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An Innovative Mechanism to Amplify Testing Force Resolution of Silicon Dioxide Micro Cantilevers

Hsien-Kuang Liu*, Wei-Chong Liao**, and Yuan-Ming Wang***

Keywords：amplify, micromechanical testing, double lever mechanism, force resolution, lubricant.

ABSTRACT

A micro cantilever is usually adopted as micro structure for sensors; therefore, the micromechanical testing of the cantilever becomes an important issue. However, due to requirement of intensive devices incorporated in compact 3C products, MEMS devices are likely to evolve as NEMS devices. Some nano scale NEMS devices may need to work with stroke in the range of micro scale. Therefore, to develop a simple testing methodology for NEMS devices that can amplify either force or stroke is important. An innovative double lever mechanism is proposed to mount on the micro force testing machine in order to increase force measurement resolution for silicon dioxide micro cantilevers with film thickness only 1μm, and achieve their valid strength and Young modulus data. Design of this double lever mechanism is based on the law of the lever using an asymmetrical lever. Two sets of asymmetrical levers with four pivot joints are combined, and bearings as well as various lubricants are applied at joints in order to minimize friction and evaluate force amplification ratio. Three kinds of lubricants with different viscosities at the bearings are found to better increase the accuracy of the mechanism than the counterpart without lubricant.

INTRODUCTION

Recently, micro-electro-mechanical systems (MEMS) have emerged for a wide range of applications including micro-motors, accelerometers, and biomedical devices. However, one of the major barriers in the large-scale commercialization of MEMS is the development of a detailed study of failure mechanisms under various kinds of loadings Soboyejo et al. (2003). Therefore, micro mechanical tests are very essential. It is easier to test MEMS materials in bending because many microdevices that move do so parallel to the substrate Sharpe et al. (2003). Jadaan et al. (2003) provided a good summary of the strength of both single crystal silicon (SCS) and polysilicon. Almost half of the SCS specimens were tested by bending in the beam configuration, and the strength ranged from 0.31 to 17.5 GPa; while the strength for polysilicon is in a narrower range of 0.57 to 4.9 GPa. To test microdevices by bending, specimens are usually designed as cantilevers. Cheng et al. (2015) also adopted cantilevers with designed stacking of CMOS thin films, and their equivalent elastic moduli and CTEs are determined, respectively, from the resonant frequency and static thermal deformation tests by bending. On the other hand, tensile test of a thin film specimen is more difficult than bending test, because it is not easy to judge whether the film is along the testing direction. Yoshioka et al. (2000) developed an on-chip technique that can avoid the alignment problem. This technique transfers the torsional loading as tensile loading, and results show that Young's moduli of SiO_2 and Si_3N_4 thin films are respectively 74 and 340 GPa.

Due to evolution of internet of things (IoT), 3C products may consist of more MEMS devices with dimension approaching nano scale, such as NEMS devices. Hence, micro mechanical tests may not satisfy the requirement; on the other hand, nano testing methodology is more eagerly requested. Nano indenter is widely adopted for nano testing. Mechanical properties of bilayer graphene/poly(methyl methacrylate) (GR/PMMA) and reference PMMA thin films are investigated using various nano indentation, punch, and scratch tests Kotsilkova et al. (2016). This bilayer film shows lower fracture strength, strain and toughness than the PMMA film due to interfacial delamination. The lower fracture strength may be also due to localized

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* *Professor, Department of Mechanical and Computer Aided Engineering, Feng Chia University, Taichung, Taiwan 40724, ROC.*

** *Professor, Department of Civil Engineering, Feng Chia University, Taichung, Taiwan 40724, ROC.*

*** *Graduate student, Department of Mechanical and Computer Aided Engineering, Feng Chia University, Taichung, Taiwan 40724, ROC.*

stress field near the indenter and the measurement could be improved by averaged tensile strength data using modified micro force testing machine proposed in this paper. On the other hand, the graphene layer contributes to the improvements of hardness and resistance to scratch for both freestanding and supported GR/PMMA films. GR/PMMA thin films with this merit have potential in future shielding applications for protection of electronic devices.

Although some NEMS devices have nano dimension, their working stroke may be in the range of micro scale. Therefore, to develop a simple testing methodology that can amplify either force or stroke is important. Bolzmacher et al. (2010) developed an amplification unit of stroke based on a lever, with the load transmission placed in the middle and the resistance force and the fulcrum (i.e. fixation) at the opposite ends. By applying a piezo-electrically induced displacement to the load transmission point, the membrane that is fixed at one side (fulcrum) exerts an amplified displacement with a ratio of 5-13 at the opposite end. Similar results are found in references (Conway et al., 2007; Devoe et al., 1997). They adopted either external amplifying mechanism such as compliant parallel guiding linkage for strain amplification, or internally leveraged amplifiers such as bimorph cantilevers for stroke amplification. This infers that leverage mechanism is an innovative mean to either amplify displacement or force during testing or applications.

Authors (Liu et al., 2007, 2010) ever designed specific fixtures that can mount on the micro force testing machine to conduct fatigue tests on silicon films (SCS) and coated silicon films (CSCS). SCS shows shorter fatigue lives of 7.05×10^{6} to 5.35×10^{7} cycles when the strain amplitude ranges from 0.0038 to 0.0023, while CSCS shows longer fatigue lives of 1.00×10^{7} to 2.86×10^{7} cycles when the strain amplitude ranges from 0.006 to 0.0035. In this paper, a novel double lever mechanism is designed to mount on the micro force testing machine in order to enlarge the measured force of tested 1 μm thick SiO_2 cantilevers. The purpose of this study is to enhance force measurement resolution of the machine, and at the same time to retain the advantages of the machine such as large stroke and capability for fatigue test. Design of this double lever mechanism is based on law of the lever using two sets of asymmetrical levers (balance). To implement this double lever mechanism, light aluminum alloy is adopted because of the capacity limitation of load cell. Bearings are adopted at four pivot joints of the mechanism in order to minimize friction. Various lubricants applied at bearings are the key parameter that would influence force amplification ratio of the machine, and their effects will thoroughly be discussed in the paper.

EXPERIMENTAL PROCEDURES

Fabrication of SiO_2 cantilever microbeams

The initial material used for cantilever microbeams is a 4 inch single crystal silicon (SCS) wafer. As mentioned in reference (Yoshioka et al., 2000), SiO_2 is widely used in multilayer materials for microdevices; therefore, it is chosen for cantilever beams to understand its basic properties. The length of the SiO_2 beam is designed as 300 μm, 400 μm, 500 μm, 600 μm, and 700 μm; the width is 100 μm; and the thickness is 1.0 μm. Initially, SiO_2 with thickness 1.0 μm is deposited on both sides of Si wafer by wet oxidation (oxidation & diffusion furnaces, Lindberg 55667, USA). Lithography process transfers geometry of cantilever microbeam from first mask to the front side surface. Then conduct spin coating of photoresist on back side surface. Front side SiO_2 patterned by mask 1 is etched by BOE (Buffered Oxide Etch, buffered HF). SiO_2 layer patterned by a second mask on back side surface is stripped off by BOE. Finally, TMAH is adopted to completely remove back side silicon patterned by SiO_2 layer and a silicon dioxide cantilever microbeam is achieved. The detail of the beam fabrication procedure is shown in figure 1.

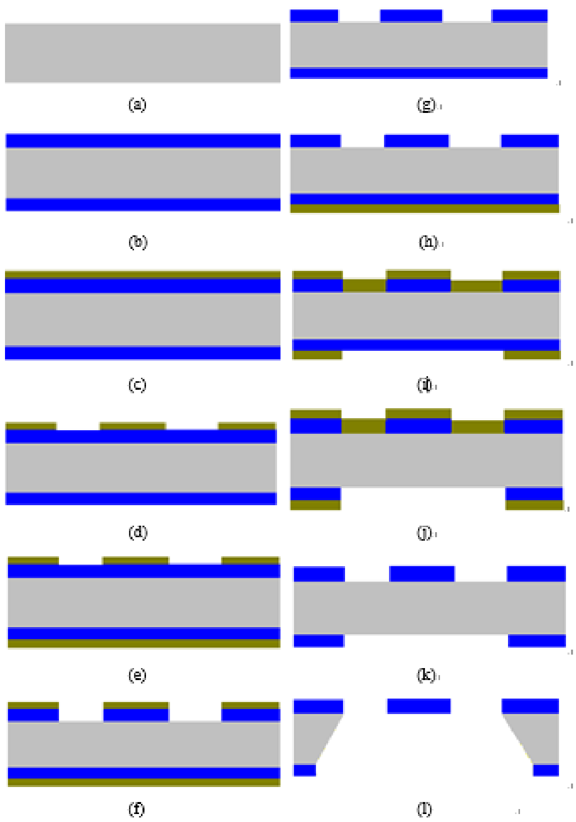


Fig. 1. Processing flow chart for SiO_2 cantilever: (a) 4” silicon wafer, (b) wet oxidation of SiO_2 on both sides, (c) spin coat MA-P1225 photoresist on front side, (d) transfer cantilever beam pattern from mask 1 to wafer by lithography process, (e) spin coat

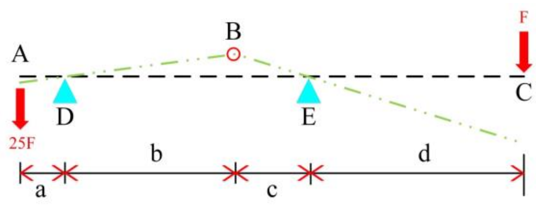
MA-P1225 photoresist on back side, (f) BOE (buffered oxide etch) etching of front side SiO_2 patterned by mask 1, (g) remove photoresist by acetone, (h) spin coat MA-P1225 photoresist on back side, (i) transfer pattern from mask 2 to back side by lithography process, (j) BOE etching of back side SiO_2 patterned by mask 2, (k) remove photoresist by acetone, (l) TMAH (tetramethylammonium hydroxide) etching of back side silicon.

Design and fabrication of the double lever mechanism

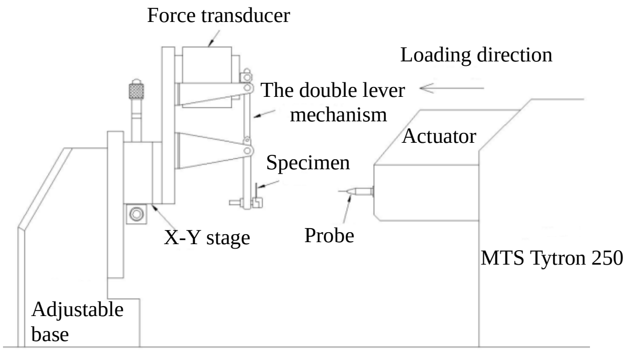
The double lever mechanism that can significantly enlarge measured micro force during testing of thin film specimens is the key innovation in this work. Design of a double lever mechanism is based on law of the lever using an asymmetrical lever (balance). For first set of asymmetrical lever shown in figure 2(a), by choosing length of effort lever arm "d" five times longer than length of resistance lever arm "c", resistance force at point B is 5F, which is five times effort force at point C. Similar situation occurs between points A and B. In the mechanism, two fulcrums are designed such that two ratios (d/c, b/a) between lengths of effort lever arms (d, b) and lengths of resistance lever arms (c, a) are both equal to 5. By series connection of second identical asymmetrical lever with first one, a double lever mechanism is achieved such that resistance force at point A is 25F, twenty five times effort force at point B. This simple designed, creative, compact mechanism can accomplish considerably theoretical force amplification ratio of 25 with the same direction of initial effort and resultant resistance forces. The schematic setup of this mechanism is depicted in figure 2(b). To implement this double lever mechanism, aluminum alloy is adopted due to its light weight and is easy to be manufactured. The manufactured mechanism is shown in figure 2(c). Multiple holes are drilled in frames for the mechanism because the holes can reduce the weight distributed on the force transducer (load cell). Bearings are adopted at four pivot joints, A, D, B, and E in order to minimize friction. Various lubricants including WD-40, blended oil, and engine oil are further applied at bearings to reduce friction. Experimental force amplification ratio is achieved via dividing measured resistance force at point A by effort force at point C. Due to effect of friction, experimental force amplification ratio is likely to be smaller than theoretical force amplification ratio of 25. Force transformation efficiency is defined by the ratio of experimental force amplification ratio to theoretical force amplification ratio. Effect of lubrication on experimental force magnification ratio is investigated in this paper, and it is the key parameter to implement this creative mechanism.

Flexural testing

The flexural test on the SiO_2 cantilever microbeam is conducted by the MTS Tytron 250 micro-force testing machine. The detail of basic testing without the double lever mechanism is described by authors elsewhere (Liu et al., 2008). The resolution of load and displacement of the machine is 10^{-3}N and 1.0 μm, respectively. This machine with mounted double lever mechanism is able to further enhance the force measurement resolution. As shown at left hand side in figure 2(c), the basis of the mechanism is mounted on an x-y table that can precisely adjust position of the beam. In order to apply loading on the beam, a tungsten micro-probe with a special design socket is firmly held on the actuator of the machine to contact the beam. The flexural test is conducted by first touching the probe on the free end of the cantilever microbeam. The applied force "F" at point C is then enlarged by this mechanism and theoretical force amplification ratio of 25 leads to resistance force of 25F at point A measured by load cell. Experimental force amplification ratios depend on what kind of lubricant is used and will be measured and discussed in the paper. The enlarged force is then detected by the load cell at point A and recorded by the computer. The testing machine is set up at a constant crosshead speed mode that the probe moves toward the beam at a constant rate of 4.0 μm/s. During the test, the force and displacement are recorded by the computer through the load cell and actuator in the machine in order to obtain mechanical properties. 5 replicate tests were conducted in order to obtain one valid data. In order to investigate the bending failure modes of the SiO_2 cantilever microbeams, scanning electron microscope (SEM) is utilized to carefully inspect bended beams. Correlation between microstructure and mechanical behavior can be proposed.



(a)



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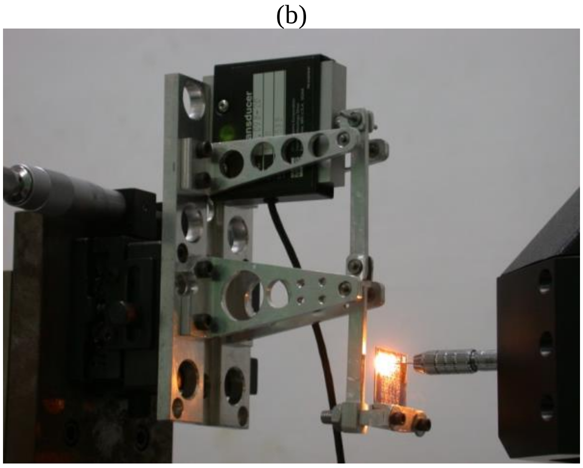

(c)

Fig. 2. (a) Theoretical base of a double lever mechanism showing that two fulcrums with two longer effort lever arms lead to force amplification ratio of 25 with arm ratios both b/a and d/c equal to 5, (b) schematic diagram of the double lever mechanism mounted on MTS Tytron 250 testing machine, (c) testing of SiO_2 cantilever with mounted double lever mechanism.

RESULTS AND DISCUSSION

The scale up effect of the mechanism

Figure 3 depicts the front view of a fabricated SiO_2 cantilever. This micrograph shows that the cantilever has length of 500 μm, width of 100 μm, and thickness of 1.0 μm. The dimensions agree well with what the initial design is. Since back side surface of SiO_2 cantilever is achieved by etching out the whole silicon wafer attached to the SiO_2 film by TMAH, roughness of back side and front side surfaces must be different. Surface roughness is measured by Alpha-step surface profiler. Front side surface average roughness R_a is 13.81 nm, while back side surface average roughness R_a is 31.36 nm.

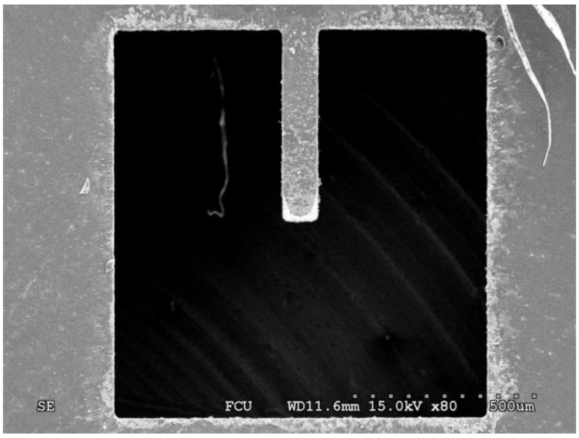

Fig. 3. Front view of fabricated SiO_2 cantilever.

Table 1 shows theoretical and experimental force amplification ratios by testing thicker silicon cantilevers with dimension 50/600 μm thickness/length via the double lever mechanism. Without mechanism, a tungsten micro-probe directly touches the free end of the silicon microbram and applies bending load until the microbeam breaks. Upon breakage, maximum force is recorded as shown in table 1. The maximum average force of 0.1264 N is achieved from 5 identical testing data. With mechanism, measurement methods are divided into four categories due to different lubricating conditions at joints, including no lubrication, WD-40, blended oil, and engine oil lubricant. Upon breakage of cantilever, maximum average force is measured. Ratio of average force with mechanism to that without mechanism is experimental force amplification ratio. Later, achieved experimental force amplification ratios are applied to measure maximum bending forces of 1μm thick SiO_2 cantilevers. For no lubrication case, ratio of average force 1.2523 N (with mechanism) to 0.1264 N (without mechanism) is 9.91. Theoretical force amplification ratio is 25; while four experimental force amplification ratios corresponding to four different lubricating conditions are 9.91, 15.02, 17.59, and 16.31, respectively. Without lubrication, experimental amplification ratio of 9.91 is quite low and transformation efficiency is only 39.64 %. This indicates that friction at four pivot joints A, B, D, and E of the mechanism shown in figure 2(c) causes significant loss of force transfer. With lubrication, transformation efficiency is substantially increased up to more than 60.08%. Blended oil offers the best lubricating effect at four pivot joints so that it achieves highest transformation efficiency of 70.36% and experimental amplification ratio of 17.59. Viscosities of three kinds of lubricants are also provided in table 1, ranging from 2.3 mPa·s to 69.5 mPa·s. Blended oil lubricant has optimized viscosity of 13.8 mPa·s and leads to highest amplification ratio. Although WD-40 with lower viscosity of 2.3 mPa·s can provide fair lubricant effect, upon loading low viscosity lubricant film could be too thin to provide stable effect due to breakage and volatility of the film. On the other hand, engine oil with higher viscosity of 69.5 mPa·s could cause stiction at mechanism joints and reduce lubricant effect. Therefore, both WD-40 and engine oil lubricants result in moderate amplification ratios.

Table 1. Testing thicker silicon cantilever with thickness/length of 50/600 μm by the double lever mechanism in order to achieve experimental force amplification ratios.

	Without mechanism	With mechanism			
Cantilever number	No lubrication	No lubrication	WD-40 Lubricant (*viscosity*=*2.3mPa·s*)	Blended oil lubricant (*viscosity*=*13.8mPa·s*)	Engine oil lubricant (*viscosity*=*69.5mPa·s*)
1	0.1231	1.1959	1.8923	2.2041	2.0672
2	0.1180	1.2625	1.9086	2.2657	2.0846
3	0.1265	1.4396	1.9074	2.1985	2.0213
4	0.1347	0.9948	1.8997	2.2107	2.0581
5	0.1299	1.3689	1.8869	2.2349	2.0819
Maximum average force (N)	0.1264	1.2523	1.8990	2.2228	2.0626
Standard deviation σ of average force (*Percentage of average force*)	0.0057 (*4.51%*)	0.1538 (*12.28%*)	0.0084 (*0.44%*)	0.0248 (*1.12%*)	0.0228 (*1.11%*)
Experimental amplification ratio		9.91	15.02	17.59	16.31
Theoretical amplification ratio		25	25	25	25
Transformation efficiency		39.64 %	60.08 %	70.36 %	65.24 %

In addition to amplification ratio, consistency of measured average forces is important to apply this mechanism, and this can be evaluated through standard deviation. The combination of standard deviation of average force and transformation efficiency is equivalent to the meaning of tolerance for the mechanism. As shown in table 1, standard deviations of average forces measured by the machine without and with the mechanism are compared. Standard deviation is calculated based on five experimental data. Without mechanism, standard deviation is 4.51% of the average force, while with mechanism but no lubrication standard deviation is 12.28% of the average force. This indicates that measurement of enlarged force by the mechanism without lubrication is likely to be inconsistent. With three means of lubrication, standard deviations are significantly improved and their percentages of corresponding average forces are in a small range from 0.44% to 1.12%. This depicts that lubrication of the mechanism substantially improves the consistency in the measurement of enlarged force. As shown in table 2, using experimental force amplification ratios, original maximum bending force F_{max} can be achieved by dividing enlarged average force by the amplification ratio, which is then adopted to calculate the bending strength of SiO_2 cantilever microbeams. Figure 4 depicts lubricating and length effects on bending strength of 1.0 μm thick SiO_2 cantilever microbeams loaded at front side. Strength of the microbeam decreases as the microbeam length increases. This trend is also found in author's other work (Liu et al., 2010). For each beam length, due to various lubricating effects of the mechanism and different standard deviations bending strength from high to low is tested with blended oil, engine oil, WD-40 lubricant, and no lubrication. As higher friction may cause both loss of force transfer and larger standard deviation of the measured average force, blended oil lubricant can avoid previous two drawbacks and result in highest and consistent measurement data. As shown in table 3, for SiO_2 beam length of 300 μm subjected to front side loading bending strengths from high to low are 7.049, 6.997, 6.701 and 5.713 GPa respectively for tests with blended oil, engine oil, WD-40 lubricant, and no lubrication. Similar trend is also found for beams with longer lengths.

Table 2. Applying experimental force amplification ratios on testing of the SiO_2 cantilever with thickness/ length of 1/300μm.

	With mechanism			
	No lubrication	WD-40 lubricant	Blended oil lubricant	Engine oil lubricant
Enlarged average force (N)	3.1×10^{-3}	5.6×10^{-3}	6.9×10^{-3}	6.3×10^{-3}
Experimental amplification ratio	9.91	15.02	17.59	16.31
Original average force F_{max} (N)	3.17×10^{-4}	3.72×10^{-4}	3.91×10^{-4}	3.89×10^{-4}
Theoretical amplification ratio	25	25	25	25
Transformation efficiency	39.64 %	60.08 %	70.36 %	65.24 %

Table 3. Lubricating and length effects on bending strength of SiO_2 cantilever microbeams loaded at both front and back side surfaces.

Beam length (μm)	Loading direction	No lubrication	WD-40 lubricant	Blended oil lubricant	Engine oil lubricant
		Bending strength (GPa)			
300	Front side loading	5.713±0.303	6.701±0.295	7.049±0.247	6.997±0.258
	Back side loading	5.599±0.301	6.603±0.274	6.951±0.255	6.883±0.262
400	Front side loading	5.511±0.301	6.578±0.289	6.876±0.242	6.831±0.251
	Back side loading	5.431±0.302	6.532±0.301	6.814±0.253	6.716±0.259
500	Front side loading	5.227±0.297	6.484±0.246	6.829±0.241	6.724±0.245
	Back side loading	5.117±0.299	6.374±0.239	6.737±0.249	6.608±0.253
600	Front side loading	5.125±0.299	6.276±0.235	6.718±0.238	6.546±0.243
	Back side loading	5.013±0.306	6.173±0.249	6.632±0.246	6.451±0.256
700	Front side loading	5.036±0.298	6.204±0.248	6.627±0.237	6.378±0.237
	Back side loading	4.839±0.297	6.031±0.236	6.509±0.251	6.317±0.247

Figure 5 indicates lubricating and length effects on bending strength of SiO_2 cantilever loaded at back side surface. As stated in section 3.1, front side surface has lower roughness R_a 13.81 nm than R_a 31.36 nm of back side surface. For MEMS devices, lower roughness usually leads to higher strength because defect size is proportional to roughness dimension. Compared figure 5 with figure 4, strength of various beams loaded from back side surface are lower than those loaded from front side surface. Supported data are also found in table 3. For example, for beam length of 700 μm tested by front side loading with blended oil lubricant its bending strength 6.627 GPa is higher than the counterpart 6.509 GPa by back side loading. Similar comparison results are found for beams with shorter lengths and tested with different lubricating means.

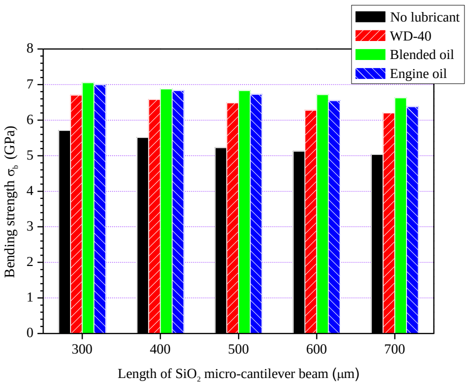

Fig. 4. Lubricating and length effects on bending strength of 1 μm thick SiO_2 cantilever microbeams loaded at front side surface.

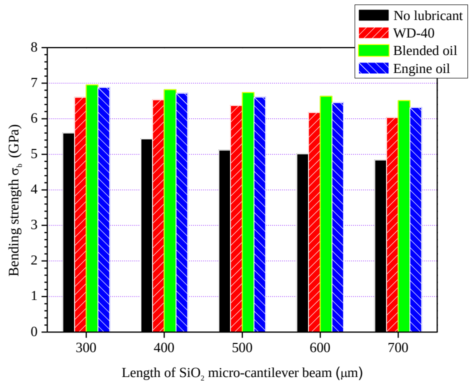

Fig. 5. Lubricating and length effects on bending strength of SiO_2 cantilever microbeams loaded at back side surface.

Young's modulus of SiO_2 beams

Figure 6 depicts stress-strain curves for 1/300 μm thickness/long SiO_2 cantilever microbeams loaded at front and back side surfaces, and highest points at both curves represent bending fracture. SiO_2 cantilevers longer than 300 μm also depict similar stress-strain curves as that in figure 6. Straight lines for stress-strain behaviors indicate that the SiO_2 cantilever is brittle. Therefore, the slope of the straight stress-strain line is the Young's modulus of the cantilever. As shown in figure 6, slope of the line by front side loading is larger than that by back side loading. Young's moduli of beams with various lengths are also depicted in table 4. According to the data, beam length does not affect Young's modulus of the beam. This conclusion is similar to author's previous work for silicon beams (Liu et al. 2008). Due to smaller surface roughness of front side surface than that of back side surface stated in section 3.1, the average Young's moduli of cantilevers tested at front side and back side surfaces are 133.71GPa and 126.58GPa, respectively. These values are similar to those achieved by Li et al. (2003). This suggests that the Young's modulus of micro scale cantilever is proportional to its surface roughness. Luo et al. (2004) also proved that Young's modulus of electroplated Ni thin film is proportional to its surface roughness. It is postulated in their paper that the drop in modulus is associated with an increase in porosity of the film, and porosity plays a similar role as surface roughness.

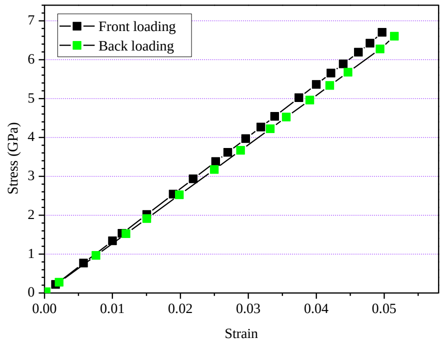

Fig. 6. Stress-strain curves for 300 μm long SiO_2 cantilever microbeams tested at front and back side surfaces with the WD-40 lubricated mechanism.

Table 4. Summary of Young's modulus.

Young's modulus (GPa)	Length (μm)				
	300	400	500	600	700
Front side	134.64	129.18	121.87	144.31	138.55
Back side	127.51	128.32	123.21	118.95	134.91

Advantages of the double lever mechanism

In the MEMS research field, measurement facilities need to provide the resolution that matches devices with micro meter scale. The testing machine used in this paper is a MTS Tytron 250 with force resolution of 10^{-3} N, displacement resolution of 1.0μm, and stroke of 100 mm. Based on authors' mechanical design knowledge, motivation of this paper is how we can upgrade force resolution of the MTS Tytron 250 machine and apply it in the measurement of miniature devices. Since the thickness of SiO_2 beam tested in this work is 1.0 μm, it is even smaller than diameter of the nanowires 1.2 μm tested in reference (Brown et al., 2011). This demonstrates that the proposed mechanism is able to upgrade the machine for testing nano materials. Besides, authors consider that the mechanism is innovative because similar mechanisms have been adopted in references (Bolzmacher, 2010, Conway, 2007, Devoe, 1997). Based on a similar lever mechanism, the force amplification ratio of a double lever mechanism proposed here is of 15.02-17.59; while in reference (Bolzmacher, 2010) stroke has an amplification ratio of 5-13. The amplification ratio in this manuscript is higher than that in reference (Bolzmacher, 2010).

Preliminary results of force amplification ratio shown in table 1 demonstrate that this double lever mechanism is applicable to upgrade the machine. As we divide force resolution 10^{-3} N of the machine by the amplification ratio 17.59 (=4.194^2), it turns out to be 5.69×10^{-5} N, a better resolution of the machine. Furthermore, if we extend this double lever mechanism as the triple lever mechanism using three sets of asymmetrical levers, the magnification ratio could presumably increase up to 73.77 (=4.194^3). This new amplification ratio could further revise resolution of MTS Tytron 250 as 1.36×10^{-5} N, a fine resolution good for sub-micron MEMS devices. Moreover, if a new design is proposed such that length of effort lever arm "d" is ten times longer than length of resistance lever arm "c", theoretical force amplification ratio of the triple lever mechanism would be 1000. Besides, the double lever mechanism has more advantages including reliable, compact, large stroke, and is easy to manufacture. Maximum stroke of the mechanism is 4000 μm which is calculated by dividing the original machine stroke 100 mm by theoretical force amplification ratio 25. Moreover, the machine with the mechanism can measure averaged mechanical properties instead of local properties of MEMS materials, and is able to conduct dynamic test, such as fatigue test on nano materials.

Failure modes of SiO_2 beams

Figure 7 indicates the bended 700 μm long SiO_2 cantilever microbeam showing smooth fracture surface. This depicts that the failure mode of the cantilever is a brittle fracture. This result is coincident with the straight stress-strain curve shown in figure 6. In the micrograph, due to the microfabrication process the residual silicon film at the fixed end of the microbeam underneath SiO_2 film is observed. Since it is quite close to the fixed end, measurement results should not be influenced.

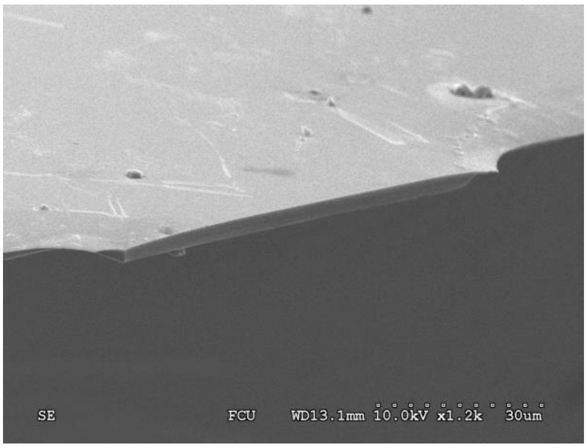

Fig. 7. Micrograph of the bended 700 μm long SiO_2 cantilever microbeam showing smooth fracture surface.

CONCLUSIONS

An innovative double lever mechanism has been proposed in this work to mount on the micro force testing machine and the force measurement resolution of the machine is greatly improved. The modified machine is used to conduct bending tests on 1.0 μm thick SiO_2 cantilevers with various lengths.

The important findings of this study are as follows. First, maximum force amplification ratio of the mechanism is 17.59; second, the ratio enables the machine to amplify maximum force of failed SiO_2 cantilever from 3.91×10^{-4} N to 6.9×10^{-3} N which can be detected by the machine with force resolution of 1.0×10^{-3} N; third, a large testing stroke of 4000 μm is achieved; fourth, the mechanism can conduct dynamic nano testing, and is easy to be manufactured. Tested by the machine with blended oil lubricated mechanism, SiO_2 cantilever with length/width of 300/100 μm loaded from front side surface has the highest bending strength of 7.049 GPa, while the cantilever with length/width of 700/100 μm loaded from the back side surface has the lowest bending strength of 6.509 GPa. Average Young's moduli of cantilevers tested at the front side and back side surfaces are respectively 133.71GPa and 126.58GPa. With these results, it is demonstrated that the mechanism is a simple and effective mean to enhance force measurement resolution of the testing machine for MEMS devices, and the mechanism is likely to further increase its force resolution by extending the double lever mechanism as a triple lever mechanism.

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測試二氧化矽微懸臂樑之新型力量放大機構

劉顯光 王淵民
逢甲大學機械與電腦輔助工程學系

廖為忠
逢甲大學土木工程學系

摘 要

微懸臂樑經常作為微感測器，因此微懸臂樑的機械性質測試成為微機電系統重要議題，甚至需要延伸到奈米機電系統。有些奈米機電系統尺度很小，卻需要具有微米的行程，所以開發新型簡單測試方法，又能放大測試力量或行程非常重要。本論文提出一種新型雙槓桿力量放大機構，可以與微拉力試驗機結合，能維持較大行程，並能針對厚度僅有 1 微米的二氧化矽薄膜微懸臂樑，測試出正確的彎曲強度及楊氏模數。機構的設計串聯兩套非等臂槓桿機構，其關節處必須適當潤滑，使機構具備最大的力量放大倍數。