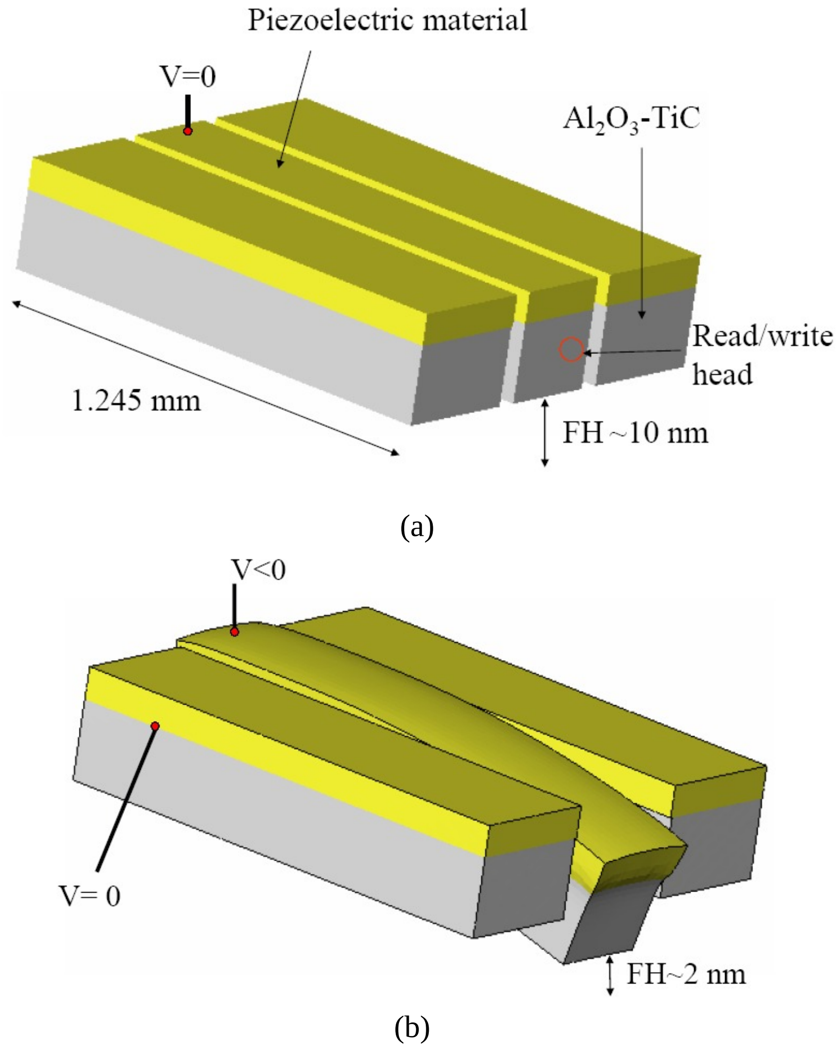


Fig. 1. Two operational modes of a FH control slider with piezoelectric actuation. (a) passive mode; (b) active mode.

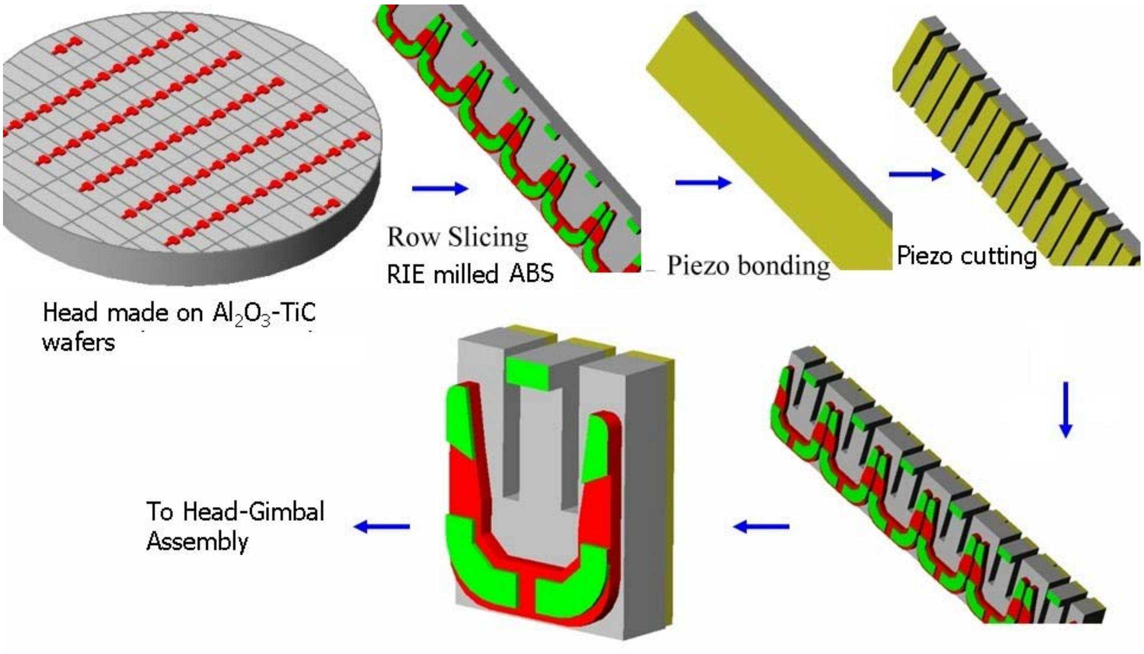


Fig. 2. Schematic diagram of the process flow.

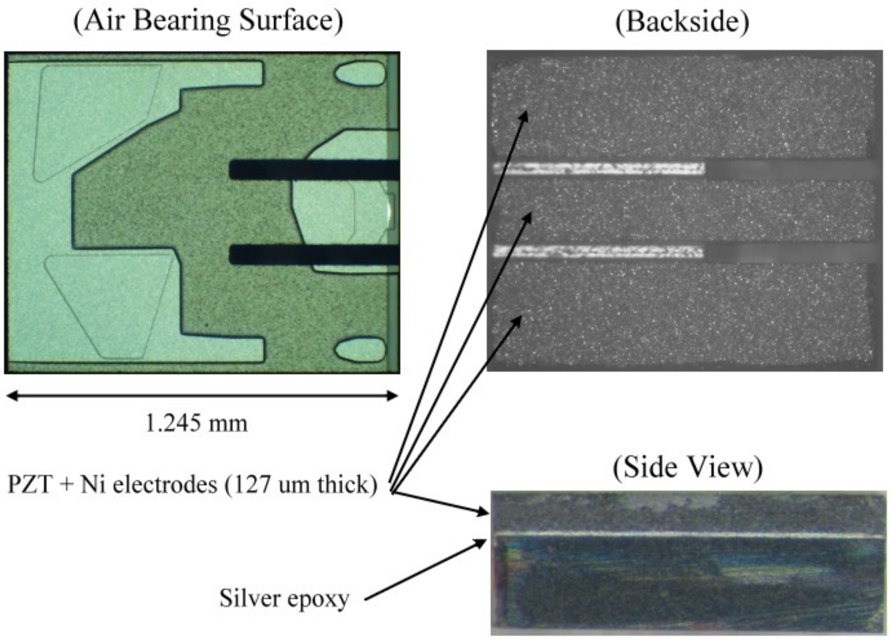
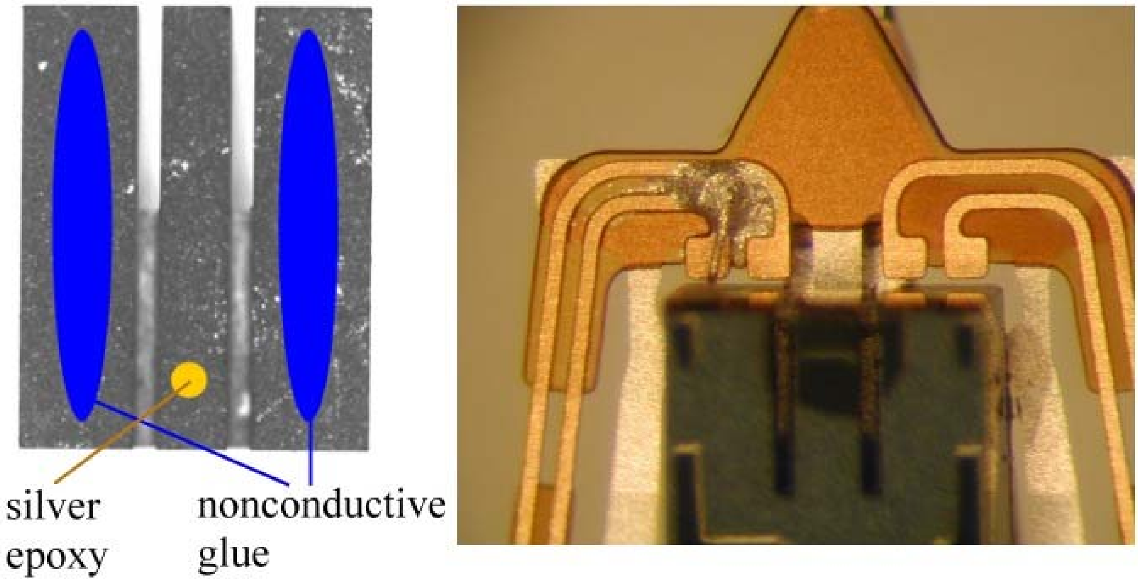
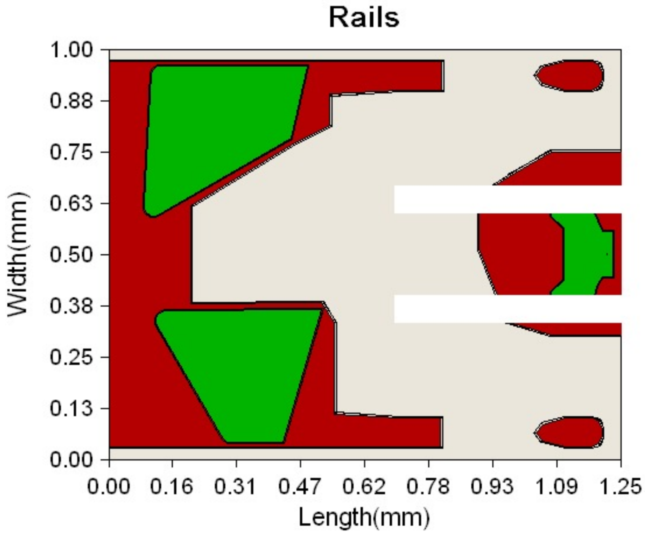


Fig. 3. Fabricated Al_2O_3-TiC slider with a layer of piezoelectric material bonded on the back-side.

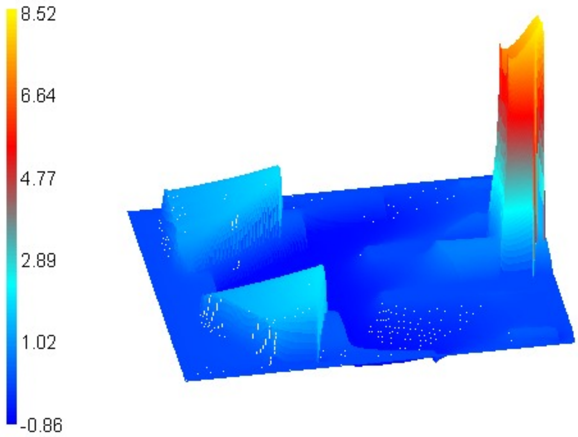


(a) (b)

Fig. 4. HGA of the fabricated slider.



(a)



(b)

Fig. 5. (a) A pico-slider ABS used in this study. The two white rectangles are slits through the entire thickness of the slider; (b) Air bearing pressure profile at radial position 29.89 mm, 0 degree skew. The scale displayed is normalized to ambient pressure: $(p - p_a)/p_a$.

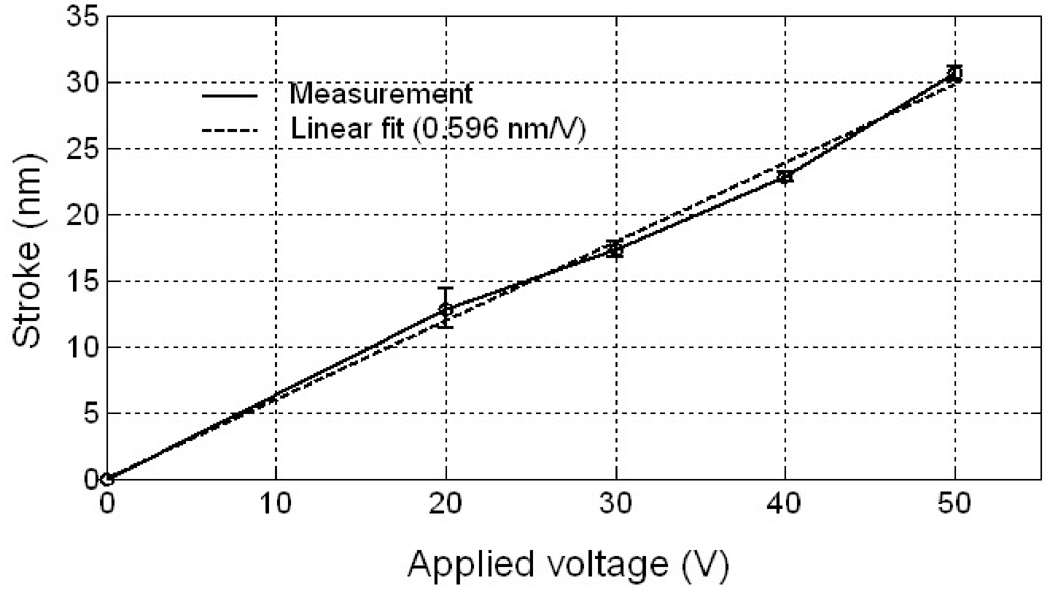


Fig. 6. Measured actuation stroke as a function of applied voltage. The error bars represent one standard deviation from corresponding mean values.

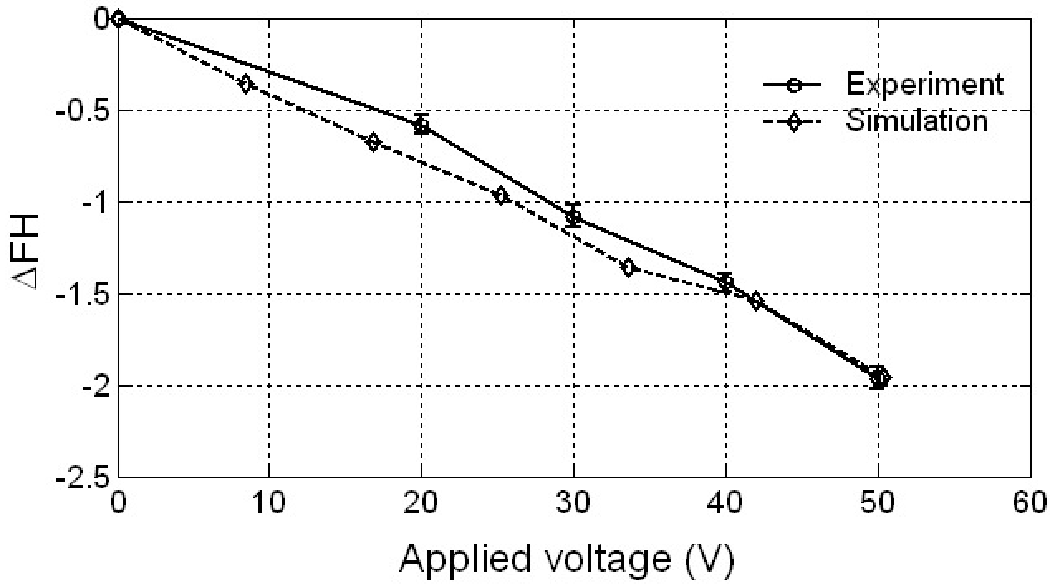


Fig. 7. Comparison of gap FH reduction between the experimental and numerical results (15000 rpm, 29.89 mm, 0 degree skew). The error bars represent one standard deviation from corresponding mean values.