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KNN Lead-free biaxial piezoelectric MEMS Mirror on 200 mm Si wafer

L.Mollard[1], C.Dieppedale[1], A.Hamelin[1], G.Le Rhun[1]
[1] Univ. Grenoble Alpes, CEA, Leti, F-38000 Grenoble, France.

laurent.mollard@cea.fr

Summary:
This work presents the first KNN-biaxial non-resonant MEMS mirrors manufactured on 200 mm silicon substrate. The performances of the biaxial MEMS mirrors with reflector diameters ranging from 0.5×0.5 to 2×2 mm², integrating 1-µm thick sputtered potassium sodium niobate $(K_{0.3}Na_{0.7})NbO_3$ piezoelectric thin film from Sumitomo Chemicals, are presented. These mirrors, which exhibit rotational resonant frequency of 32.5 kHz, 7.5 kHz and 1.92 kHz, have been tested in non-resonant mode at 200 Hz and at higher frequencies. An optical angle of up to 6° can be obtained depending on the driving frequency.

Keywords: MEMS mirror, Piezoelectric, KNN, Lead-free, Actuator.

Due to their compact size, affordability, and minimal power consumption compared to conventional mechanical scanning systems, MEMS mirrors [1] find widespread use across various applications. These include projection display systems for augmented reality (AR) and virtual reality (VR) smart glasses, biological imaging, and Light Detection And Ranging (LIDAR) system [2], among others.

Piezoelectric actuation emerges as a promising choice, offering notable advantages such as high force, low voltage requirements, high frequency capability, and rapid response times. For a long time, lead Zirconate Titanate (PZT) stands out as the leading piezoelectric material, boasting competitive electromechanical coupling and a high piezoelectric coefficient. However, the environmental impact of lead present in PZT raise significant concerns regarding the practical application of piezoelectric MEMS mirrors. The release of lead and its associated compounds during the manufacturing process poses a substantial threat to both the environment and human health [3].

To replace PZT actuators, various families of lead-free piezoelectric materials have been developed. Among them, sodium potassium niobate (KNN) emerges as particularly promising due to its elevated Curie temperature and high piezoelectric coefficient [4].

This work presents the performances of biaxial piezoelectric MEMS with mirror diameters ranging from 0.5×0.5 to 2×2 mm², as presented in Tab. 1, integrating sputtered potassium sodium niobate $(K_{0.3}Na_{0.7})$ NbO_3 thin film from Sumitomo Chemicals [5][6]. This 1 µm-piezoelectric motor exhibits a high piezoelectric coefficient ($e_{31,f}$ = 11 C/m²) and high dielectric constant (ε=1200) making it suitable for actuating performance.

The KNN biaxial MEMS mirrors, fabricated on 200 mm silicon wafer, as shown in Fig.1, have rotational resonant frequency of 32.1, 7.5 and 1.92 kHz respectively, depending on mirror diameter. The results obtained with these non-resonant mirrors exhibit the following characteristics (a) collective 200 mm silicon manufacturing process (b) low voltage operation of only 20V in non-resonant mode (c) an optical angle of 7.5° at 690 Hz frequency for the 2×2 mm² mirror, as shown in Fig.2 (d) a frequency range of up to 5100 Hz and 28000 Hz for the 1×1 mm² and 0.5×0.5 mm² mirror respectively. These results are state-of-the-art compared to the results previously obtained with PZT material and other actuation motor using non-resonant driving mode, as represented in Fig.3, [2][7].

The KNN lead-free piezoelectric material integrated into actuators offers potential applications in various fields from Light Detection And Ranging (LIDAR) systems to biomedical applications, thanks to the full biocompatibility of KNN material [8].

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Tab. 1: KNN MEMS mirror variants described in this work

Design variant	Resonant frequency	Mirror size	MEMS Footprint
	(kHz)	(mm²)	(mm²)
(a)	1.92	2×2	≈8×8
(b)	7.5	1×1	≈4×4
(c)	32.1	0.5×0.5	≈2.5×2.5

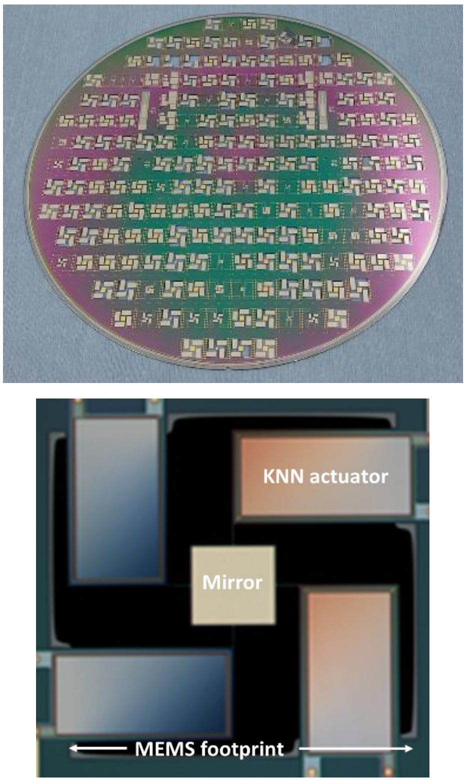

Fig. 1. 200 mm silicon wafer of KNN-MEMS mirrors and MEMS mirror top-view.

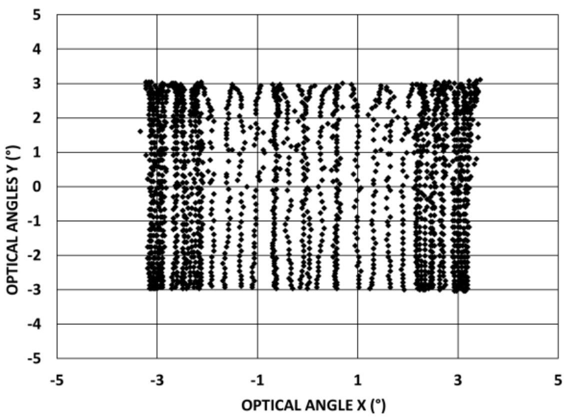

Fig. 2. 2D scanning representation of KNN MEMS mirror – Design variant (a) – 50 points per fast axis – 20 V voltage, 200 Hz fast/horizontal axis and 4 Hz ramp slow/vertical axis.

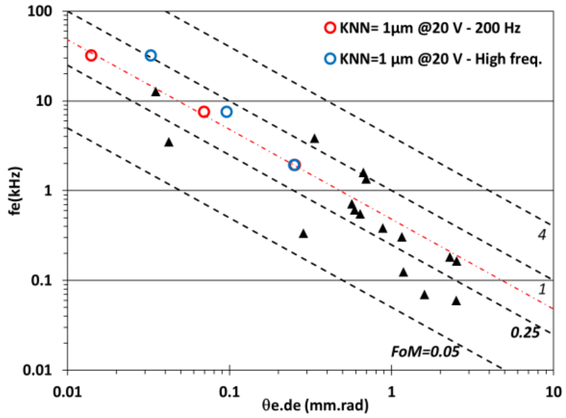

Fig. 3. FoM values previsouly reported in [2] (▲) and this work ((○ for 200 Hz fast axis and ○ for highest frequency on fast axis)

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