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Micro Energy Harvester with $(K,Na)NbO_3$/Silicon Composite Cantilevers

ニオブ酸カリウムナトリム/シリコン複合カンチレバーを用いた小型振動発電素子

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1. Introduction

Harvesting the electric power from ambient resouces, such as sunlight, wind, heat gradient, vibration and so on, is an promising solution for autonoumous sensor systems. Vibration based energy harvester becomes a key technology to maintain a stable power supply to the system [1]. $Pb(Zr,Ti)O_3$ (PZT) based energy harvester is actively researched owing to high piezoelectric constant of the PZT. However, it is unlikely to spread such harvesters into environment since Pb has high toxicity.

In our previous work, $(K,Na)NbO_3$ (KNN) instead of PZT was applied as a piezoelectric material for energy harvester [2]. The KNN turns out not only being an environmental-friendly material but also possessing high power figure of merit (FOM) [3]. The previous device, constructed from a silicon proof mass and four clamped-clamped KNN cantilevers, achieved wide band responces due to high nonlinear characteristics. However, output power was not so high.

In this study, the KNN/silicon (Si) composite structure was applied to the harvester. The device fabrication became simplified and the output power was extremely improved.

2. Design and Fabrication

The previous paper reported the harvester using a quatrefoil proof mass suspended by KNN beams as shown in **Fig. 1** [2]. However, we could not obtain the adequate output power from this device since both compressive and tensile strains exist in the bending KNN beam and negate the charge each other.

Si support layer was adopted to enhance the device performance. By using this structure, strain in the KNN was redistributed to avoid the negation effect. For 2-µm thick KNN beam and 2-µm thick KNN/10-µm thick Si composite beam, strain distribution was calculated numerically with commercial FEM simulator (ANSYS). **Fig.2** shows the calculation results when the tip displacement,

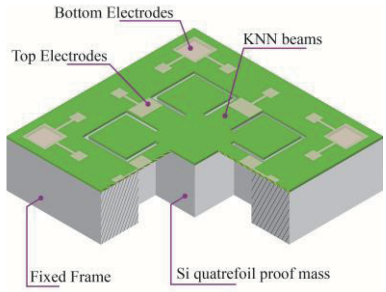

Fig.1 Illustration of wide band micro-energy harvester applying KNN piezoelectric thin films [2]

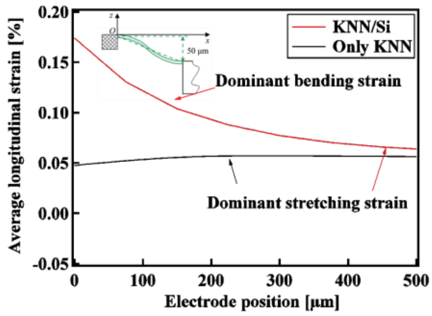

Fig.2 Average strain of piezoelectric element along the electrode position for downward deflection of 50 µm

cantilever length, and width were set to 50 µm, 1500 µm, and 500 µm, respectively. The strain shown in **Fig.2** was averaged for the thickness direction. From this result, avoiding negation of the strain was confirmed.

The harvester was fabricated using bulk micromachining technologies for KNN/SOI wafer based on the manufacturing flow disclosed in Ref. 2. At first, bottom electrode, KNN piezoelectric film, and top electrode were deposited on SOI wafer and patterned. Finally, proof mass and beams were fabricated by using the deep reactive ion etching (RIE). The SEM image of the harvester is shown in **Fig. 3**.

3. Results and Discussion

Figure 4 shows the relationship between output power from each beam and frequency under the input acceleration of 5 m/s^2. In this result, the load resistance was optimized to 141 kΩ.

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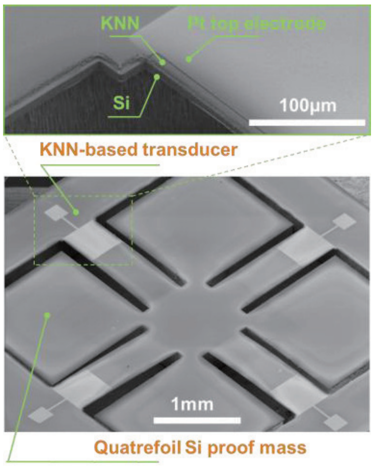

Fig.3 SEM micrograph of KNN-based energy harvester device

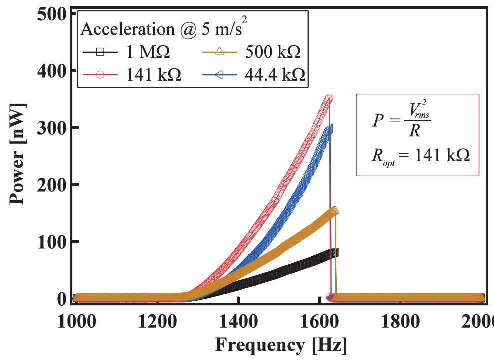

Fig.4 Power spectra for each beam of the harvester with respect to different resistive load

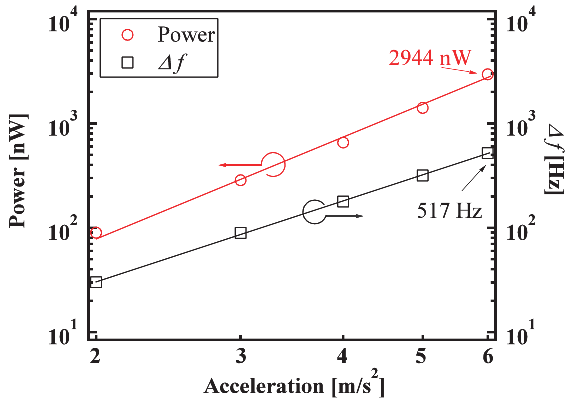

Fig.5 The power and bandwidth of the whole device as a function of the input acceleration

Figure 5 shows the maximum output power and Δf as a function of input acceleration. The Δf was defined in Ref. 2 and was difference between jump up and down frequency. Also the maximum power of the whole micro-energy harvester was defined four-fold larger than output of each beam.

At the acceleration of 6 m/s^2, the maximum power and bandwidth were 2.9 μW and 195 Hz, respectively. The power density, which is quotient of the maximum power for the device volume, was up to 555 μW/cm^3 that was about 4 times larger than the previous result [2].

Table 1: Geometric dimensions of KNN-based energy harvester with multi-beam KNN/Si structure

Piezoel. material	a_0 [g]	P [μW]	Δf [Hz]	PD [μWcm^{-3}]	PD×BW [mWcm^{-3}Hz]
d_{31} KNN (This work)	0.6	2.9	517	555	108.2
d_{31} KNN [2]	1.5	0.7	412	122	14.6
d_{31} AlN [4]	2.0	0.1	650	34	8.5

PD = Power Density; BW = Band Width

Table 1 shows the survey of the state of the art in the piezoelectric MEMS energy harvesters using the clamped-clamped beams. The performance of the micro-energy harvester applying lead-free KNN piezoelectric thin film at low input acceleration can be comparable to that of PZT-based energy harvester.

3. Conclusion

The (K,Na)NbO_3 (KNN) based energy harvester with multi-beam KNN/Si structure poses a high possibility for circumventing the dilemmas, environmental and bandwidth issues, of conventional piezoelectric micro-energy harvesters. This work demonstrated the KNN-based micro-energy harvester might achieve the high power density of 555 μW/cm^3 and high (PD×BW) of 108.2 mW.cm^{-3}.Hz.

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