ESD Analysis of Thermal Actuated MEMS Chips

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1 Overview

We are specialized in producing thermally actuated *et*MEMS^{TM} at the in-house 150mm wafer fabrication facility located at Woburn headquarter. This capability allows us to reduce the fabrication cost through tight control of manufacturing yield and quality and continuously improve the performance of our MEMS-based products through the combination of design and process improvements. Moreover, we have developed vision-based automatic wafer testing tools that ensure each individual MEMS chip's dynamic performance and quality.

Conventional MEMS are based on electrostatic actuation that is prone to electrical charge build-up induced drift and moisture-induced electrical shorting requiring expensive hermetic sealing. Photonwares' MEMS is based on the electro-thermal driven actuation principle. Our unique etMEMS^{TM} design provides advantages for fiber optic components, including:

1. Large actuation force over mm
2. Low direct driving voltage <5V
3. A few fabrication steps, high yield
4. No need for a hermetic package
5. Intrinsic tolerance to EDS

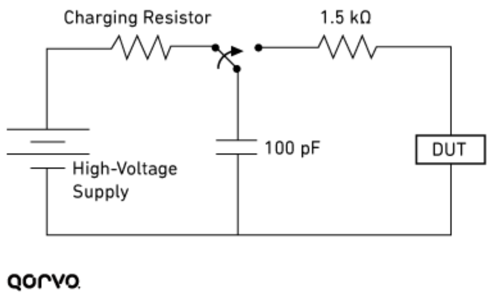
Our MEMS switches and VOAs are based on single crystal silicon, exceptional material that does not deform, fatigue, or wear out over time, and its dimensions and mechanical properties are immune to stress unless a critical fracture stress level or a permanent deformation high temperature is reached. Data results from testing show that Photonwares MEMS switches and VOAs still work within specifications after many billion cycles.

We have performed ESD tests using FSVOA chips which is an abbreviation of Free-Space Variable Attenuators, a family of MEMS mirror/shutter chips. This type of chip is also used in a variety of non-latching switches as an optical mirror. By intrinsic operation principle, the ESD qualification results of FSVOA is applicable to all families of *et*MEMS^{TM}. The FSVOA with 500um and 350um size of mirrors were selected for the qualification tests. By similarity, the other products of this family will be automatically qualified with this module, including all available configurations, wavelength range options, and input/output fiber and connector options.

2 ESD Model

Human Body Model (HBM) is applied to analyze the ESD (electric static discharge) about FSVOA type of MEMS devices. The common HBM is presented as below.

Human Body Model ESD Test & Classification Levels



Classification	Voltage Range (V)
0Z	<50
0A	50 to <125
0B	125 to <250
1A	250 to <500
1B	500 to <1000
1C	1000 to <2000
2	2000 to <4000
3A	4000 to <8000
3B	≥8000

Source: Industry Council on ESD Target Levels & JESD22-C101F

Figure 1: HBM in electricity

HBM (500V, 100pF, 1.5kΩ) is generally applied for the survivability test of ESD on MEMS devices.

FSVOA is purely resistive based on electric-thermal effect actuation, having the resistance ~70Ω at 4~5V operating voltage. Per the ohm rule, the voltage crossing two electrodes can be calculated as ΔV = 500Vx70Ω/(1.5kΩ+70Ω) ~ 22.3V.

In FSVOA, the minimum gap between the positive and negative electrodes over the entire chip is larger than 100um, having the potential strongest E-field < 0.23V/um, which is 40x smaller than 10V/um commonly considered as the potential of voltage break-down. So, the voltage break-down isn't an issue anymore in FSVOA.

The next possible damage is mechanical, caused by the high temperature due to the charge releasing ESD.

HBM(500V, 100pF, 1.5kΩ) stores the electricity energy **$E = CV^2/2 = 100\times10^{-12} \times (500V)^2/2 \sim 12.5uJ$** in total. Let's examine the temperature rising when all stored energy **12.5uJ** to be released to FSVOA fully.

3 Tests Performed

3.1 Case #1: 500um FSVOA (12/2013)

500um of FSVOA is the MEMS mirror, widely used in all fiber optic non-latching switches. The main specs of 500um FSVOA is 1) 4.5V driving voltage; 2) 70Ω resistance @ 4.5V; Maximum rating voltage is 6V.

Numerical Analysis:

- ❖ FSVOA can be fully activated by 4.5V in 5ms duration, requiring the necessary energy $E = 5ms \times (4.5V)^2/70\Omega \sim 1.45mJ$.
- ❖ Experimentally, the significant deformation of FSVOA was measured after 10minutes of 6V operation, while no impact of the FSVOA performance can be measured by applying 10seconds of 6V.
- ❖ Conservatively, the damaging heating criteria is set as 6V over 1s, meaning the necessary energy for damage $E > 1s \times (6V)^2/75\Omega \sim 480mJ$ by rising of temperature.

- ❖ Because the total electric energy ~12.5uJ charged in HBM is several orders smaller than that of damaging criteria in FSVOA, the charged electricity in HSM can't damage FSVOA at all.

Experiment Results: 13 samples were tested under HBM (500V, 100pF, 1.5kΩ). **None was failed and had the degradation of performances.**

3.2 Case #2: 350um FSVOA (11/11/2021)

350um of FSVOA is newly developed to have a high resonant frequency > 2.3kHz while keeping the most legacy of FSVOA performances. The main specs of 350um FSVOA are 1) 4.2V driving voltage; 2) 70Ω resistance @ 4.2V; Maximum rating voltage is 5.2V.

Numerical Analysis:

- ❖ FSVOA can be fully activated with 4.2V over 5ms duration, meaning the necessary energy of $E = 5ms \times (4.2V)^2/70\Omega \sim 1.45mJ$ for full mirror displacement.
- ❖ Experimentally, the significant deformation of FSVOA was measured after 10minutes of 5.2V operation, while no impact of the FSVOA performance can be measured by applying 10seconds of 5.2V.
- ❖ Conservatively, the potential damaging criteria are assumed as 5.2V over 1s duration, meaning the potential damage of energy $E > 1s \times (5.2V)^2/70\Omega \sim 386mJ$.
- ❖ Because the electric energy ~12.5uJ charged in HBM is several orders more minor than that of damaging criteria (386mJ) in FSVOA (350um), the charged electricity in HSM can't damage FSVOA at all.

4 Conclusion

The tests validated that *et*MEMS™ chips can sustain HBM (500V, 100pF, 1.5kΩ)**.**