DEVELOPMENT OF ELECTROMAGNETIC PROBE FOR MICRO FORCE MEAUSREMNT

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ABSTRACT

Micro/Nano force measurement is becoming more essential in the fields of AFM metrology, biomedical industries, chemical industries, and material science. For the micro/nano force measurement, a cantilever mounted with Ni/Cr conducting wire has been fabricated by MEMS process. The cantilever with high sensitivity can be driven by Lorentz force which is generated by applying current into the wire under uniform magnetic flux. In order to measure micro/nano force precisely, the cantilever is controlled to a null position with the Lorentz force opposing to a vertical input force. The active measurement method by null balance is more accurate and sensitive than passive measurement method using a piezoresistive cantilever. For this measurement, the simple electromagnetic circuit is analyzed and constructed to obtain high magnetic flux density, and a spring constant for high force sensitivity and a resonant frequency for the stable control of the cantilever are analyzed by FEA. After the construction of a system with a displacement sensor and a controller, the basic measurement characteristics such as a resolution, linearity, and repeatability, will be determined by experiment, and the comparison calibration with a commercial cantilever will be carried out. This electromagnetic active probe can be used as a transfer standard for the micro force evaluation and dissemination. It would also be applicable to various researches and industries, such as binding-force measurement between molecules, force lithography, and nanoindentation

1. INTRODUCTION

Needs of micro/nano force measurement are increasing more and more in the fields of nanotechnology, biology, chemistry and so on. Specially, a cantilever can be used as an important tool to measure and analyze interaction characteristics between a sharp tip and molecules on sample surface. For example, a scanning probe microscope (SPM) with a highly sensitive cantilever, such as AFM, LFM, FMM, STM, MFM and so on, is widely used in the various fields for the purpose of identifying physical phenomena in nano-scale. Also, it can be used for nanoindenting, scratching, wearing to measure hardness, adhesion, durability, etc. Recently, force lithography for data storage and biology applications for new medicine development are becoming more important. The force lithography by precision force control can make a pattern mechanically on a disk which is not changeable chemically or optically. Cantilever-based biological sensors for biomolecules detection have been being developed. In this field, the cantilever is considered as an effective tool since it can measure even small interaction force between biomolecules such as DNA, virus, bacteria, etc. For example, the binding force measurement between biomolecules can be used to identify antigen/antibody characterization and to investigate protein.[1]-[3] As above, the sensitive cantilever can be used in many application fields, but the exact value of its spring constant must be given for the accurate measurement and control. However, the spring constant values of cantilever given by the manufacturer are not quite reliable since they are mostly computed values based on the shape and the thickness information, which may cause great errors. A lot of spring-constant determination methods using mainly natural frequency change have been proposed, but they have no traceability, and are destructive or inaccurate. Among the determination methods, the direct comparison method with a reference force is considered to be more recommendable and reliable.[4]-[6]

In order to provide the accurate spring constant information of cantilevers to users, KRISS is, as other NMIs are, developing a nanoforce standard by using an electrostatic force balance and a transfer standard by using an electromagnetic force compensation method.[7]-[10] A highly sensitive electromagnetic probe with Ni/Cr conducting wire has been designed and manufactured in KRISS. For direct comparison, the electromagnetic probe will be controlled at null position by adjusting Lorentz force, and the current applied to the probe will be measured.
A piezoresistive cantilever can be a good candidate as a transfer standard or a nanoforce sensor, but the passive detection method using the deformation of the cantilever is not sensitive in comparison with the active one. Figure 1 shows the principle of the electromagnetic probe and the overall system constructed. The system has permanent magnets for uniform magnetic flux generation, optical devices for the detection of the cantilever deformation, and the stages for alignment and movement.

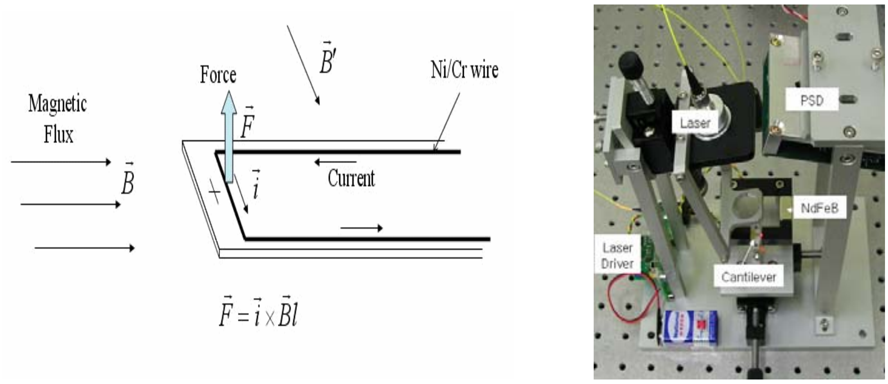


Figure1: Principle of measurement and system construction

2. DESIGN AND ANALYSIS OF CANTILEVER

The method which determines theoretically the spring constant of the cantilever may have great uncertainty because the thickness and material properties in microscopic scale can not be obtained easily. So, a highly sensitive nanoforce sensor traceable to SI units must be developed.
The cantilever with conducting wire for the electromagnetically-driven probe must have a low spring constant value in order to measure nN scale force. We are trying to manufacture the cantilever having thickness around 1 μm to reduce the stiffness. Ni/Cr(8:2) alloy was used for conducting wire.

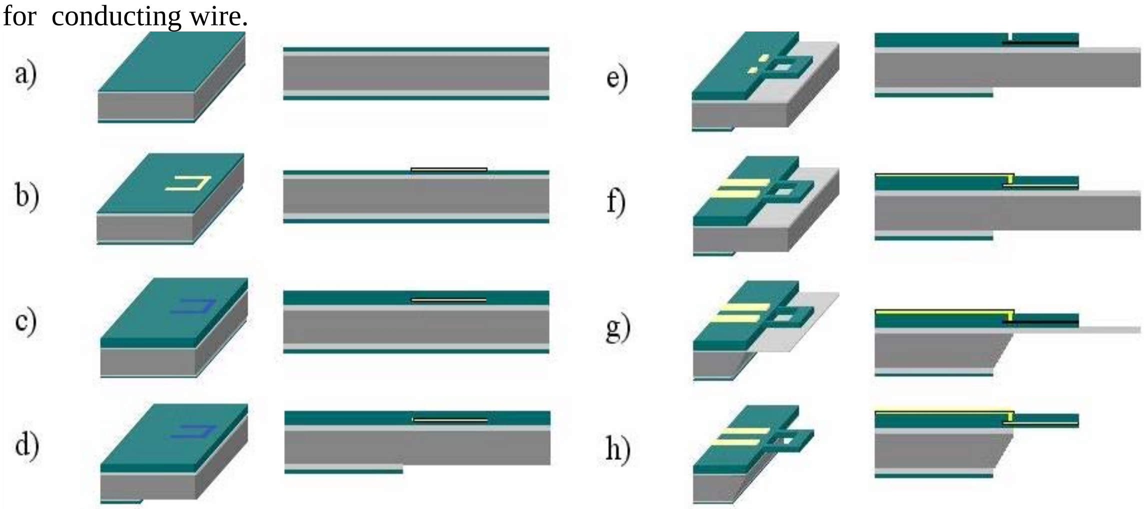


Figure2: Cantilever Fabrication Process

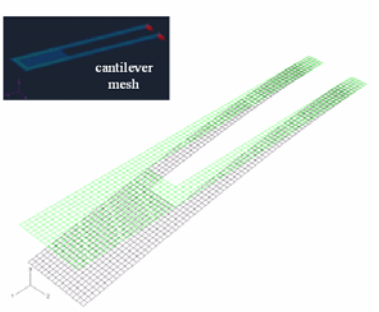
Followings are the details of fabrication process of Figure 2.

a) SiO_2(3500 Å) deposition by thermal oxidation and Si_3N_4 (1500 Å)deposition by LPCVD
b) Patterning of Ni/Cr alloy(1200 Å) by photolithography and by E-beam (Lift-off process)
c) Si_3N_4 deposition(8000 Å) by PECVD
d) Backside Si_3N_4 etch by RIE and SiO_2 wet etch by BOE
e) Si_3N_4 etch for cantilever and contact hole by RIE
f) Ti/Au deposition (1000/5000 Å) for electrical contact
g) Backside KOH etch
h) SiO_2 Removal

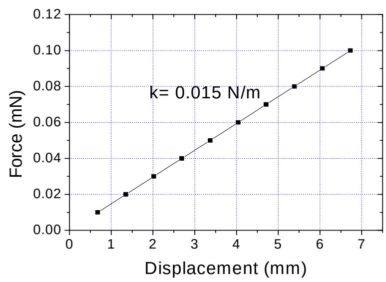
For a rectangular cantilever, the spring constant value is given by following equation.

$$K = \frac{3EI}{L^3} = \frac{Ebh^3}{4L^3} \qquad (1)$$

where E is Young's modulus; L, Length; b, width; h, thickness.
The stiffness of the cantilever is one of the most important parameters which can determine the resolution of the force measurement with the displacement detection performance in the null balance method. Since it is difficult to obtain the spring constant below 0.01 N/m for a conventional rectangular shape of cantilever retaining over 1 μm thickness, the shape of the cantilever must be modified. The cantilever was designed and analyzed by using FEA program. The overall dimension is 80 μm × 400 μm × 1 μm as shown in Figure 3(a).
According to the analysis results, the stiffness is 0.015 N/m as given in Figure 3(b). Also, the 1st natural frequency is 4.2 kHz, and the 2nd and 3rd one is 30.7 kHz and 38.7 kHz, respectively. The fundamental natural frequency is high enough to obtain the large bandwidth of the electromagnetic probe.
Since the spring constant is 0.015 N/m, the best force resolution of the electromagnetic probe is 0.015 nN, if the resolution of displacement detection is assumed to be below 1 nm. In order to improve the performance, the sensitivity of the displacement sensor also needs to be increased.



(a)FEA Result



(b) stiffness

Fig.3: Analysis result of the cantilever

For the electromagnetic probe, a uniform magnetic flux and an optical detection system are required. The used permanent magnet, NdFeB38H, is relatively stronger, but more sensitive to temperature change than SmCo or Alnico. According to the results of electromagnetic FEA program, MXWELL, when the gap in which the probe is positioned is 10 mm, magnetic flux density is 0.29 T and when the gap is 8 mm, 0.32 T. A laser beam deflection system including a laser diode and a PSD is used to detect the deformation of the electromagnetic probe.

3. FBRICATION

According to the above process, the cantilever with conducting wire has been manufactured. Figure 4 shows the cantilevers fabricated with 4″ wafer before h) process. Also, various cantilevers different from the electromagnetic probe type were designed together in order to make them a piezoresistive cantilever through P^+ doping process. The array of the piezoresistive cantilevers will be used for nano/bio technology applications, etc.
Figure 5 shows the resulting cantilever after all processes. The cantilever has been warped when it was released from the wafer completely. This results from the stress difference between upper and lower planes of the cantilever. The different Si_3N_4 deposition methods and the position of the Ni/Cr conducting wire may cause the warp of the cantilever. In order to reduce the distortion characteristic, c) process would be replaced by LPCVD.

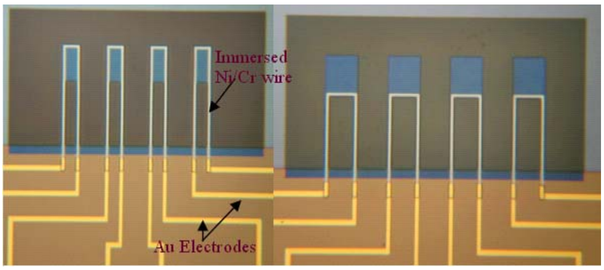


Figure4: Cantilever shape

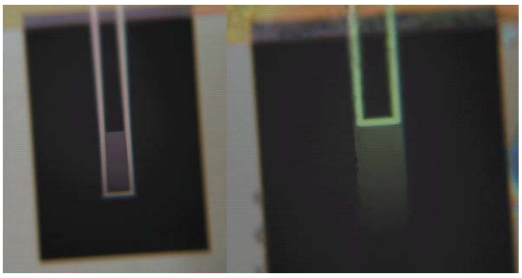


Figure5: Cantilever released from wafer

For the better optical detection and/or the immobilization of biomolecules, Au must be deposited on the upper cantilever surface additionally. Thin Au film with ~ 20 nm thickness is enough to reflect the beam and to immobilize the biomolecules, which is expected not to change total stiffness largely.

4. CONCLUSIONS

KRISS is developing the electromagnetic probe to measure and to generate the micro/nano force. A cantilever having thickness about 1 μm has been designed and analyzed with FEA. The cantilever was fabricated according to a designed process, which is being modified continuously. The final target value of the spring constant is around 0.01 N/m. The electromagnetic probe would be used to calibrate commercial cantilevers by comparing directly each other

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