UNIVERSITI TEKNOLOGI MARA

5th I-CReST 2025

INTERNATIONAL CONFERENCE ON RESEARCH AND PRACTICES IN SCIENCE, TECHNOLOGY AND SOCIAL SCIENCES

SYNERGY FOR FUTURE SUSTAINABILITY: BRIDGING SCIENCE, TECHNOLOGY AND HUMANITIES

Proceeding Book

UNIVERSITI TEKNOLOGI MARA
CAWANGAN SELANGOR, KAMPUS DENGKIL
MALAYSIA

13th SEPTEMBER 2025

ORGANISED BY: Centre of Foundation Studies

STRATEGIC PARTNER: UiTM Global

IN COLLABORATION WITH: UTM

I-CReST 2025: 082-046 – Investigation of Nickel and Gold-based RF MEMS Creep Deformation: Simulation Approach using NanoHub

Muhammad Danial Abd Aziz, Farah Liyana Muhammad Khir*

Faculty of Applied Sciences, School of Physics and Material Sciences, Universiti Teknologi MARA, Shah Alam, 40450 Shah Alam, Selangor, Malaysia.

*E-mail: farah668@uitm.edu.my

ABSTRACT

This study focuses on the investigation of the beam dimensions and electrical parameters on creep deformation in radio frequency microelectromechanical systems (RF MEMS) fixed beam switches. For RF MEMS, creep is a time-dependent deformation that occurs under sustained stress on the structure and represents a significant issue in the long-term reliability of MEMS devices operating under continuous applied voltage. The RF MEMS simulation was performed using the nanoHUB to monitor the behaviour of the RF MEMS creep on a constant voltage of 20 V with various structures where the beam thickness and initial air gap were varied. For the MEMS simulation, we focus on two materials, namely Nickel and Gold. The first investigation involved the variation of beam thickness from 1 µm to 5.45 µm, while keeping the initial gap constant. Whilst in the second investigation, the beam thickness was kept constant, and the initial air gap was varied from 0.9 µm to 5 µm. The result from the first investigation shows that Nickel demonstrates the lowest deformation when the beam thickness was 2 µm and the initial air gap was kept constant. The initial air gap is important as it determines the distance between the beam and the substrate, with shorter gaps leading to more deformation. In the second investigation, Nickel showed the lowest deformation when the beam thickness was constant, and the air gap was set to 2.5 µm. This research indicates that beam dimensions play a larger role in the creep behaviour of one material. It can also be concluded from both results that the material selection affects RF MEMS creep, as both deformation shows Nickel creep much faster than Gold due to its highest RF creep. For future recommendations, it is recommended to include different types of materials in this study to enhance understanding of the materials in RF MEMS creep.

Keywords: RF MEMS; nanoHUB; creep deformation; beam dimensions; applied voltage

1. INTRODUCTION

The MEMS have been undergoing rapid evolution and innovation, where they can be commonly seen as pressure and temperature sensors, accelerometers, gas chromatography, and other sensor devices [1-5]. The RF MEMS plays an important role in high-power components in modern electronics [6]. Integrating RF MEMS and Metal oxide semiconductor field-effect transistors (MOSFETs) is commonly preferred due to their high input resistance, voltage control, and fast switching characteristics. Precise electrical control and signal amplification are required for high-performance systems, making the performance of MEMS switches is highly valuable for managing high-frequency data with minimal power loss [7]. RF MEMS switches are widely recognised for their superior performance compared to traditional solid-state switching devices, such as PIN diodes and FETs. As mentioned in [8], MEMS switches outperform PIN diodes and FETs in microwave and millimetre-wave applications due to their superior linearity and low insertion loss. Likewise, [9] emphasized that MEMS switches offer advantages such as high isolation, low insertion loss, zero DC power consumption, low noise, enhanced linearity, and capability to operate up to millimetre-wave frequencies. These characteristics make RF MEMS preferable for reconfigurable microwave antennas, tunable filters, and satellite communication systems, where conventional technologies fall short in terms of size, power efficiency, and linearity.

Despite these advantages, creep deformation remains a significant issue, affecting longevity and reliability. Continuous mechanical and electrical stress leads to creep, reducing stiffness and increasing the risk of permanent damage. Nickel and Gold are highly prone to creep under high stress [10]. Creep can cause permanent deformation below the material yield strength, compromising device durability. Selecting the right materials and using robust design and modelling techniques is crucial to minimizing creep effects. In addition to material selection, long-term RF MEMS reliability often faces an issue particularly on the failure mechanisms due to metal creep, dielectric charging, stiction, and fatigue, particularly in metal-to-metal contact switches [9]. According to [9], creep is defined as the tendency of a material to deform or to move permanently to relieve stresses, resulting in a long-term reduction to levels of stresses due to material deformation, which are below the yield or final strength of the material. This issue is critical because it affects the long-term accuracy and mechanical behaviour of the MEMS switch, leading to loss of switching function.

Advanced simulation tools such as nanoHUB play a crucial role in enabling researchers to model material behaviour, evaluate structural reliability, and optimize the performance of RF MEMS devices. These platforms support detailed analysis of electromechanical interactions, including the effects of actuation voltage, beam geometry, and material selection on device operation. By simulating long-term mechanical stress conditions, nanoHUB facilitates the prediction and mitigation of creep deformation, ultimately enhancing the reliability and functional lifespan of RF MEMS components.

2. LITERATURE REVIEW

PIN diodes are integral components in RF and microwave circuits due to their ability to act as variable resistors. PIN diodes are ideal for use in RF switches, attenuators, and phase shifters, where low insertion loss and high linearity are required for maintaining the integrity of the signal. However, PIN diodes are larger in size and often require high reverse bias voltage to achieve the desired switching characteristics, making them less optimal for smaller, more compact devices [11]. These limitations of PIN diodes have driven the search for alternative technologies, such as RF MEMS, that can overcome these shortcomings while providing enhanced performance, smaller form factors, and reduced power consumption [9].

RF MEMS (Radio Frequency Microelectromechanical Systems) technology presents a more advanced and efficient solution for high-frequency applications. RF MEMS devices integrate both mechanical and electrical properties, offering more precise control over RF signals compared to traditional semiconductor-based devices like PIN diodes. RF MEMS devices such as switches, tunable capacitors, and resonators have emerged as promising alternatives to PIN diodes, offering several advantages like lower insertion loss [12], faster switching speeds [13] and higher isolation at high frequencies [14].

There are many alternative materials that have been under investigation for the development of the RF MEMS technology. Nickel and Gold are two common materials that are widely used as the main material for the RF MEMS switch. Nickel is a particularly suitable material for RF MEMS devices due to its strong mechanical, thermal, and electromagnetic properties. The material shows mechanical robustness with an ultimate strength of roughly 1.5 Gpa, five times greater than coarse-grained Nickel, offering improved durability for MEMS applications [15]. On the other hand, Gold is an outstanding material for RF MEMS applications due to its unique properties. Its excellent electrical conductivity, characterized by a resistance of roughly 2.4×10^{-8} Ωm, guarantees minimal contact resistance, which is crucial for dependable operation in RF switches and other MEMS components [16].

According to [15], the creep that causes slow deformation of materials can occur through various mechanisms depending on the properties of the materials and the operating conditions. Basically, creep deformation can be categorised in three stages: primary creep, secondary creep, and tertiary creep. Primary creep caused by a decrease in the strain rate due to material strengthening caused by dislocation movement [17-19]. Secondary creep is when the strain rate becomes constant as work hardening and thermal softening reach equilibrium [15][18][19]. Whilst tertiary creep, involves an accelerating strain rate that can lead to deformation.

Therefore, the study regarding the creep deformation through simulation is important to understand the parameters that are possible to cause a creep deformation, from the material selection, voltage applied, and the beam design (thickness and initial gap). By having a clear understanding on these parameters, an optimisation of the RF MEMS switch can be easily done upon the fabrication of the device.

3. METHODOLOGY

For this study, an openware simulation namely nanoHUB was used to investigate how RF MEMS experience creep deformation over time. The investigation in this study focuses material properties, beam dimensions, and electrostatic force inputs. Quantitative data were obtained from various studies, each contributing valuable insights into material behaviour, including creep response, mechanical properties, and deformation characteristics. Table 1 shows constant parameters to ensure that the consistency analysis focuses on the influence of material properties.

Table 1. The material properties of RF MEMS will be constant

	Value
The permittivity of free space (ε_o)	$8.85 \times 10^{-12}\ F/m$
Electrode length (l)	400 µm
Creep rate coefficient (1/hour) (A)	0.002
Voltage input	20 V

For the material selection, this study limits on the investigation of Nickel and Gold as main material. Table 2 and 3 shows parameters tested in the simulation nanoHub respectively.

Table 2. The parameters of Nickel materials tested in the simulation nanoHub

Types of work	Young's Modulus	Poisson ratio	Yield stress	Residual stress	Length	Thickness	Width	Initial Gap (g_0)
Simulation and modelling [20]	197.3 Gpa	0.3	0.7 Gpa	8.4 Mpa	500 µm	2 µm	120µm	5µm

Table 3. The parameters of Gold materials tested in the simulation nanoHub

Types of works	Young's Modulus	Poisson ratio	Yield stress	Residual stress	Length	Thickness	Width	Initial Gap (g_0)
Simulation and modelling [21]	98.5Gpa	0.42	75 Mpa	30.3 Mpa	457.8 µm	5.45 µm	84.3 µm	4.5 µm

3.1 Investigation of Beam Thickness on RF MEMS

The investigation on beam thickness was conducted to observe its effect on the creep deformation characteristics of RF MEMS devices. In this study, only the thickness of the beam was varied to examine how changes in this parameter influence the creep behaviour, as shown in Table 4. Thus, in this work, the applied voltages of 20V were used and were applied to the structure for 200 hours to monitor the resulting deformation.

Table 4. The variation of the thickness for Nickel and Gold used in this investigation

Nickel		Gold	
Types of work	**Initial Gap**	**Types of work**	**Initial Gap**
Simulation and modelling [20]	2 µm	Simulation and modelling [21]	5.45 µm
My work 1 [20]	1 µm*	My work [21]	2.73 µm*
Simulation and modelling [22]	4 µm	Simulation and modelling [25]	2 µm
My work 2 [22]	2 µm*	My work [25]	1 µm*
My work 3 [23][24]	3 µm*	My work [23][26]	6 µm*

** The parameters chosen to test the creep behaviour are based on the research paper.*

3.2 Investigation of the Initial Gap between the Beam and Substrate on RF MEMS

The investigation on the initial gap between the beam and substrate was conducted to monitor their effect on the RF MEMS creep deformation characteristic. In this study, only the initial gap was varied to examine how changes in this parameter influence the creep behaviour, as shown in Table 5.

Table 5. The variation of the initial gap for Nickel and Gold used in this investigation

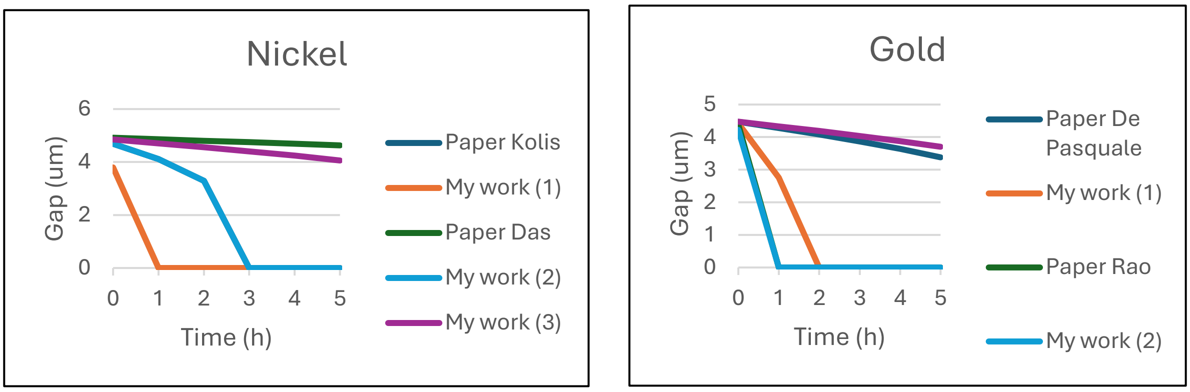
Nickel		Gold	
Types of work	**Initial Gap**	**Types of work**	**Initial Gap**
Simulation and modelling [20]	5 µm	Simulation and modelling [21]	4.5 µm
My work 1 [20]	2.5 µm*	My work [21]	2.30 µm*
Simulation and modelling [22]	1.8 µm	Simulation and modelling [25]	3.2 µm
My work 2 [22]	0.9 µm*	My work [25]	1.6 µm*
My work 3 [23][24]	4 µm*	My work [23][26]	5 µm*

* *The parameters chosen to test the creep behaviour are based on the research paper.*

4. RESULTS AND DISCUSSION

In this study, the aim is to establish how different factors such as the type of material, the thickness of the beam, and initial gaps affect the long-term deformation behaviour of these devices when a sustained voltage is applied.

4.1 Effect of Beam Thickness on RF MEMS Creep Deformation



(a) (b)

Fig. 1. The gap as a function of time with different beam thicknesses when applied with 20 V for (a) Nickel and (b) Gold

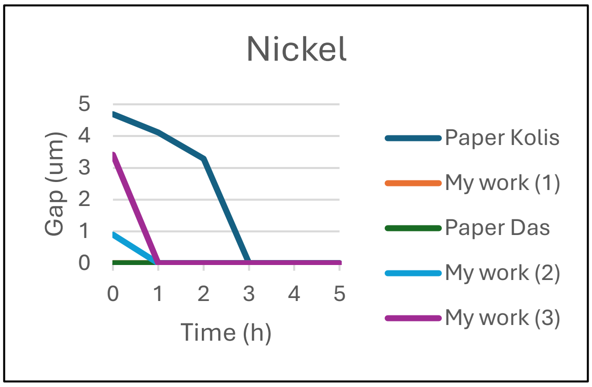
First, the creep deformation of Nickel and Gold beams with different thicknesses, all under a constant voltage of 20V and 40 V were analysed respectively. For Nickel (refer to Fig. 1 (a)), the results show that thinner beams deform faster. The 1 µm beam (My work (1)) collapsed completely within 1 hour, indicating rapid deformation. The 2 µm beam (Kolis, 2020) took about 4 hours to fully collapse. The 3 µm beam (My work (3)) deformed more slowly, with the gap reducing to 4.0583 µm after 5 hours. This trend confirms that increased thickness reduces deformation due to higher stiffness.

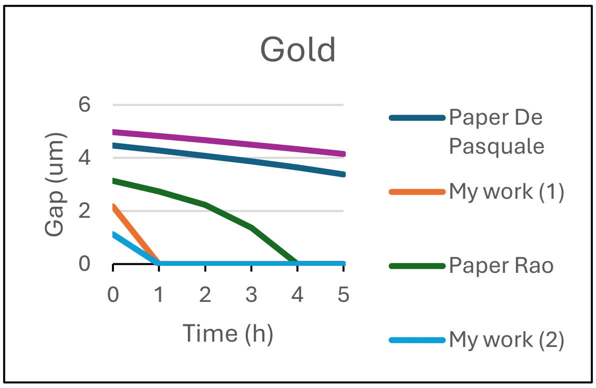
For Gold (refer to Fig. 1 (b), the deformation is generally slower than Nickel, showing better creep resistance. The 2 µm and 2.73 µm beams (My work (2) and My work (1)) reached 0 µm in 2 hours, slower than Nickel's 1 µm beam. The 5.45 µm beam (De Pasquale & Soma, 2011) showed a smaller gap reduction from 4.4699 µm to 3.38065 µm in 5 hours. The 6 µm beam (My work (3)) showed the slowest deformation, with the gap reducing to 3.70475 µm after 5 hours.

We suggest that thinner beams deform faster due to lower stiffness, and Nickel deforms more quickly than Gold due to its lower creep resistance. Thicker Gold beams provide the highest resistance to deformation, making material and thickness selection crucial for MEMS reliability under moderate voltages.

4.2 Effect of Initial Gap Between Beam and Substrate

The initial gap (g_0) between the beam and substrate is one of the possible factors in determining creep deformation in RF MEMS switches. The early hypothesis suggests that smaller gaps produce much stronger electrostatic forces, accelerating beam deflection and creep, while larger gaps result in weaker forces and slower deformation.





(a) (b)

Fig. 2. The gap as a function of time with different initial gaps between beam and substrate when applied with 20 V for (a) Nickel and (b) Gold

Fig. 2 shows an agreement with the earlier hypothesis where the simulation results for Nickel at 20V (refer to Fig. 2 (a), show that 0.9 µm gap (My work (2)), immediate creep occurs due to the high electrostatic force. At 2.5 µm (My work (1)), deformation was present, but slower creep deformation. Das et al. (1.8 µm) show similar behaviour as My work (1). Interestingly, for a bigger gap, i.e. 4.69 µm (Kolis), creep is significantly delayed, appearing only after 3 hours.

We observed a similar trend for Gold at 20V. For a 1.12 µm gap (My work (2)), the beam deforms rapidly, while 4.97 µm gap (My work (3)), the deformation is much slower. Although Gold is more ductile than Nickel, the initial gap dominates the creep behaviour, where smaller gaps lead to faster deformation due to stronger electrostatic forces. In terms of material behaviour, Nickel deforms faster at smaller gaps due to its stiffness and stronger response to the electrostatic force, despite being less ductile. However, Gold, while more ductile, shows slower creep at larger gaps, indicating that electrostatic force remains the dominant factor, especially at small g_0.

This investigation confirms that smaller initial gaps cause faster creep due to stronger electrostatic forces, while larger gaps slow down deformation. Nickel is more responsive at small gaps due to its stiffness, while Gold deforms more at larger gaps due to its ductility.

5. CONCLUSION

This study provided valuable insights into the creep deformation behaviour of Nickel and Gold in RF MEMS devices under a constant applied voltage of 20V. The results show that Nickel deforms faster than Gold due to its lower creep resistance, making it less suitable for long-term reliability. In contrast, Gold exhibited slower and more stable deformation, highlighting its superior performance for durable RF MEMS applications.

Additionally, beam thickness played a significant role at 20V. Thinner beams deformed more rapidly due to reduced stiffness, while thicker beams resisted creep more effectively, confirming that mechanical rigidity is key to controlling deformation. The initial gap between the beam and the substrate also influenced deformation; smaller gaps experienced greater deformation, while larger gaps provided improved mechanical stability. An understanding of how these parameters affect the mechanical behaviour of the RF MEMS could lead to optimized structural designs for better stability and performance.

ACKNOWLEDGEMENT

The authors would like to acknowledge the various resources and tools that have facilitated this research, including the nanoHUB Lab simulation platform. The accessibility and user-friendliness of these tools have been essential in conducting and completing this study.

REFERENCES

[1] G. M. Rebeiz, RF MEMS. Hoboken, NJ, USA: Wiley, 2003. doi: 10.1002/0471225282

[2] M. Esashi, "Revolution of Sensors in Micro-Electromechanical Systems," Japanese Journal of Applied Physics, vol. 51, no. 8R, p. 080001, 2012. doi: 10.1143/JJAP.51.080001

[3] Y. Tanaka, "Recent advancements in physical and chemical MEMS sensors," The Analyst, vol. 149, no. 13, pp. 3498–3512, 2024. doi: 10.1039/D4AN00182F

[4] R. Bogue, "MEMS sensors: past, present and future," Sensor Review, vol. 27, no. 1, pp. 7–13, 2007. doi: 10.1108/02602280710729068

[5] J. Bryzek, S. Roundy, B. Bircumshaw, C. Chung, K. Castellino, J. R. Stetter, and M. Vestel, "Marvelous MEMs," IEEE Circuits and Devices Magazine, vol. 22, no. 2, pp. 8–28, 2006. doi: 10.1109/MCD.2006.1615241

[6] H.-H. Yang, H. Zareie, and G. M. Rebeiz, "A High Power Stress-Gradient Resilient RF MEMS Capacitive Switch," Journal of Microelectromechanical Systems, vol. 24, no. 3, pp. 599–607, 2015. doi: 10.1109/JMEMS.2014.2335173

[7] A. P. De Silva et al., "Motorola MEMS switch technology for high frequency applications," in Proc. 2001 Microelectromechanical Systems Conf., 2001, pp. 22–24. doi: 10.1109/MEMSC.2001.992733

[8] J. F. Martins Filho, 2015 SBMO/IEEE MTT-S Int. Microwave and Optoelectronics Conf., Porto de Galinhas, Brazil, Nov. 3–6, 2015. Piscataway, NJ, USA: IEEE, 2015.

[9] V. Bhatia, S. Kaur, K. Sharma, P. Rattan, V. Jagota, and M. A. Kemal, "Design and Simulation of Capacitive MEMS Switch for Ka Band Application," Wireless Communications and Mobile Computing, vol. 2021, pp. 1–9, 2021. doi: 10.1155/2021/2021513

[10] S. Das, S. R. Mathur, and J. Y. Murthy, "Finite-Volume Method for Creep Analysis of Thin RF MEMS Devices Using the Theory of Plates," Numerical Heat Transfer, Part B: Fundamentals, vol. 61, no. 2, pp. 71–90, 2012. doi: 10.1080/10407790.2012.646170

[11] G. D. Patil and N. R. Kolhare, "A Review Paper on RF MEMS Switch for Wireless Communication," Int. J. Eng. Trends Technol., 2013. [Online]. Available: http://www.internationaljournalssrg.org

[12] T. Purtova and H. Schumacher, "Overview of RF MEMS technology and applications," in Handbook of MEMS for Wireless and Mobile Applications. Cambridge, UK: Elsevier, 2013, pp. 3–29. doi: 10.1533/9780857098610.1.3

[13] T. G. S. M. Rijks et al., "MEMS tunable capacitors and switches for RF applications," in Proc. 24th Int. Conf. Microelectronics (ICMEL), 2004, pp. 49–56. doi: 10.1109/ICMEL.2004.1314557

[14] A. Q. Liu, A. B. Yu, M. F. Karim, and M. Tang, "RF MEMS Switches and Integrated Switching Circuits," J. Semicond. Technol. Sci., vol. 7, no. 3, pp. 166–176, 2007. doi: 10.5573/JSTS.2007.7.3.166

[15] H. H. Hsu, M. Koslowski, and D. Peroulis, "An experimental and theoretical investigation of creep in ultrafine crystalline nickel RF-MEMS devices," IEEE Trans. Microw. Theory Techn., vol. 59, no. 10, pp. 2655–2664, 2011. doi: 10.1109/TMTT.2011.2163727

[16] J. G. Noel, "Review of the properties of gold material for MEMS membrane applications," IET Circuits, Devices and Systems, vol. 10, no. 2, pp. 156–161, 2016. doi: 10.1049/iet-cds.2015.0094

[17] S. Ghosh, "Analysis of Creep Deformation," Preprints, 2024. doi: 10.20944/preprints202412.1894.v1

[18] A. Somà, M. M. Saleem, and G. de Pasquale, "Effect of creep in RF MEMS static and dynamic behavior," Microsystem Technologies, vol. 22, no. 5, pp. 1067–1078, 2016. doi: 10.1007/s00542-015-2469-8

[19] Y. Zhang, J. Sun, H. Liu, and Z. Liu, "Modeling and Measurement of Thermal–Mechanical-Stress-Creep Effect for RF MEMS Switch up to 200 °C," Micromachines, vol. 13, no. 2, p. 166, 2022. doi: 10.3390/mi13020166

[20] P. A. Kolis, Quantification of Uncertainty in the Modeling of Creep in RF MEMS Devices: A Dissertation, 2020.

[21] G. De Pasquale and A. Soma, "MEMS Mechanical Fatigue: Effect of Mean Stress on Gold Microbeams," Journal of Microelectromechanical Systems, vol. 20, no. 4, pp. 1054–1063, 2011. doi: 10.1109/JMEMS.2011.2160044

[22] S. Das, M. Koslowski, S. R. Mathur, and J. Y. Murthy, "Finite Volume Method for Simulation of Creep in RF MEMS Devices," in Proc. ASME IMECE, 2011, vol. 11, pp. 119–128. doi: 10.1115/IMECE2011-62660

[23] G. Guisbiers et al., "Materials selection procedure for RF-MEMS," Microelectronic Engineering, vol. 87, no. 9, pp. 1792–1795, 2010. doi: 10.1016/j.mee.2009.10.016

[24] H. H. Hsu, M. Koslowski, and D. Peroulis, "An experimental and theoretical investigation of creep in ultrafine crystalline nickel RF-MEMS devices," IEEE Trans. Microw. Theory Techn., vol. 59, no. 10, pp. 2655–2664, 2011. doi: 10.1109/TMTT.2011.2163727

[25] K. S. Rao et al., "Design, Modeling and Analysis of Perforated RF MEMS Capacitive Shunt Switch," IEEE Access, vol. 7, pp. 74869–74878, 2019. doi: 10.1109/ACCESS.2019.2914260

[26] A. Somà, G. De Pasquale, and M. M. Saleem, "Experimental investigations of creep in gold RF-MEMS microstructures," in Proc. SPIE 9517, Micro- and Nanotechnology Sensors, Systems, and Applications VII, 2015, p. 95170H. doi: 10.1117/12.2181071