Microelectronics Reliability xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Microelectronics Reliability

journal homepage: www.elsevier.com/locate/microrel

Long-term stresses on linear micromirrors for pico projector application

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ARTICLE INFO

Article history:
Received 19 May 2017
Received in revised form 5 July 2017
Accepted 18 July 2017
Available online xxxx

Keywords:
MEMS
Micromirror
Long-term
Reliability
Mechanical degradation
Electrical degradation

ABSTRACT

Micro electromechanical system (MEMS) micromirrors are interesting devices to be adopted in pico projector application. In fact, together with laser sources, they can be adopted to obtain an always in focus projected image. The reliability of these devices is not yet been addressed. In this paper, we investigate the reliability of micromirrors subjected to long-term stresses. The preliminary results and their interpretation is addressed at the end of this paper. The results led us to think about two different degradation mechanisms. Permanent and recoverable stiffness variation can both influence the mechanical tilting angle of the device during long-term stresses. These two different mechanisms may affect the correct behavior of the device. Further measurements will be needed in order to validate the preliminary hypothesis made in the last section of this paper.

1. Introduction

MEMS micromirrors have seen a vast array of applications since their first development by Kurt E. Pettersen in 1980 [1]. Amongst the many possible applications, the most noticeable are in the optical switches field, in the scanning optical devices for healthcare use and in the pico-projectors branch [2]. This last field of application has been very important in the last decade [3] due to the booming smart device market that led to a considerable growth of the pico projectors market.

Many types of micro electromechanical system (MEMS) based pico projectors can be distinguished, each one corresponding to a different implementation of the projector. A first successful type of micromirror is the digital micromirror device (DMD) developed by Texas instruments [3] which is the core element of the DMD projection system in which each mirror is responsible for the depiction of a single pixel [4]. Another type of MEMS micromirror is the biaxial micromirror [3], which is responsible for the whole depiction of the projected image thanks to its ability to rotate around two different axes. This last application is often compared to the combination of two single axial torsional scanning mirrors [3], which combines the motion of two micromirrors to create the projected image. Two examples of these two micromirrors are the ones developed by ST Microelectronics [5]. The first responsible for the depiction of the horizontal lines of the projected image is called *resonant* micromirror (RM), the other one responsible for the depiction of the vertical lines is called *linear* micromirror (LM). Due to their different final application, the two devices present some substantial differences in terms of working frequencies and driving waveforms. The RM in fact works with a square wave of frequency 25 kHz, whereas the LM is turned on with a ramp of frequency 60 Hz. The LM device will be the main focus of this paper.

Different failure mechanisms can influence the reliability of MEMS devices. The failure mechanisms may have an electrical origin like charge trapping [6] or electrostatic discharges [7] or a mechanical origin like stiction [8], creep and viscoelasticity [9].

Very few papers in literature addressed the reliability of micromirrors. An example is in [8]. The reliability of micromirrors subjected to long-term stresses (i.e. mirror remains tilted in a fixed position for a prolonged time) has not yet been addressed.

In order to prevent eventual failure modes, in this paper the effect of artificial long-term stresses on linear micro-mirrors was investigated. In particular, both mechanical and electrical constraints which could affect the correct behavior of the devices were identified.

2. Device description

As can be seen in Fig. 1 the LM (developed by ST Microelectronics) has a rectangular shape in order to be able to collect all the reflection coming from the resonant device [5].

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http://dx.doi.org/10.1016/j.microrel.2017.07.081
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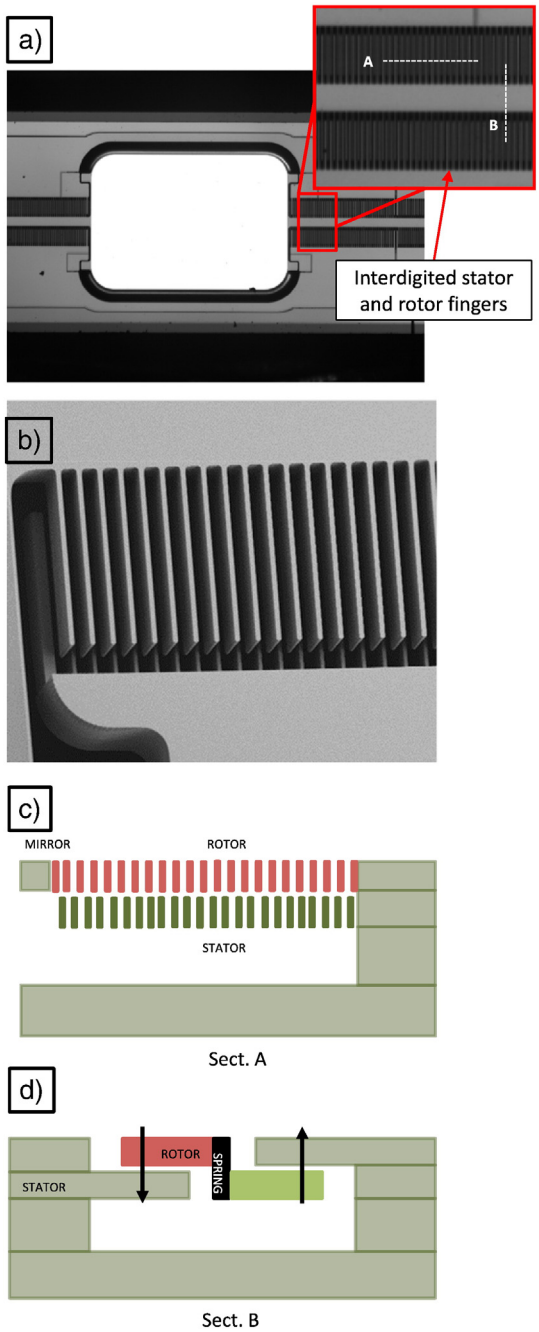

Fig. 1. a) View of the LM device with two sections (A and B) highlighted on the comb fingers. b) Zoom on the comb finger based torsion mechanism of the micromirror. c) Schematization of the section A highlighted in fig. a. d) Schematization of the section B highlighted in fig. a, the arrows indicate the direction of the movement of the micromirror structure once it's turned on. Dimensions of the micromirror not in scale.

The driving method is the well-known comb drive and since the LM device has a linear nature, its torsion bars are very long in order to be able to produce the required torque necessary to the motion of the micromirror [5]. The fingers of the comb drive are not laying on the same plane, which means that stator and rotor fingers (see Fig. 1d) are separated by a vertical gap. This separation allows for a DC operational mode in which the mirror remains tilted at a fixed mechanical angle under the application of the required DC voltage.

The main realization process sequence of the mirror is schematized in Fig. 2. The linear mirror is integrated by wafer to wafer polymeric bonding (Fig. 2a). The cap wafer contains the cavity, whereas the "sensor" wafer with the mirrors starts its processing by using an SOI substrate. After some process operation completion, polysilicon layer is deposited on it and defined to provide the bottom finger structures of rotors and stators (Fig. 2b). Once cap and MEMS wafers are bonded through polymeric thermos-compression, the latter one is thinned by back grinding and finished by Chemical Mechanical Polishing. Al thin film is then deposited by PVD and patterned to form the mirror reflective surface and wire bonding pads, and finally rotor and stator structures are released through HF bath (Fig. 2c) [5].

3. Measurement system and stress procedure description

The schematic of the measurement system adopted to characterize the linear device is depicted in Fig. 3a. The setup is composed of a Laser, a CCD camera, a target, a support for the micromirrors and the instruments necessary to the device actuation and data acquisition.

The working principle is described in the following: the laser is turned on and it is set to hit the electrically tilted micromirror that stands on the support placed on the optical breadboard (see Fig. 3b). The reflection of the micromirror appears on the target and is acquired by the CCD camera. With some data elaboration, it is possible to derive the optical angle (θopt) of the mirror from the acquired images. The mechanical angle (θmech) is derived from the optical angle using the relation $\theta\text{opt} = 2\theta\text{mech}$. In the remaining sections of this work we will refer only to the mechanical angle. An example of DC and frequency characterization of a typical linear device is depicted in Fig. 4a and b.

As it can be noticed, (i) the higher the actuation voltage, the higher the resulting mechanical angle (Fig. 4a), (ii) the resulting mechanical angle presents a linear behavior as a function of the applied voltage between 120 V and 170 V (Fig. 4a) and (iii) for high frequencies (>80 Hz), the behavior of the maximum mechanical angle differs from the one expected in the working range (≤60 Hz; Fig. 4b) [5].

The timeline describing the nature of the stress carried out on the linear device is depicted in Fig. 5. In this case the linear micromirror is actuated with a DC voltage [5] of 120 V for a fixed amount of time (15 h), and in this interval of time its mechanical angle is constantly monitored through subsequently repeated image acquisitions and successive data elaboration. At the end of this interval of time, the device is turned off and it undergoes a recovery time of 8 h with no bias constantly applied. However, to enable the evaluation of the behavior of the micromirror during the OFF state recovery time, the LM is turned on at logarithmic times in this intervals and an image acquisition is carried out in order to evaluate the variation of the mechanical angle during the recovery time. This procedure is repeated five times in sequence in order to study the cumulative effects of five long-term stresses and is also repeated at different actuation voltages (150 V, 180 V).

4. Long term results

In Fig. 6 the behavior of the mechanical tilting angle of the linear mirror is presented for the first of the five actuation periods with a driving voltage of 120 V applied for 15 h.

As it can be seen after the turn on of the device the mechanical angle is subjected first to a constant decrease followed by an increase starting at about 300 min.

In Fig. 7 the variation in time of the mechanical angle for each of the five consecutive stresses is depicted. After the first 15 h of actuation during the recovery phase, the mechanical angle reaches a final

Please cite this article as: M. Silvestrini, et al., Long-term stresses on linear micromirrors for pico projector application, Microelectronics Reliability (2017), http://dx.doi.org/10.1016/j.microrel.2017.07.081