Journal of Engineering Science and Technology Review 15 (SI) (2022) 67 - 70
Special Issue in honor of Prof. T. Tanaka

JOURNAL OF
Engineering Science and Technology Review

www.jestr.org

Research Article

Study of the Behavior of Water Droplets under the Influence of a Uniform Electric Field on Samples of Borosilicate Glass

Ioannis Baroutis[1], Michael G. Danikas[1,*] and Ramanujam Sarathi[2]

[1]Democritus University of Thrace, School of Engineering, Department of Electrical and Computer Engineering, Xanthi 67100, Greece
[2]Indian Institute of Technology Madras, Department of Electrical Engineering, High Voltage Laboratory, Chennai 600 036, India

Received 1 March 2019; Accepted 2 April 2021

Abstract

This paper investigates the behavior of water droplets on the surface of borosilicate glass samples. Borosilicate glass is used in MEMS and this is due to its special properties, such as its excellent insulating property, its inertness to most chemical substances, its easy connection to silicon and its optical permeability. In this paper, water droplet conductivities and wet etched borosilicate glass samples– are investigated. It seems that droplet conductivity plays a dominant role in determining the flashover voltage of the aforementioned samples.

Keywords: microelectromechanical systems (MEMS), borosilicate glass, flashover voltage, surface discharges, water droplets, water conductivity

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1. Introduction

Microelectromechanical Systems (MEMS) are systems and devices that are built in mincrometer dimensions. The term comes from the USA although in Europe such systems are referred to also as MicroSystems Technology (MTS) and in Japan as Micromachines. The development of techniques for the construction of semiconductors and more generally of electrical circuits at the level of micrometers or even of nanometers has led to a revolution for the developments of the integrated circuit (IC) industry. Such miniaturization gave an immense boost to micromechanical, mincromagnetic, microfluidic and microchemical fields [1].

Generally speaking, MEMS are consisted of mechanical microstructures, microactuators, microenergizers and microelectronics, all of them combined in silicon chips. MEMS are very small and they are visible only with the aid of a microscope. Their dimensions start from 1 μm. During the past decades there were publications in which several MEMS devices have been presented [2-4]. Important elements in there functioning are the transduction mechanisms. The latter are the physical processes which transform various signals from one form of energy to another form of energy [5].

The choice of materials for MEMS depends on many economic and technical factors. Evidently, the aim is always the improvement of the performance and the reduction of costs [6]. Silicon (Si), silicon dioxide (SiO_2), metals, among them, aluminum (Al), titanium, (Ti), palladium (Pd), nickel (Ni), copper (Cu), polymers and ceramics (silicon nitrates Si_3N_2, aluminum nitrates AlN and titanium nitrates (TiN) are some of the most important materials used for MEMS [6]. Conventional processing techniques for the manufacturing of MEMS are thick photoresists, grayscale lithography and deep reactive ion etching (DRIE) [7-9]. Further processing techniques developed for the manufacturing of MEMS, such as surface micromachining, bulk micromachining and lithography plating and molding, have also been reported [9-12].

MEMS applications include, among others, pressure sensors, chemical sensors, inertial sensors [5], microfluidics [13], inkjet printers, radio frequency and GPS technology as well as microgrippers [14].

2. Borosilicate glass

Borosilicate glass has a smooth surface, is non-flammable, transparent, inert and it presents excellent chemical stability. Generally, it has very good chemical resistance to acids, halogens, alkalis and organic substances. Its basic difference from other types of glasses (e.g. quartz) is that it also contains borium oxide (B_2O_3). It has a small thermal expansion coefficient, which is very close to the thermal expansion coefficient of silicon. This in turn allows a bonding between glass and silicon thus increasing immensely its usability for MEMS microprocessing [15]. Borosilicate glass is generally fragile and the main factors determining its mechanical strength are surface cracks, cavities and other surface alterations. Surface cracks of even 5 to 10 μm depth – from an intense thermal stressing - may cause its collapse [16, 17].

Borosilicate glass is transparent, colorless and permeable to the visible light. It allows the transmission of ultraviolet radiation to a greater extent than a simple glass and thus it can be used for photo-chemical reactions [16]. It has been proven that annealing at the right temperature may increase the etch rate of borosilicate glass [18]. Under normal conditions, borosilicate glass has very good insulating properties with an ohmic specific resistivity of 10^{15} Ω.cm. Its surface ohmic resistance an environment without humidity is 10^{15} / cm^2. Breakdown of borosilicate glass may result either from a purely electric cause or from an excessive localized increase of temperature. Borosilicate glass is better from an

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[*] E-mail address: mdanikas@ee.duth.gr

ISSN: 1791-2377
doi:10.25103/jestr.147.10

electrical point of view than silicone for MEMS for microfluidics and for biomedical applications [19].

Borosilicate glass is ideal for microfluidics as well as for biomedical and biochemical applications because of its biocompatibility. It can also be used for wafer level packaging (WLP) and for chip scale packaging (CSP) [15, 20, 21]. In [18, 22-25] details are given as to the various processing techniques of borosilicate glass together with their respective advantages and disadvantages.

One of the problems facing borosilicate glass is the flashover phenomenon. In the context of this paper, experimental results will be presented and discussed regarding the flashover performance of borosilicate glass samples which have been subjected to wet etching with KOH and NaOH.

3. Experimental details

The samples were of rectangular shape (7,45 x 2,1 cm) with a 1 mm thickness. Before the wet etching, care was taken into to clean the samples from pollution particles. The samples were cleaned at first with isopropanol alcohol and then with water and with the aid of ultrasound sonicator. After that the samples were put into a hot air oven. It has to be noted that with wet etching no particular design/arrangement on the borosilicate glass sample was created. Twenty samples were subjected to wet etching with solutions of KOH and NaOH of various concentrations, ten samples were etched with a solution of KOH (from 10% up to 100%) and ten samples were etched with a solution of NaOH (also from 10% up to 100%). The various samples were characterized from the type and the concentration of the solution, e.g. a “20% KOH sample” means that the sample was subjected to wet etching with a solution of 20% KOH concentration. The purpose of this paper is to investigate the influence of KOH/NaOH concentration on the roughness of the surface and its behavior w.r.t flashover phenomena.

The electrode arrangement was a uniform electrode arrangement described in [26-28]. Two half cylindrical electrodes made of copper with rounded edges created a uniform electric field (Fig. 1). No sharp points were allowed on the surface of the electrodes. The water conductivities investigated were 1.4 μS/cm, 100μS/cm, 200 μS/cm, 500 μS/cm, 1000 μS/cm, 2000 μS/cm, 5000 μS/cm and 10000 μS/cm. The conductivity measurements were performed with the aid of an electronic measuring device of conductivity of Type WTW inoLab cond Level 1 with a probe WTW Tetracon 325. Because of the hydrophilicity of the borosilicate glass samples and the restricted dimensions of the samples, only one droplet was put at a time on the sample surface. The droplet volume was 0.025 ml. Larger droplet volumes could not be put on the sample surface since there was an easy deformation and breakup of the droplet even before the application of the voltage. The distance between the electrodes was 2.5 cm.

The high voltage was supplied by a 100 V/ 20 kV transformer. After positioning the droplet on the glass surface, the voltage was slowly raised until flashover occurred. After that and after cleaning the surface and positioning a new droplet on it, the voltage was raised up to the previous flashover value minus 1.2 kV, so that no new flashover would occur. At this voltage value, the arrangement would stay for 5 min. If no flashover occurred, the voltage was raised by 0.4 kV and the procedure was repeated until flashover occurred. The new flashover value was recorded (Fig. 2). The reason for allowing the voltage for 5 min at each voltage level was because a certain time was required for the droplet to deform and for the PD to start leading finally to a flashover. Since we had 20 glass samples and 8 different water conductivities, we had the total of 160 measurements. Figs. 3-8 show indicative results of the variation of flashover voltage with water droplet conductivity for some borosilicate glass samples.

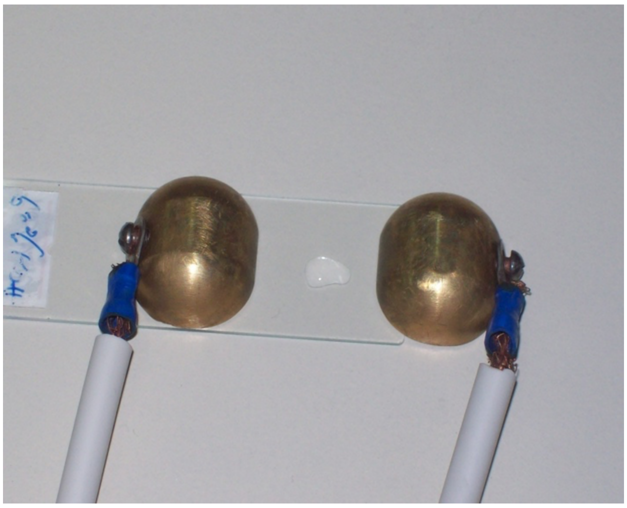

Fig. 1. Electrode arrangement with a water droplet on a borosilicate glass sample.

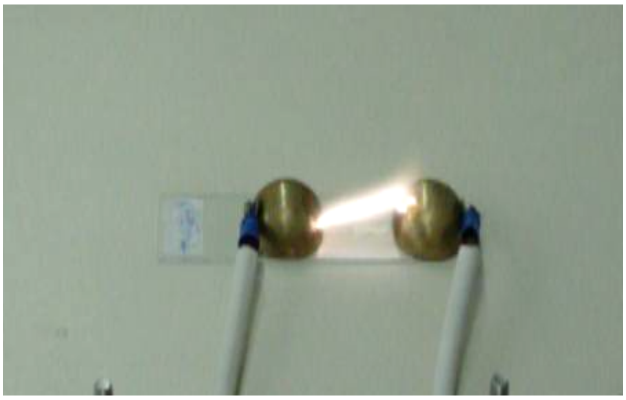

Fig. 2. Air flashover in a borosilicate glass sample.

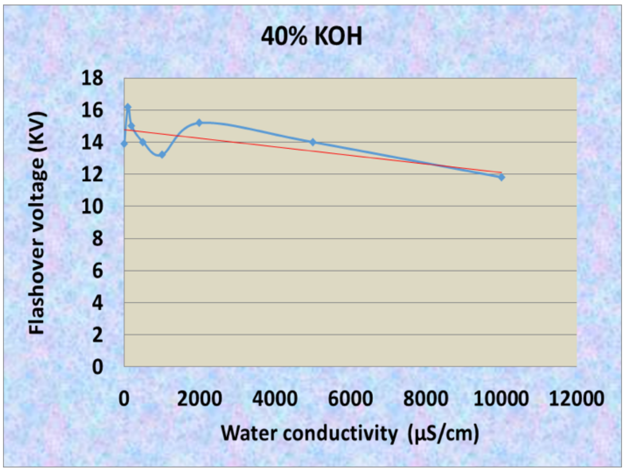

Fig. 3. Flashover voltage variation with water droplet conductivity for a 40% KOH sample.

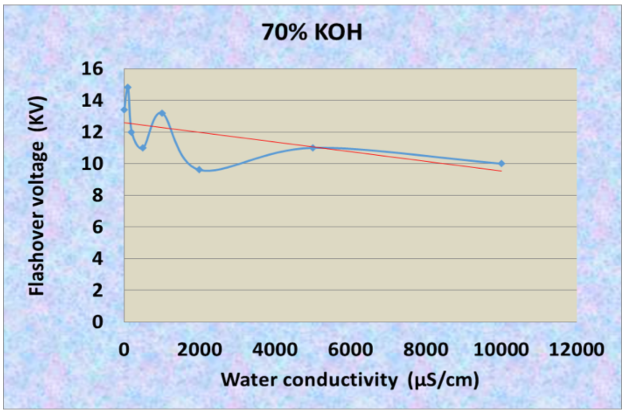

Fig. 4. Flashover voltage variation with water droplet conductivity for a 70% KOH sample.

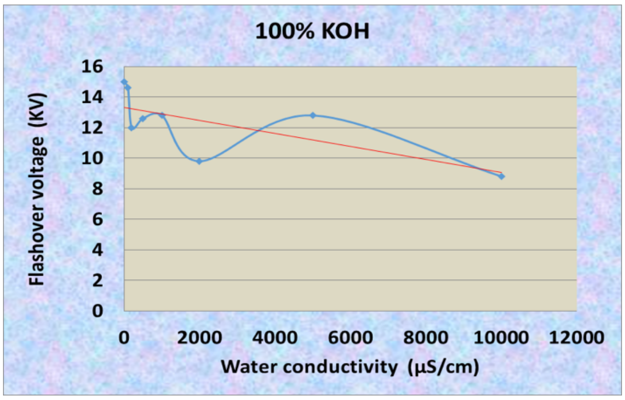

Fig. 5. Flashover voltage variation with water droplet conductivity for a 100% KOH sample.

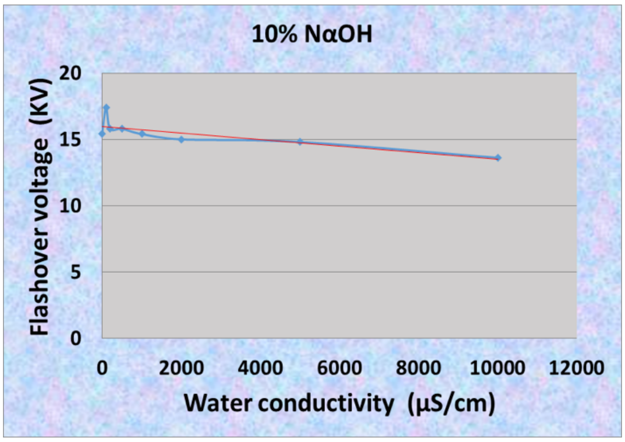

Fig. 6. Flashover voltage variation with water droplet conductivity for a 10% NaOH sample.

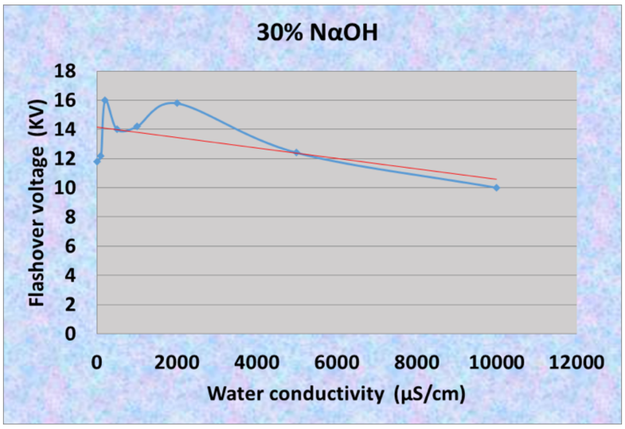

Fig. 7. Flashover voltage variation with water droplet conductivity for a 30% NaOH sample.

4. Discussion

Previous studies have shown that water conductivity affects the flashover voltage on an insulating surface [29, 30], i.e. with increasing conductivity the flashover voltage decreases. There is, however, a number of borosilicate glass samples which does not obey the aforementioned rule. In some samples it was observed an increase of flashover voltage was noted with increasing water conductivity, whereas in other samples the flashover voltage was about constant with increasing conductivity [31]. This may be due to the fact that we had relatively few measurements, bearing in mind that flashover is an inherently statistical phenomenon [32, 33]. Sample roughness does not seem to affect the flashover voltage, although surface roughness - generally speaking - renders droplet deformation more difficult and thus results in a higher flashover voltage. It is possible that remnants of alkalis from the wet etching on the sample surface might have played a role since no reference was made from the supplier of a specific cleaning procedure of the samples [34]. It is possible that such remnants may have played a decisive role in the experimental results. It is well known that such remnants may influence the conductivity of the sample [35]. It is also known that the position of the droplet w.r.t. the electrodes influences the flashover voltage [26-28, 30, 36], and since a positioning of the droplet exactly in the middle of the distance between the electrodes was impossible, the latter may have affected the experimental results.

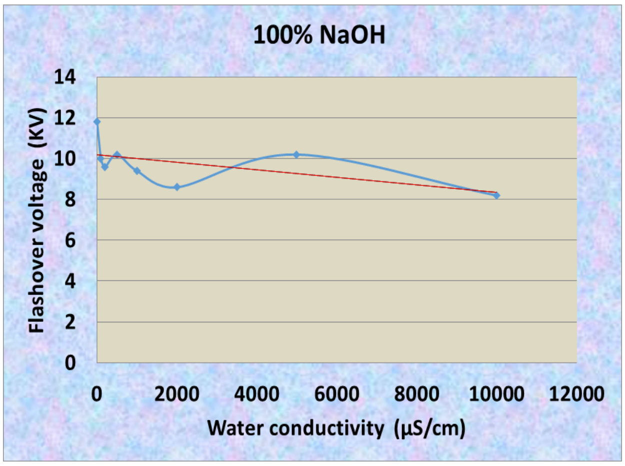

Fig. 8. Flashover voltage variation with water droplet conductivity for a 100% NaOH sample.

5. Proposals for future work

The general trend of the results indicates a dependence of the flashover voltage on water droplet conductivity on a smooth surface, such as that of borosilicate glass sample. Since there is a question regarding the samples showing an occasional upward trend of flashover voltage with water droplet conductivity, further research is suggested with emphasis on many more measurements and a statistical analysis of the data.

6. Conclusions

In the context of this work, some results were presented regarding the variation of flashover voltage with water droplet conductivity. Although the general trend for most of the samples is a downward one with increasing water conductivity, there were some exceptions. These are probably due to the presence of remnants of alkalis from the wet etching.

Acknowledments

The authors thank Prof. V. Madhurima of Mizoram University, India, for the supply of the borosilicate glass samples and Dr. Debarun Dhar Purkayastha for supplying information regarding the preparation of the aforementioned samples.

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