Research Proposal

Submitted to the chair of the DEIS education committee by

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2013 DEIS graduate fellowship

Patterned high-k metal oxide dielectric films for plastic electronic circuits

Abstract

Electronics is rapidly changing from the original bulky and heavy devices to smart and light weight mobile appliances. Plastic electronic opens new avenues and produces low cost, low weight, flexible, and high volume production compatible solutions. Materials required for manufacturing plastic electronics include conductors, semiconductors, and dielectrics. Much effort is spent on the development of organic semiconductors, whereas less efforts are devoted to the investigation of dielectric materials. Dense high-k films, processed on flexible and highly elastic substrates are required for the production of large area integrated circuits, sensors, and actuator systems. Currently, no practical method is available to achieve this goal. In my PhD project, I work within an interdisciplinary team of researchers, from physics, chemistry, and electrical engineering on the development of a structuring tool for highly reliable insulating oxide layers. So far structuring of aluminium thin films on flexible plastic substrates has been achieved. In the proposed project, I intend to take this idea to new grounds by showing the preparation of important components in flexible electronic devices, such as resistors, inductors, capacitors, and field-effect transistors by direct writing of insulating oxide layers.

MOTIVATION AND STATE OF THE ART

Dielectric layers are a key element in every electronic circuit. Numerous ways of fabricating and patterning dielectric layers for flexible organic electronics have been proposed up to this point [1–4]. The most promising one, used as the basis of this work, is the growth of insulating oxides by electrochemical anodisation [5–8]. Hassel et al. proposed a scanning droplet cell microscope (SDCM) for local anodisation and Mardare et al. showed the patterning possibilities of this versatile device [9, 10]. In my PhD project, I have combined the knowledge of my

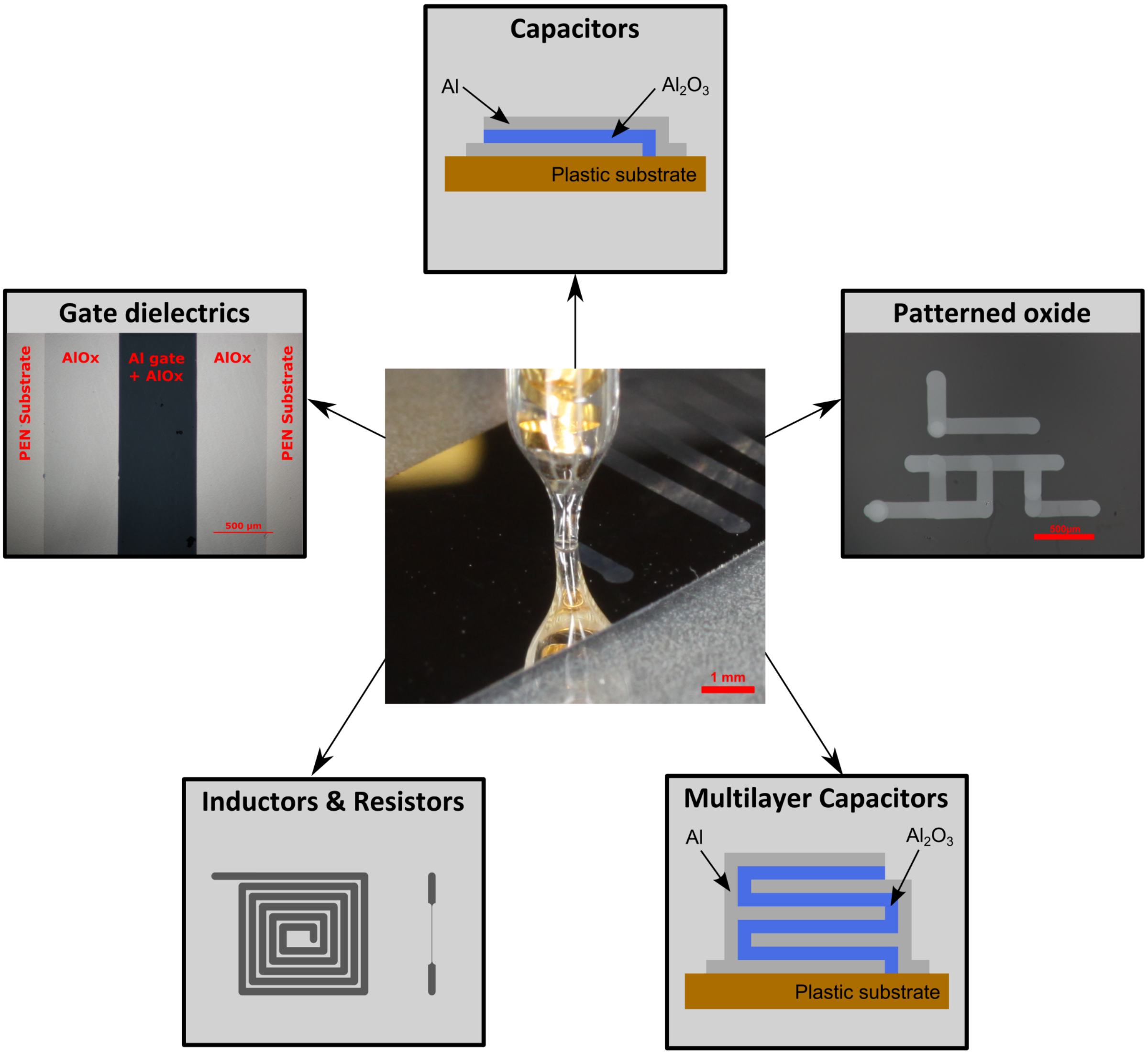

Figure 1 – Applications and possibilities in flexible electronics for the scanning droplet cell microscope (SDCM).

supervisors Prof. Siegfried Bauer and his group about processing on polymer substrates with the knowledge about the SDCM from Prof. Achim Walter Hassel and his team and developed a way of structuring nm-thick aluminium oxide layers on flexible plastic substrates by direct writing with the SDCM, recently published in Electrochimica Acta [11]. By bringing this two fields from physics and chemistry together it is possible to fabricate oxide layers which exhibit excellent dielectric properties with a dielectric constant of 10 and leakage currents in the range of $1\,nA \cdot cm^{-2}$. The central picture in Figure 1 shows the glass capillary of the SDCM while writing anodised aluminium oxide lines on a flexible polyethylene naphthalate (PEN) plastic substrate, together with application schematics. In the further development of my PhD work the basic structures shown in Figure 1 will be implemented in practical devices in cooperation with the electrical engineering groups of Profs. Takao Someya and Tsuyoshi Sekitani in Tokyo. Currently, this versatile anodisation technique is used as a way of patterning electronics on flexible plastic substrates which could possibly be included in reel-to-reel processing.

Now it is desirable to further explore the structuring possibilities of this technique, for manufacturing basic circuit elements like resistors, capacitors, inductors, and transistors.

INTENDED RESEARCH GOAL

I have chosen to focus my research on flexible electronics, particularly the fabrication and structuring of high quality insulating oxide layers for gate and floating gates in field-effect devices. Nowadays, the demand for mobile and adaptable electronic devices is increasing. Companies are looking intensely for ways to make electronics large scale, cheap, lightweight, easy to process, and even flexible or stretchable. To fulfill this needs completely new avenues for electronics have to be found.

In my research I will show that the SDCM is a platform that enables the fabrication of all basic circuit elements required in plastic electronic circuits (resistors, capacitors, and inductors). Besides the passive components, also high quality dielectric layers for organic field effect transistors (OFETs) are provided. Furthermore, the fabrication of capacitors with high capacitance per area is intended to meet the needs of flexible electronic circuit design.

In this project inductors, capacitors, and resistors circuit elements on flexible PEN substrates will be fabricated by patterning with the SDCM, as illustrated in Figure 1. Electrical characterisation of the circuit elements will reveal the performance of the fabricated dielectric layers. A second goal is the fabrication of capacitors with high capacitance per area, since this increases the integration degree in flexible electronic circuits. This goal is achieved by fabrication of multilayer structured capacitors. Finally, I will combine the elements shown in Figure 1 in an LRC circuit to demonstrate the wide application potential of the technology.

WORK PROGRAM

In my project I will develop ways of manufacturing basic circuit components on flexible substrates with the SDCM.

In the first part of the proposed project resistors, capacitors, and inductors will be manufacture and characterised with $I-V$ measurements and impedance spectroscopy. Figure 1 shows a schematic drawing of the intended thin film resistors, inductors, and capacitors. Aluminium is chosen as material since its oxide has a relatively high dielectric constant of $8-10$, shows good anodisation properties, and is already intensely used for anodisation at our department [8]. The resistance of the resistor stripe will be trimmed by anodisation. By writing full oxide on the fringes of the stripe or an oxide layer on top of it, it becomes possible to adapt the lateral width of the stripe and the thickness of the film, respectively. This allows to change its resistance as required. Capacitors will be manufactured by fabrication of metal-insulator-metal (MIM) structures. In a next step all this circuit elements will be put together to form a full working oscillating circuit consisting of all three basic circuit elements. For this purpose the knowledge gained by investigating the single components will be used. First promising results of capacitors and gate dielectrics for OFETs have been submitted to the Siemens VAI-IEEE Student

Paper Contest 2012 and received a Best Paper Award. Furthermore, a poster about the technique presented at the 9th International Symposium on Electrochemical Micro & Nanosystem Technologies 2012 received a Best Poster Award.

The second part of the project is focused on the fabrication of capacitors with high capacitance per area. To achieve this goal, a multilayer stack of parallel capacitors will be processed, as depicted in the respective picture of Figure 1. First experiments with a four layer system have already yielded $2\,\mu F \cdot cm^{-2}$, which is expected to be improved further by adding more layers and changing the dielectric layer thickness.

The patterning technique via the SDCM has potential application not only in flexible electronics. It may also be interesting for biomedical and capacitive sensing. The high quality oxide layers written by the SDCM are cheap, lightweight, and prone to mass production. Results of my work will be published in IEEE periodicals and other high impact journals. I will also present my results at annual CEIDP meetings.

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