A way to implement the electro-optical technique to inertial MEMS

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ABSTRACT

This paper describes a new way to analyze inertial MEMS with the electro-optical technique. Usually, this technique is used in failure analysis to probe on electronic devices from old technologies to modern VLSI. In our case, we make use of the variation in power of the reflected beam between different layers of materials in an accelerometer (MEMS). We introduce a new method based on the electro-optical technique to extract a physical resonant frequency in inertial MEMS.

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1. Introduction

Today, inertial micro-electromechanical systems (MEMS) are increasingly being used in a wide range of objects, from airplanes or the automotive industry to smartphones or medical uses (pace-maker) in our case. High miniaturization and cost reduction are the principal arguments of current development. However, these characteristics influence the performance of the accelerometers and make its qualification and reliability more difficult.

The basic building block of inertial MEMS is composed of sensing elements to acquire the reaction of the measurement system. A proof mass, which is the most massive object, is often made from polycrystalline silicon and move as a function of acceleration. This acceleration is measured between fixed comb and the proof mass through capacitance measurement. The properties and dimensions of all these components (Fig. 1) are critical for their application.

Basically, any system mounted on springs has a periodical movement after excitation. The amplitude of this movement is maximized for certain excitation frequencies, called resonance frequencies. An interesting property of the resonance frequency is that a small variation in the excitation frequency results in a large change in amplitude, as shown in Fig. 2.

This physical property can be of great use for sensors: by exciting a mechanical structure at its resonant frequency or a multiple, a small actuation results in a large change in amplitude of the vibrating structure.

If this amplitude change can be measured accurately, a sensor with high sensitivity can be obtained.

On the other hand, the degree of wearing, process errors due to dimension or package contamination are given by the monitoring of resonant frequency, which is an intrinsic property of components.

Numerous methods are used to determine the resonant frequency, with the first being electric methods.

The C(f) plot, obtained by an impedance analyzer with bias, can be used to obtain the frequency but generally, the quality factor and the low response do not permit easy screening.

A lock-in amplifier detects the smallest variation of signal and thus provides the information on resonant frequency and phase. This ultimately translates to electrical response in the system.

These two methods require the knowledge of the range of frequency because high resolution is needed to observe one pic.

The optical method involves more setup but performs the screening of larger windows. The principal technique is the Laser Doppler Vibrometer. The device is subjected to vibration and the displacement was screened by Doppler Effect Laser.

The purpose of this abstract is not to describe the most efficient electro-optical method but to present a different way with an EOFM [4] by diversifying its use.

2. General principle and setup

2.1. Electro-optical principle

The interactions between light and silicon, while the latter is subjected to a varying electrical field, have been studied for more than 50 years.
There are several mechanisms to explain how light can interact with silicon [2], but according to R. Soreff and J. Bennett in [3], free carriers are the main source of light absorption in silicon. If the transistor polarization changes (VGS or/and VDS) when the electric field is varying, then the free carrier concentration is also changing. This leads to the modification in the reflected beam intensity, according to absorption coefficient changes in the optical path inside the device under test:

$$\Delta \alpha_{fe} = \frac{\lambda^2 q^4}{8\pi^2 c^2 e_0 n_0^2} \left( \frac{\Delta N_e}{m_e^* u_e(1)} + \frac{\Delta N_h}{m_h^* u_h(1)} \right).$$

In this equation, $\lambda$ is the laser wavelength, $q$ the electron charge, $T$ the temperature, $\mu_e$ and $\mu_h$ are the mobility of electrons and hole, respectively, $N_e$ and $N_h$ the free carrier density of electrons and holes, respectively, $\alpha$ the absorption coefficient, $c_0$ the light velocity, $n_0$ the refractive index of undoped silicon and $e_0$ the air permittivity. Such induced changes in carrier densities can be found at the transistor level when it is dynamically stimulated. If an incident light beam is sent onto a dynamically active transistor, it is possible to monitor the variations in the voltages that induce these free carrier density changes.

This is achieved by acquiring the reflected beam and deducing the electrical waveform at the point. This exploitation of modulation of the reflected beam is known as Electro-Optical Probing [5] (EOP).

### 2.2. Common setup

EOP has been designed for backside analysis. Indeed, the multiplication of the metal layers makes front side analysis very hard to perform by limiting the optical access of active areas. For heavily doped silicon, there is only a small range of the electromagnetic accessible to reach active structures. It has also been shown that the modulation ratio is the highest inside the area under the gate and close to the drain [2]. In conclusion, for probing of the electrical activity, there is a need to use monochromatic light near the band gap of silicon. Infrared lasers suit well for this application. In the common acquisition setup, the device is electrically stimulated by a test pattern generator.

A laser source is combined with a laser scanning module in order to scan the component and obtain knowledge of the spatial position of the laser beam. A part of the incident light is reflected on the device and hits a semi-reflecting mirror that sends the beam to an InGaAs photodiode. This photodiode converts the light signal to an electrical one. The latter is then amplified by a RF amplifier and acquired by an oscilloscope to extract the waveform at this point. A second method involves the use of a spectrum analyzer (after the RF amplifier) to extract the amplitude level of one frequency. Thereafter, this frequency is mapped via the use of software. A schematic of the complete setup is available in Fig. 3 and an EOFM's example of a part of an electronic device is available Fig. 4.

There are some controversies on the use of the appropriate wavelength to perform such probing. Indeed, the two values usually found across the literature are 1300 nm and 1064 nm. The latter is supposed to bring a finer spatial resolution but is potentially invasive due to the fact that the corresponding energy is bigger than the silicon band gap. Some photoelectric effect can occur. For this study, all of the waveforms have been acquired with a 1300 nm laser.

### 3. Results

### 3.1. Electro-Optical frequency mapping results

The pattern image (Fig. 5) has been done with the reflected laser beam. We can see one part of the MEMS with the fixed combs (black part) and the proof mass (white parts).

The focus has been fixed on the proof mass. This part is moving at a particular frequency, depending on the voltage applied at the pins of the MEMS.

Three things are observable in Fig. 6. The first of which is the direction of the comb. The orange color on the right image (Fig. 6) proves that we have the same direction for two edges. The second observation is shown in both of the images in Fig. 6. We can only see the edge of the proof mass due to the property of the reflected laser beam into the same material. This observation is due to the difference in reflected laser beam when the material or focus is changed.

The most important observation in Fig. 6 has been circled out in red. We have a part of fixed comb which showed an unexpected small movement (as indicated by the orange line). In the case of failure analysis, this method is able to pinpoint the location in the MEMS where we can have a problem.
3.2. Electro-Optical Probing results

In this section of the paper, we make use of the EOP to find the resonance frequency. We conduct probing at a single point in order to extract several waveforms at different voltages (Fig. 7).

Depending on the location (where we choose to probe) and the voltages applied on the MEMS, we do not have the same result. For this experiment, our choice of probing location was in the center of the black parts. At 4.2 V and 4.8 V, we are in a better configuration to get more of the reflected beam (orange and turquoise waveforms in Fig. 7).
focus has been done on the white parts. If we have more signals, it is due to the time that we stay in the white parts. In this case, the greater range of movement for the comb is between 4.2 and 4.8 V, both inclusive.

4. Discussion

This technique proves the capabilities to analyze another type of component. Concretely, if a part of comb is unfixed or the moving parts are not able to go to the maximum of its abilities, we can observe the defect. Our technique can be used even if there is a thick layer of silicon on the MEMS due to the transparency of the silicon at 1.3 μm.

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References


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