Investigation of dielectric degradation in capacitor simulating structures by Kelvin Probe Force Microscopy

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This paper presents a method to characterize the surface potential of poly(methyl metacrylate) (PMMA) as a dielectric in a two-dimensional capacitor structure using Kelvin Probe Force Microscopy (KPFM). In this paper the surface potential of an unbiased, in-plane capacitor structure is mapped, which could be used to distinguish between contact potential and applied potential when investigating the potential distribution of a biased capacitor structure.

Introduction

Capacitors represent a high percentage of failures in e.g. power electronic devices [1]. One of the degradation mechanisms in metallized film capacitors is the electric field induced degradation of the dielectric. One sign of this degradation is a generation of charge traps in the polymer, which reduces its electric resistance [2]. This change could in theory be detected by using KPFM on a simplified capacitor structure.

KPFM is a method based on scanning probe microscopy, which is mostly used in connection with atomic force microscopy (AFM). It measures the electrostatic force between a metal-coated AFM tip and the sample and from that it outputs the surface potential distribution of the scanned area [3]. This method has the advantages that both high spatial and voltage resolutions are obtainable, the method is non-destructive with respect to the surface due to the lack of contact between the surface and the probe, and it can be conducted on poorly conducting materials, such as polymer films.

The electrostatic force between the metal-coated tip and the sample is composed of three parts: a static DC part, a part at frequency ω and one at 2ω. The contribution at frequency ω can be nullified by applying a DC voltage corresponding to the sum of the contact potential and applied potential [4]. It is therefore relevant to know the contact potential of the structure before applying a voltage across the capacitor structure.

Materials and methods

The two-dimensional capacitors were fabricated on glass substrates. The metallization grid consists of a 130 nm thick aluminum film applied through a mask on the glass substrate. The geometry of the metallization is shown in figure 1, which also shows the five deliberately placed defects between some of the lines.

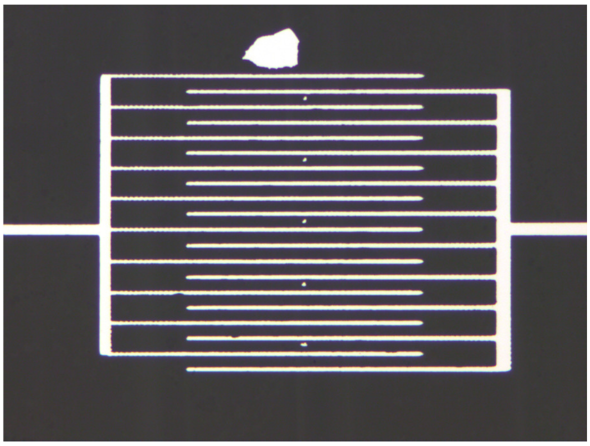

Figure 1: *Electrode geometry of the capacitor structure. The interleaving lines are roughly 8 µm wide and separated by 17 µm.*

A 2% (by weight) solution of PMMA in chlorobenzene was then spin-coated on to the substrate with the metallization at 2000 rpm for one minute. This yielded a film thickness of 150 nm.

Topography and surface potential measurements were performed on an atomic force microscope (AFM) from NTEGRA in Kelvin probe mode. One side of the capacitor structure was grounded. A cantilever with a platinum-coated tip was used. The scanned areas were 50 by 50 µm. The topography and surface potential distribution were obtained through a two-pass method, where the same line is scanned twice. The first scan measures the surface topography of the line. The second scan uses the topography obtained from the first scan to keep a distance of 20 nm to the surface, when measuring the surface potential.

Results and discussion

An image of the surface topography is shown in figure 2. It shows that the spin-coated PMMA film adopts the shape of the substrate, which makes it possible to identify the areas of the film that is above the electrode grid. The height difference between these areas and the areas without metallization is 60 nm. The sharp peaks are aluminum leftovers from the lift-off process during fabrication.

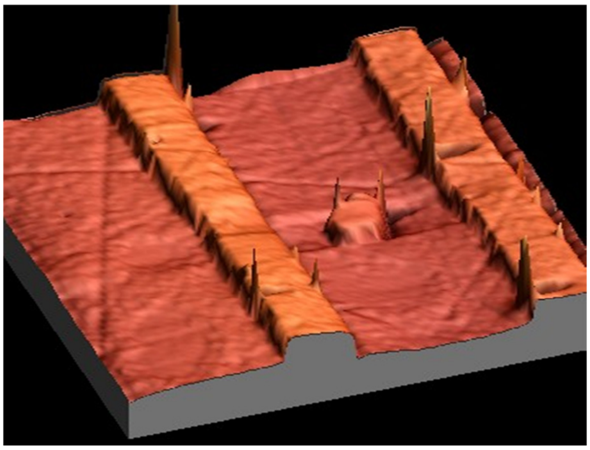

Figure 2: *Surface topography of the capacitor structure spanning two of the electrodes and one defect.*

The surface potential of the same area is shown in figure 3. Here it is seen that the presence of the metallization underneath the PMMA film significantly lowers the surface potential.

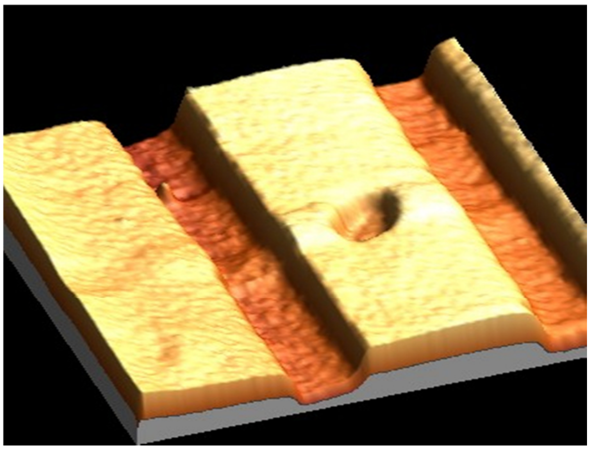

Figure 3: *Surface potential distribution of the scanned area.*

The surface potential drop is 130 mV at the left line, 170 mV at the right line, and 110 mV at the defect. This difference can be explained by the fact that only the electrode to the right was grounded. When measuring above a grounded electrode the system acts as a single capacitor. However, when measuring above the other electrode, the system is characterized as two capacitors in series, resulting in a lower capacitance.

Conclusion

Through KPFM measurements it was shown that there is a significant difference in contact potential on the PMMA film when measuring above the aluminum electrodes and when measuring above plain glass. The results indicate that in order to characterize the potential distribution in a capacitor structure using KPFM the contact potential must be taken into account.

References

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