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KNN Lead-free MEMS Mirror: Thermal behavior

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Summary:

This paper presents the thermal behavior of KNN-based quasi-static biaxial piezoelectric MEMS mirrors. These mirrors achieved state-of-the-art performance at ambient temperature across different MEMS mirror sizes. Specially, they reach an optical angle of up to 8.5° at 40V with a 2×2 mm² mirror. These mirrors were initially designed for LIDAR (Light Detection and Ranging) applications, using a 1550 nm pulsed laser with high incident power. This paper presents a series of experimental results on the thermal behavior of such KNN mirrors, which could be affected by high incident power or high ambient temperature. It shows that the mirror and KNN actuator thermal deformations are consistent with a first-order model, without any detrimental effects up to 100°C. It also demonstrates that the mirror remains operational at this temperature, with 2D beam scanning behavior consistent with previous study and no significant deviation of the spot during a 30-minutes period. These results enables a better prediction of the evolution of the KNN-mirror and 2D scanning when temperature increases for LIDAR systems or new application domains.

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

Due to their compact size, affordability, and low power consumption compared to conventional mechanical scanning systems, MEMS mirrors [1] are widely used in 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 generation, low voltage requirements, high frequency capability, and rapid response times. For a long time, lead Zirconate Titanate (PZT) has been the dominant piezoelectric material thanks to its competitive electromechanical coupling and high piezoelectric coefficient. However, the presence of lead in PZT raise significant concerns regarding the practical application of piezoelectric MEMS mirrors. The release of lead and its associated compounds poses a substantial threat to both the environment and human health [3].

To replace PZT actuators, sodium potassium niobate (KNN) emerges as particularly promising due to its high Curie temperature and strong piezoelectric coefficient [4]. The integration of lead-free KNN material integrated into actuators offers potential applications in various fields, from Light Detection And Ranging (LIDAR) systems to biomedical applications, thanks to its full biocompatibility [5].

This work presents the thermal behavior of biaxial piezoelectric MEMS mirror with 2×2 mm² diameters, as presented in Tab. 1, featuring a gold reflector. The performance of such mirrors at ambient temperature was presented previously in [6] [7]. The studied mirrors incorporate a 1.5 µm sputtered ($K_{0.3}Na_{0.7}$) NbO_3 thin film from Sumitomo Chemicals [8].

This paper demonstrates that the 2×2 mm² KNN mirror remains functional as the temperature increases and undergoes no detrimental deformation even when heated to 100 °C. The deformation of the KNN actuators based tends to shift downward, with a 40 µm decrease in the mirror's Z-position when heated to 100°C. This result is consistent with a first-order model. The mirror's planarity under temperature increase is also studied and potential optimization strategies for improving planarity are presented. In addition, the 2D-projection model under increasing temperature revealed no variation in optical angle at 50°C and a 5% increase at 100°C. This result is also consistent with previous studies [9]. Finally, the stability of 2D scanning during continuous use, at 100 °C was investigated. The finding demonstrate that a KNN

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MEMS scanner can operate at a temperature of at least 100 °C for 30 minutes without significant deviation.

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Tab. 1: KNN MEMS mirror described in this work

Reflector	Mirror Size (mm²)	MEMS Footprint (mm²)	f_x (kHz)
Au	2×2	≈8×8	1.92

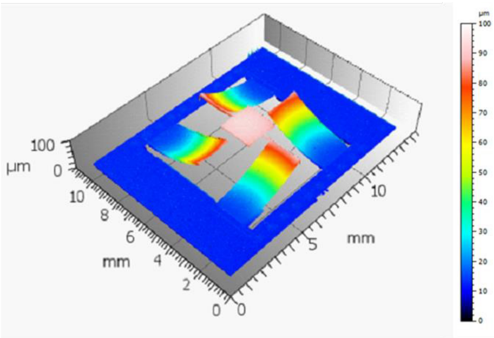

Fig. 2. Scanner deformation along Z-axis with Gold reflector at ambient (25°C).

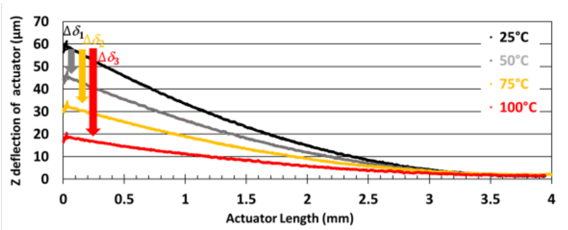

Fig. 3. Evolution of the Z-deflection of the KNN arms as a function of temperature

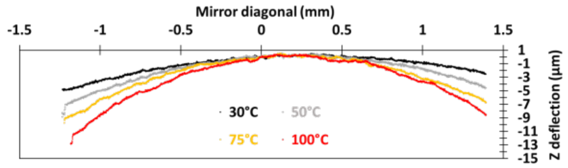

Fig. 3. Evolution of mirror deformation as a function of temperature from 25°C to 100°C.

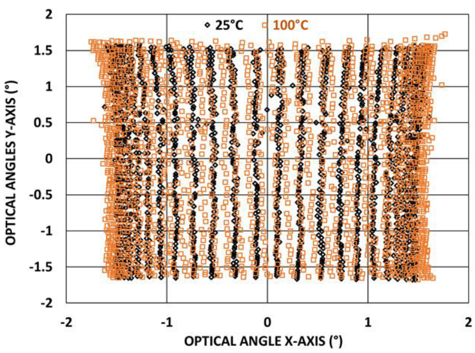

Fig. 3. 2D beam scanning at 25°C and 100°C

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