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22.3 kHz update rate Lissajous scanning using a single double resonant MEMS scanner.
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22.3 kHz update rate Lissajous scanning using a single double resonant MEMS scanner

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***Abstract*—A double resonant MEMS scanner with on-chip frequency tuning capability is presented, which enables generation of two dimensional Lissajous projection patterns with update rates of up to 22.3 kHz. The piezoelectric scanner has an electrothermal frequency tuning capability with simultaneous tuning of 4% and 0.3% of the two orthogonal movement modes, allowing Lissajous scan pattern update rate and fill factor selection.**

Keywords*—*MEMS scanner; Lissajous scanning; frequency tuning

I. Introduction

Fast update rate two-dimensional projection and scanning systems have distinct application potentials in areas such as Lidar or biomedical imaging. While raster scan approaches are most common they, in general, limit the achievable frame update rate by low axis speeds in the tens to hundreds Hz. Alternative approaches using Lissajous scanning, where two resonance axes are used simultaneously, have been demonstrated, specifically using MEMS scanning mirrors [1] or piezo actuated fibre scanner [2]. This demonstrated update rates of up to 60 Hz with fill factors of more than 86%. Recently selection rules and mathematical models to select frequencies for maximising update rates have been developed [3]. While the selection rules allow best case scenario selection in most cases, this includes actuating double resonant scanning mirror away from their main resonance frequencies to create closed Lissajous scan, which reduces achievable field of views. We have recently developed a fast scanning MEMS that allows double resonant movement and frequency tuning of the resonance [4]. Electrothermal based tuning shows different tuning gradients for the orthogonal scan modes, with one axis changing frequency by 4% while the other changes by 0.3%. In this work we will improve the angular range and show a simultaneous driving scheme allowing widely tunable Lissajous scanning with maximum scan angles and selection of update rate and fill factor.

II. MEMS design

The MEMS scanning mirror concept is identical to the device shown in [4]. Briefly, the scanner consists of a 200 µm mirror aperture surrounded by a circular gimbal frame and a second elliptical frame holding piezoelectric actuators (see Fig. 1). The actuators are split into 4 quadrants to allow independent driving of in-phase resonant actuation. The MEMS is fabricated using a commercial multi-user process (PiezoMUMPs by Memscap Inc) with a 10 µm single crystal silicon device layer, 500 nm AlN piezoelectric layer, 1 µm Al top electrode layer and 400 µm silicon substrate. The doped device layer acts as bottom electrode for piezoelectric actuation, with a 1 µm thick oxide layer allowing electrical isolation between the device layer and top electrode.

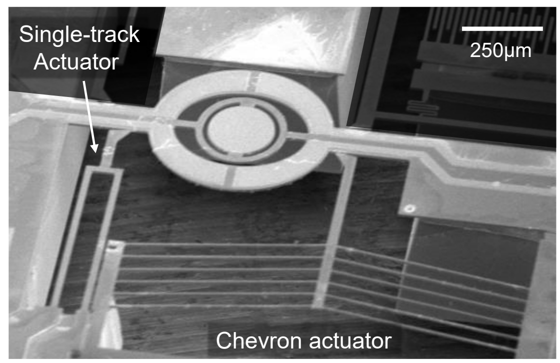

Fig. 1: Fabricated double resonant MEMS including electrothermal tuning actuators.

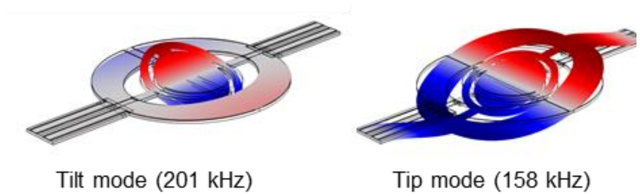

Fig. 2: Resonance mode shapes for 2D scanning.

To allow frequency tuning a chevron and single track electrothermal tuning actuator are placed in the scanner design (see Fig. 1) The actuators are fabricated in the silicon device layer. Applying a DC voltage leads to Joule heating and thermal expansion of the actuator tip which closes in to the main torsion beam of the scanner. Heat conduction and convection leads to a localised temperature increase at the torsion beam, which leads to change in material properties and stiffness and results in changes to the scanner resonance frequencies.

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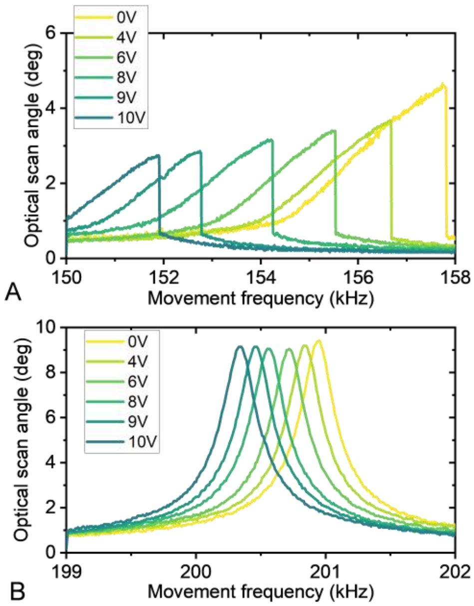

Fig. 3: Frequency tuning of both resonance modes

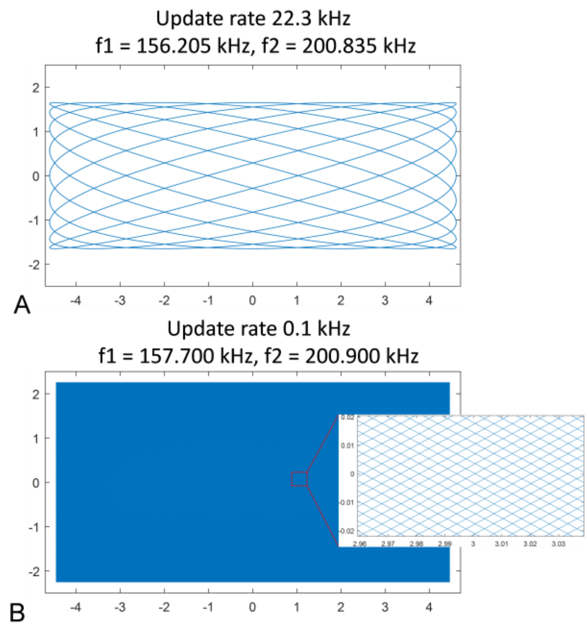

Fig. 4: Lissajous scan pattern with selectable update rate.

III. Frequency tuning Results

The two main tip/tilt resonance modes of the scanner without tuning are at 158 kHz and 201 kHz, with the respective mode shapes shown in Fig. 2. The resonance modes have a Q-factor of 70 and 500 respectively, when actuating the scanner with a 40 V offset single frequency sine-wave. To evaluate the frequency tuning potential, both of the thermal tuning actuators are driven simultaneously with a DC voltage ranging from 0 V to 10 V while a frequency sweep of the scanner is conducted. The resulting frequency response curves are shown in Fig. 3 and indicate a tuning range of 5.9 kHz for the main tip mode around 158 kHz and a tuning range of 0.6 kHz for the main tilt mode around 201 kHz. The percentage change clearly shows a significant increased tuning range of the tip mode, resulting from the more prominent bending motion of the main torsion beam for this movement mode. The reduced tuning range of the tilt mode originates from this mode only incorporating a small motion of the main torsion beam, which experiences localised heating during the frequency tuning. By having a tuning ratio difference of over an order of magnitude using a single tuning mechanism allows adjusting the movement frequency ratio, and therefore greatest common divisor (GCD) between the two movement frequencies, which itself is the essential parameter for selecting Lissajous scanning trajectories.

IV. Lissajous scanning

To evaluate the achievable GCD and resulting closed Lissajous trajectories a Matlab script evaluating tuning combinations has been created. From this, both the maximum number of achievable cross points, which is representative of a maximum fill factor of the scan trajectory, as well as pattern repetition frequency can be evaluated. While a trade-off exists between fill factor and update-rate, any point between the two scenarios can be achieved with the presented frequency tuning. Fig. 4 shows the two boundary cases, with Fig. 4A running the scanner simultaneously at 156.205 kHz and 200.835 kHz through a tuning voltage of 4 V, realising a pattern update rate of 22.3 kHz with a field of view of 3.8° by 8.4°. At this point the pattern has 9 by 7 cross-over points, showing a reduced fill factor. Fig 4B is achieved when running the scanner at 157.7 kHz and 200.9 kHz with a tuning voltage of 0V and leads to pattern crossover points of 2009 by 1577 with a dense 2D scene projection. At this point a full pattern repetition frequency is however reduced to 100 Hz with a field of view of 4.5° by 8.9°. Through the tunability of the 2D scanner a Lissajous pattern with selectable crossover point number between these two scenarios can be chosen, impacting on the achievable pattern update rate.

V. Conclusions

We have presented work on a double resonant MEMS scanner with Lissajous pattern update frequency of 22.3 kHz for a 3.8° by 8.4° scene. The specific Lissajous pattern is reached through on-chip frequency tuning of the MEMS scanner, allowing dynamic selection and optimisation for pattern frequency update rate or fill factor depending on application.

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