公益財団法人矢崎科学技術振興記念財団
国際交流援助　研究発表　帰国報告書

公益財団法人矢崎科学技術振興記念財団
　理事長 殿

国際学術会議での研究発表を終えて帰国しましたので、下記の通り報告します。

2026　年　　8　月　　20　日
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所属　　　　　　　　　国立研究開発法人産業技術総合研究所
職位　　　　　　　　　研究者

1. 発表論文名
Biaxial optical cantilever by using 2D diffraction grating and Sampling Moiré Method
二次元回折格子とサンプリングモアレ法を組み合わせた二軸光てこ方式カンチレバー

2. 国際学術会議の名称
The 12th Asia-Pacific Conference on Transducers and Micro-Nano Technology (APCOT2026)
第 12 回トランスデューサ及びマイクロ・ナノテクノロジーに関するアジア―太平洋学会

4. 国際学術会議の開催地（国、地名、会場名など）
台湾・台中・The Splendor Hotel-Taichung 台中金典酒店

5. 渡航期間
　2026　年 6 月 21 日 ～ 2026　年 6 月 25 日

6. 国際学術会議発表の要旨
　本学会では、片持ち梁形状の力センサを製作した。梁の表面には格子状の回折格子を設け、光を入射させると縦・横の二方向に広がる回折模様が反射するようになっている。センサが力を受け変形すると、この回折模様もそれにあわせて移動する、この回折模様の移動をレンズレスカメラで撮像し、サンプリングモアレ法と呼ばれる周期模様の移動を算出できる解析手法で撮像した画像群を解析することで、センサの変形及びかかった力を検出する。
　発表の反応では、力センサの用途について多く聞かれた。受けごたえとして、ロボットに組み込むようなタクタイルセンサや、細胞等の微小生物が生み出す力の計測を挙げた。提案するセンサは従来手法よりも簡便なセットアップ・製作プロセスで nN オーダの微小力計測が可能であるため、組み込みや実験室環境下での力計測に適している。

7. 国大学術会議の動向
　APCOT（Asia-Pacific Conference on Transducers and Micro-Nano Technology）は、センサ、アクチュエータ、MEMS/NEMS、マイクロ・ナノ技術を対象とするアジア太平洋地域の国際会議であり、隔年で開催されている。APCOT2026 は台湾・台中で開催され、Physical Sensor、Bio/Medical MEMS、Microfluidics、Optical MEMS、材料・加工、AI・機械学習など幅広い分野を扱った。近年は、従来の Si 基盤 MEMS に加え、3D プリンティングや新材料、柔軟デバイス、フォトニクス、バイオ・医療応用などへの展開が進んでいる。また、センサ単体の高性能化だけでなく、信号処理、AI、パッケージング、異種集積を含めたシステム化も重要な動向である。特に、複雑なセンシング情報を AI で解析し、ロボットやウェアラブル、医療デバイスへ応用する研究が増えており、MEMS 技術の応用範囲が拡大している。

以上

Biaxial optical cantilever by using 2D diffraction grating and Sampling Moiré Method

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INTRODUCTION

Cantilever-type force and displacement sensors based on the optical lever method are widely used in various fields. They can measure micro- to nano-scale motion, for example in surface evaluation of materials [1]. However, the conventional optical lever system needs extra optical parts, such as a quadrant photodiode, for two-axis sensing [2]. It also requires strict optical alignment, because the reflected beam must be placed at the center of the photo detector before measurement. To address this alignment issue, a cantilever incorporating a diffraction grating has been proposed previously [3]. When the cantilever is illuminated, the reflected striped diffraction pattern is captured by a lens-less camera and analyzed using the sampling moiré (SM) method. Since the SM method simultaneously utilizes multiple diffraction patterns, precise optical alignment is not required, and high displacement resolution can be achieved. However, in the previous design, the diffraction pattern spread only in one direction, which limited the detectable force to the downward direction.

In this work, a cantilever incorporating a two-dimensional diffraction grating is proposed (Fig.1 (a)). Illumination of the diffraction grating generates diffraction patterns in two orthogonal directions. By independently analyzing these patterns using the SM method, both the normal force and the moment acting on the cantilever can be detected. The proposed cantilever is designed, fabricated and evaluated.

PRINCIPLE, DESIGN AND FABRICATION

The operating principle of the proposed cantilever is illustrated in Fig. 1(b). When a light is incident on the cantilever, a lens-less camera captures diffraction patterns that spread in both the vertical and horizontal directions. When a force is applied, bending of the cantilever induces two-dimensional shifts in the diffraction patterns. By calibrating the relationship between applied force and pattern shift in advance, the force components acting on the cantilever can be estimated from the measured shifts.

The structural design of the cantilever is shown in Fig. 2(a). The cantilever consists of a 25 µm-thick rectangular plate supported by bellows-shaped legs. A loading point and a diffraction grating are integrated into the plate. The plate dimensions are 3 × 2.5 mm. The diffraction grating comprises lines with a width of 2 µm and a depth of 50 nm, arranged in two orthogonal directions with a spacing of 250 µm. The fabrication process is summarized in Fig. 2(b). A 25-1-400 SOI wafer was used. First, reactive ion etching was employed to form the diffraction grating. Subsequently, deep reactive ion etching (DRIE) from the top side defined the cantilever structure. After flipping the wafer, backside DRIE was performed, followed by removal of the BOX layer. Optical microscope images of the fabricated cantilever and the diffraction grating are presented in Figs. 2(c) and 2(d). The designed structures were successfully fabricated with the intended geometry.

EXPERIMENT AND RESULT

Fig. 3(a) shows the experimental setup. A laser beam was directed onto the fabricated cantilever, and the reflected light was recorded using a lens-less camera. A load cell mounted on a piezo stage was used to apply force to the cantilever. The piezo stage was driven with a displacement amplitude of 2 µm at a frequency of 0.5 Hz. A diffraction pattern captured by the lens-less camera is shown in Fig. 3(b). The intense spot observed in the upper-left region corresponds to the reflected beam. The vertical diffraction pattern exhibited a spacing of 280 µm, while the horizontal pattern had a spacing of 220 µm. The shifts of these patterns in each direction were analyzed using the SM method.

The experimental results are summarized in Fig. 4. By changing the contact position of the load cell, sensor responses corresponding to positive and negative bending moments were obtained. Downward deflection of the cantilever caused a downward shift of the diffraction pattern. In addition, Mx+ induced a rightward shift, whereas Mx− resulted in a leftward shift, demonstrating the capability of the sensor to detect moment direction.

CONCLUSIONS

In this paper, biaxial optical cantilever was proposed. The fabricated cantilever produced the diffraction pattern in two directions. By analyzing the diffraction pattern, we evaluated the response of the pattern shift when forces were applied to the cantilever.

REFERENCES

[1] T.I. Zubar, et al., Sci Rep 10, (2020), p. 14411.
[2] J. Thiesler et al., Sensors, 22 (2022), p. 314.
[3] S. Sato et al., IEEE Sensors Journal, 25 (2025), pp. 28119-28126.

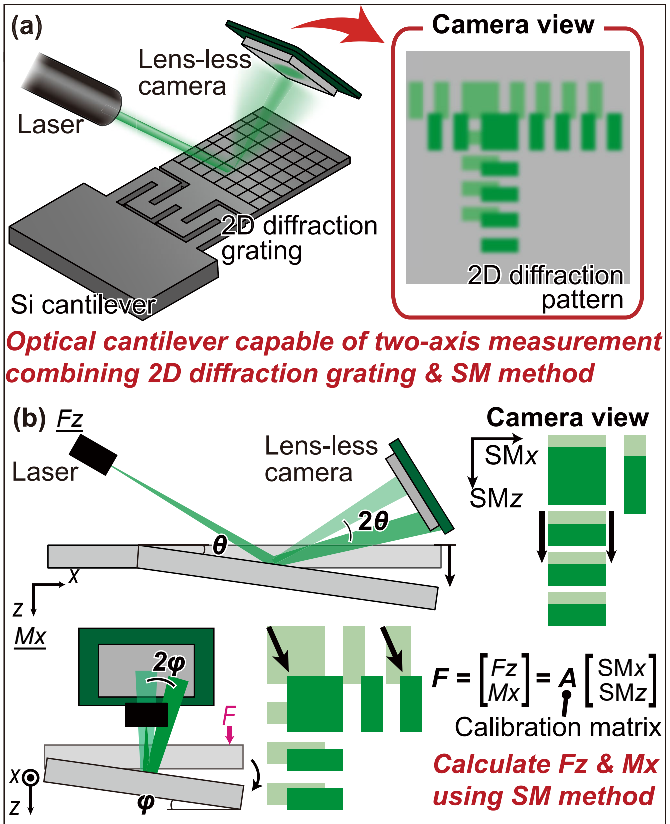

Figure 1 (a) Concept sketch of a optical lever combining the SM method and 2D diffraction grating. **(b)** Principle of the proposed device. Analyzing the two-directional shift of the diffraction pattern with the SM method.

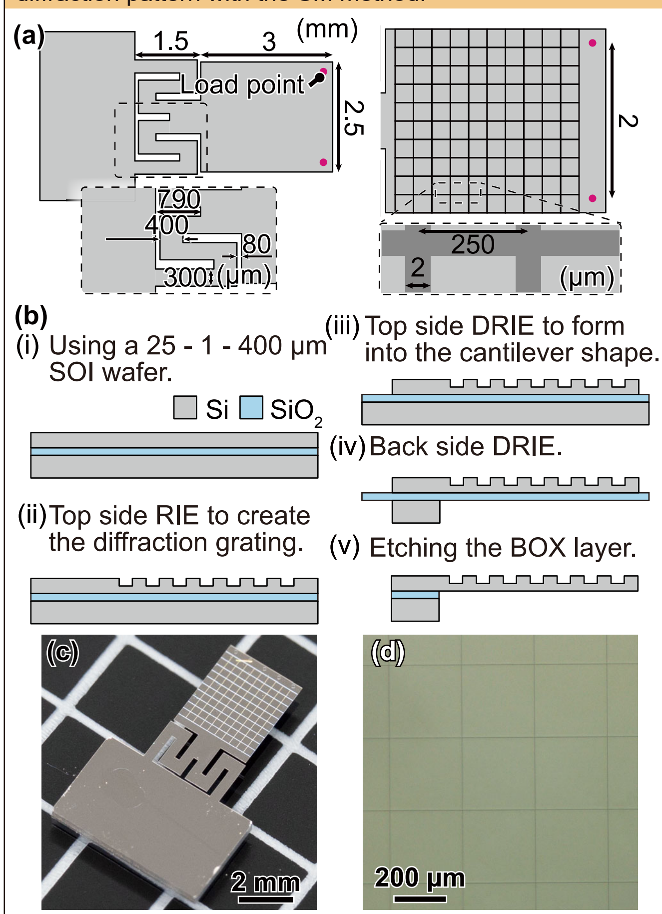

Figure 2 (a) Design of the propesd device. **(b)** Fabricated process of the proposed cantilever. **(c)** Photograph of the fabricated device and **(d)** the 2D diffraction grating.

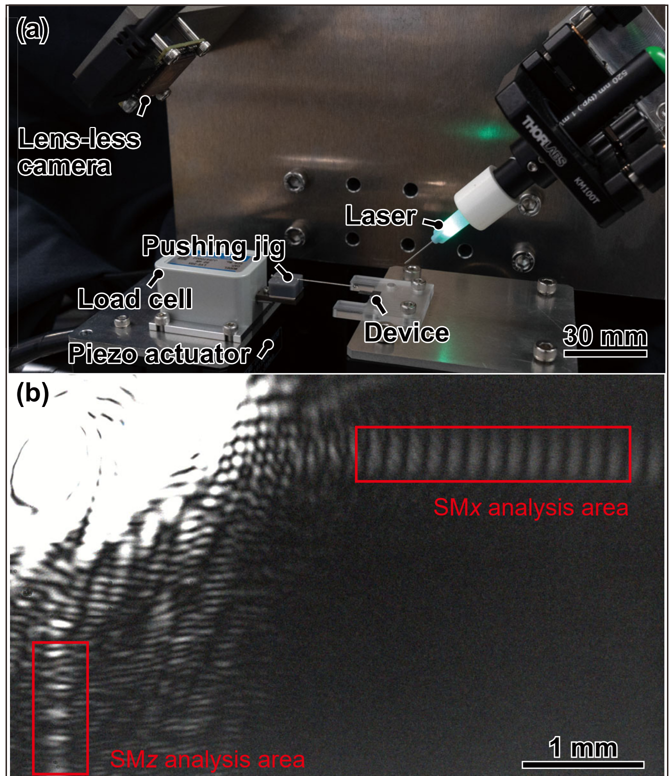

Figure 3 (a) Photograph of the setup for caribration experiment. **(b)** Captured image of the diffraction pattern.

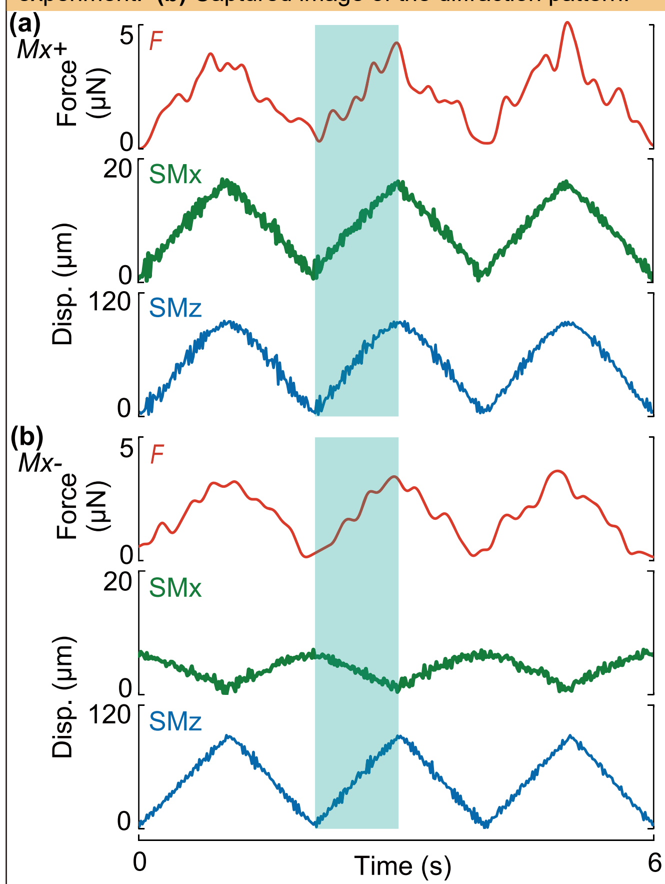

Figure 4 Results of the calibration experiments: **(a)** *Mx+*, and **(b)** *Mx−*.