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$(K,Na)NbO_3$ micro-energy harvesters with multi-beam structure
$(K,Na)NbO_3$ 用いた超小型エナジーハーベスタの開発

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1. Introduction

Vibrational energy harvesting becomes attractive to supply power to sensor nodes for widespread applications, such as structural health monitoring, emviromental observation or implant devices [1][2]. From perspective of these fields, piezoelectric energy harvesting is one of the promising technologies on account of high energy conversion efficiency and miniaturization of the system [2]. Most of them are utilized $Pb(Zr,Ti)O_3$ (PZT) film as a piezoelectric material. However, PZT is undesirable for wide distribution into environment or implantation into human body due to inclusion of Pb element.

A lead free $(K,Na)NbO_3$ (KNN) has attracted attention to PZT substitution. This material can provide a higher electromechanical coupling coefficient, compared with the conventional PZT [3]. The high quality KNN film could be obtained by using the conventional deposition method [4]. The KNN-film-micromachined structure, however, has not been well reported, whereas micromachining is a key technology for power density enhancement and cost reduction. In this study, we developed the micromachined KNN-based energy harvester.

2. Structure and Fabrication

The configuration of KNN-based energy harvester with multi-beam structure included four KNN beams and a big silicon proof mass as shown in **Fig. 1**. The proof mass consisted of main mass adding four minor proof masses. Four KNN beams were integrated with four sensing elements (Metal/KNN/Metal) which convert mechanical vibration into electricity.

This harvester was fabricated using bulk micromachining technologies. At first, bottom electrode, KNN piezoelectric film, and top electrode were deposited and patterned. Finally, proof mass and beams were fabricated by using the deep reactive ion etching (RIE) system.

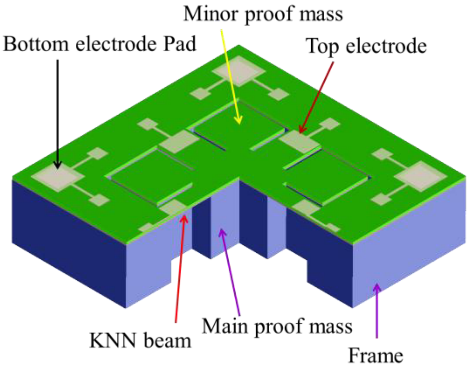
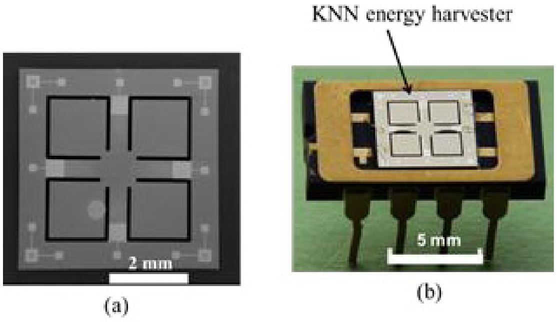


Fig. 1 Illustration of multi-KNN-beam configuration for energy harvester



(a) (b)

Fig. 2 SEM micrograph of KNN-based energy harvester device (a) and its package for evaluation (b)

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

	Beam structure	Main proof mass	Minor proof mass	Top electrode
Length [μm]	1500	1000	1500	500
Width [μm]	500	1000	1500	500
Thickness [μm]	2	500	500	0.2

3. Results and Discussion

The SEM micrograph of the KNN-based energy harvester with multi-beam structure is indicated in **Fig. 2a**. The geometric dimensions of the device were presented on **Table 1**. The device was mounted on the ceramic package for evaluation as shown in **Fig. 2b**.

The performance of the harvester was tested by using shaker which can vary input accelerations and frequencies. Output voltages of devices were

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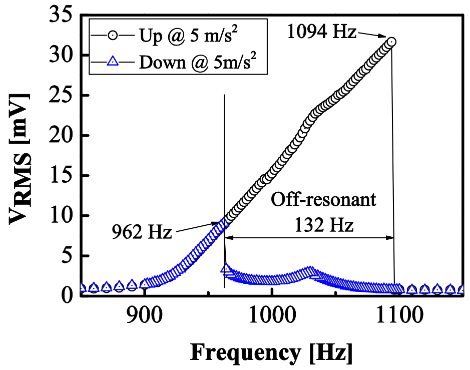
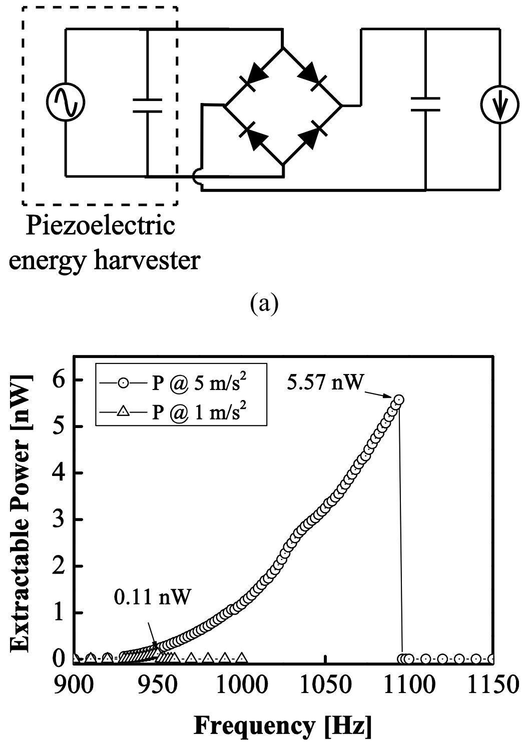


Fig. 3 Open-circuit voltage versus frequency under the input acceleration of 5 m/s^2 for each beam



(a)

(b)

Fig. 4 Schematic of conventional interface circuit (a) and extractable power of KNN-based energy harvester for one beam versus frequency (b)

measured with oscilloscope (Tektronix: DPO 7104).

Figure 3 exhibits the relationship between root-mean-square output voltage V_{rms} and frequency under the input acceleration of 5 m/s^2 at the open-circuit state. The circle-line and the triangle-line curve in Fig. 3 indicate the output voltage of energy harvester when the frequency was increased and decreased, respectively.

From these results, the nonlinear effect could be observed clearly. This characteristic enables the device to operate in a wide frequency range. Enhancement of the frequency range of 132 Hz was confirmed with the input acceleration of 5 m/s^2.

Figure 4a shows the conventional interface circuit in order to manage the electrical energy to charge a battery. According to Ottman *et. al.* [5], the extracted power of the energy harvester is expressed as follows:

$$<P>_{max} = 4 f_{ex} C_p V_{r\,m}^{2} \qquad (1)$$

where f_{ex} is power-extracted frequency, C_p is internal capacitance of the energy harvester, V_{rms} is root-mean-square output voltage of the harvester at the power-extracted frequency.

In our device, each beam obtained the average capacitance of 1.27 nF in range frequencies of 0.5 - 2 kHz. Extractable power for each beam of energy harvester is shown in **Fig. 4b**. The maximum extractable power of each beam was 5.57 nW at the input acceleration of 5 m/s^2.

3. Conclusion

The $(K,Na)NbO_3$-based energy harvester with multi-beam structure would be enabled to practical applications on account of the environmental-friendly device and the wide range of operating frequencies. This device could obtain the extractable power of 5.57 nW at low input acceleration of 5 m/s^2 or the extractable power density of 3.71 μW/mm^3.

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