Development of GaN-based Nanosensors using Surface Charge Lithography

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Abstract **– Semiconductor nanotechnology is a fast developing branch of modern engineering that offers perspectives for the development of electronic devices with superior parameters. A special and important niche in nanotechnology is allocated to the fabrication of nanosensors which are expected to exhibit higher sensitivity in comparison with classical microelectronic sensors. Various aspects of fabrication of GaN based nanosensors using Surface Charge Lithography are discussed and preliminary tests for gas sensors applications are presented.**

Index Terms **– GaN, nanostructuring, surface charge lithography, sensors.**

I. INTRODUCTION

GaN and related ternary alloys became important materials for UV light emitting devices and for high-temperature high-power electronics. MBE, MOCVD and HVPE have been developed for the epitaxial growth of these materials. A strong impetus to the development of device structures based on GaN was given by the implementation of AlGaN/GaN interface, leading to the fabrication of 2DEG FETs capable to operate at GHz frequencies with low noise and high gain parameters [1]. The development of GaN-based bipolar transistors is unfortunately limited by poor p-type doping, that is why Schottky and field effect devices became the most intensive developed electronic elements on this material [2].

An important and challenging property specific to III-group nitrides is their chemical stability. In this connection processing of the materials involved require usually high energy particles, e.g. reactive ion etching techniques instead of wet chemical treatment. This leads to the creation of surface defects which diminish the performance of the fabricated devices. An alternative technique, called Surface Charge Lithography, for meso- and nanostructuring of GaN was developed by our group over the last years [3-5]. This is a maskless technique that offers the possibility to fabricate GaN-based structures with dimensions less than 100 nm by direct ‘writing’ in a controlled fashion by the focused ion beam with subsequent photoelectrochemical etching of the sample. The role of ion beam treatment is to induce surface negative charge that shields the material against photoelectrochemical etching. The potential application of the fabricated structures by this method is demonstrated for FETs and gas sensors.

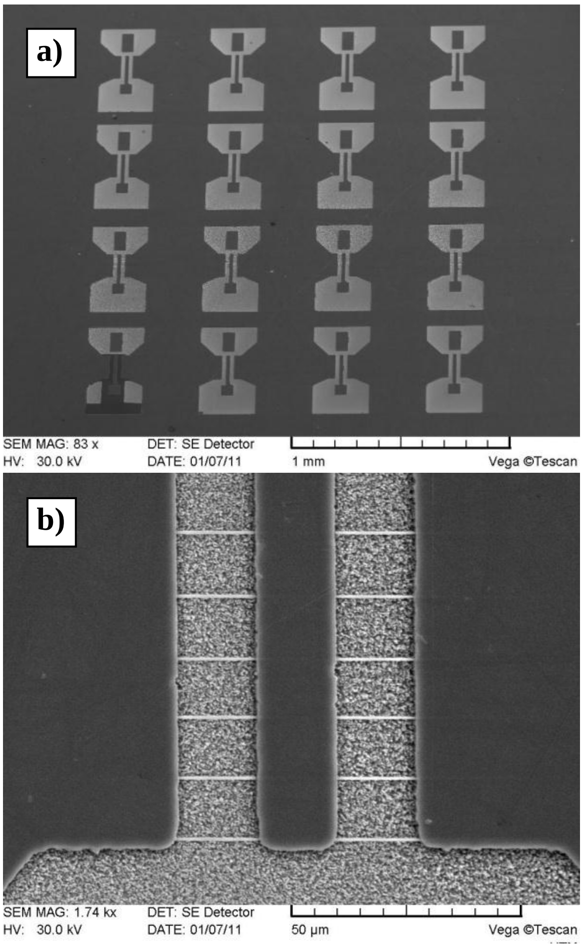


Fig.1 The general view of FETs (a) and GaN nanowalls connecting source and drain (b).

II. TECHNOLOGICAL PART

GaN epilayers used in our experiments were grown by MOCVD on c-plane sapphire substrates. The free carrier concentration was about 10^{17} cm^{-3} whereas the dislocations density was about 10^{9} cm^{-2}. Ohmic contacts were formed by evaporation of Ti/Au metals (50nm/150nm). Rapid thermal annealing necessary to improve the quality of ohmic contacts was excluded in order to avoid modifications of surface properties. For the focused ion beam treatment the FEI Strata FIB 201 was used at the energy of 30 keV and dose of $6.6*10^{12}$ cm^{-2} of Ga ions. The photoelectrochemical etching was performed in 0.1 M of KOH solution under focused UV illumination provided by a 350 W Hg lamp. Figure 1 presents the design of the future transistors after mesa-structuring with surface charge lithography method.

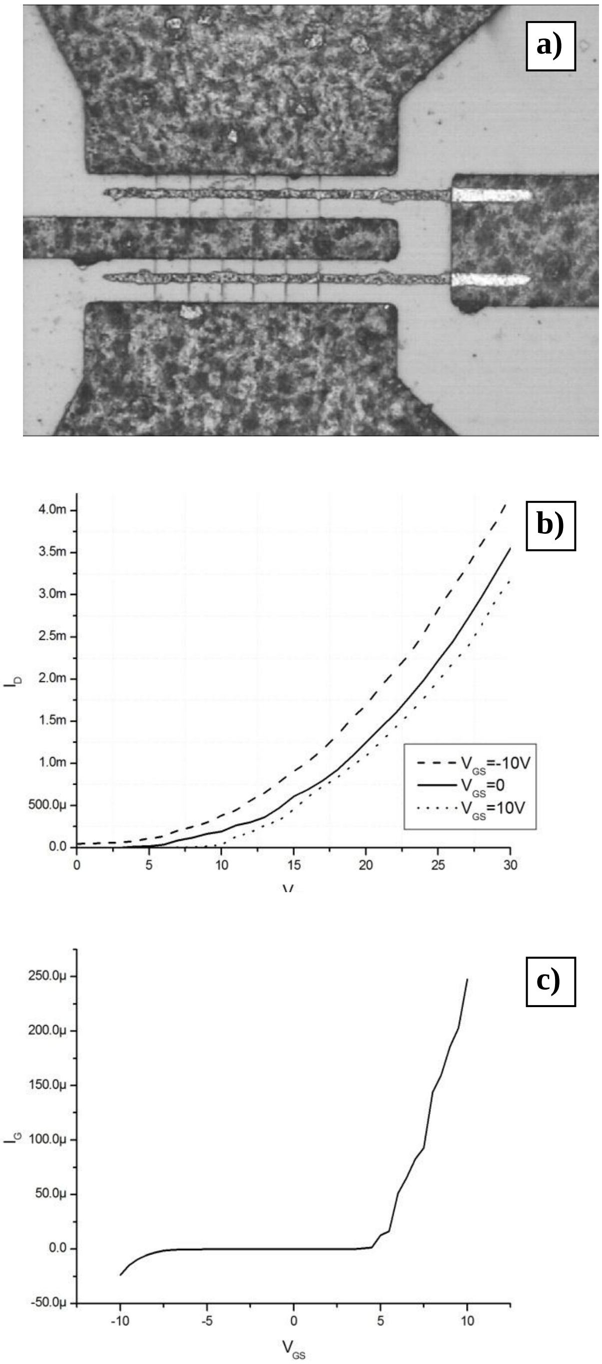


Fig.2. Ni gate on top of GaN nanowalls (a), drain current variation by gate potential (b) and gate-source I-V characteristics (c).

In order to achieve modulation of the drain-source current, we deposited Ni gate using RF-magnetron sputtering with the thickness of 500 nm after rapid thermal annealing (RTA) process at 800°C during 30 sec in nitrogen atmosphere. Thick layers are necessary in order to exclude discontinuity of the gates after lift-off process. An optical image of the final structure is presented in Figure 2a, whereas its I-V characteristics are presented in Figures 2b and 2c.

It is important to note that the gate-source characterization shows high leakage related to the highly defective gallium nitride nucleation layer which is also resistant to photoelectrochemical etching. This problem was partially solved using RIE process during 2 minutes in Ar atmosphere resulting in gate-source current decrease by almost 2 times.

As one can see from I-V characteristics illustrated in Figure 2b, there is a high leakage between Ni gate and source-drain channel related to poor Schottky contact quality resulting from the high density of surface defects caused by FIB treatment. Also the weak modulation of drain current by gate-source potential is the result of highly shunting effect of the thick channel in comparison with thin modulated space charge region.

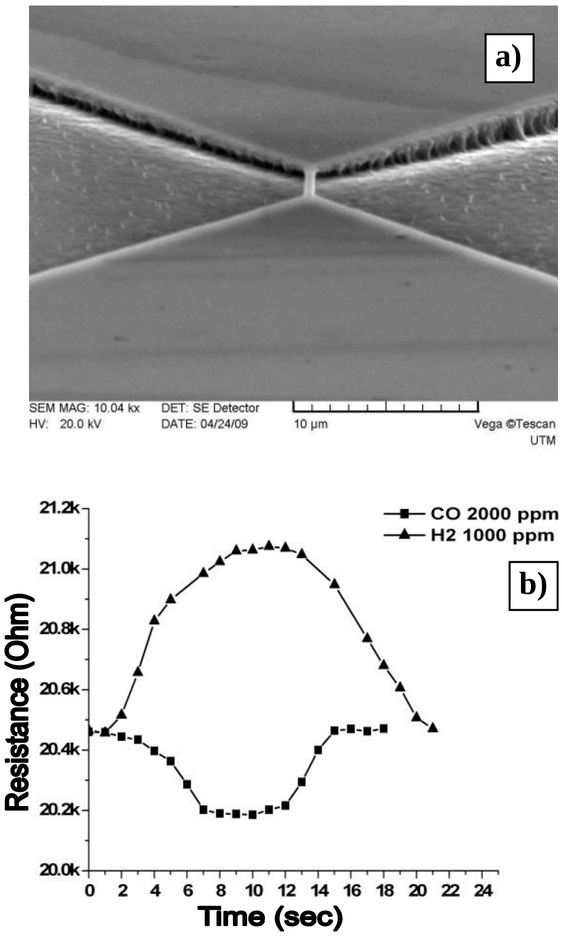
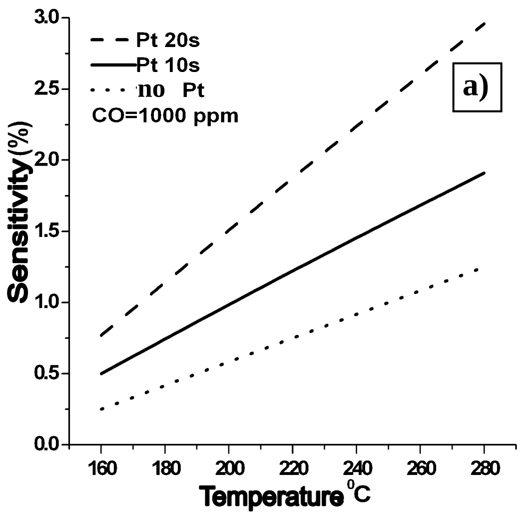


Fig.3. SEM image of the fabricated GaN-based nanowall (a) and its gas response characteristics (b)

GaN material has the potential for applications in gas sensors, especially in harsh environments where other materials exhibit fast degradation. The SCL technique was used for the fabrication of individual nanowires of GaN for the gas sensor applications. The design of the GaN nanowire-based gas sensors is presented in Figure 3, along with the gas response characteristics towards H_2 and CO gases at the temperature of 280°C.

From the characteristics involved we found a linear dependence between the sensitivity and operation temperature for both investigated gaseous species. In addition, there are different threshold temperatures: 215°C in case of 1000 ppm H_2 and 110°C for 2000 ppm of CO. The transient characteristics are promising, in particular they reveal 5 sec response and recovery times for the case of CO, and 10 seconds response time and 15 sec recovery time for H_2. The possible gas response mechanism is discussed in one of our previous paper [4].

In order to improve the sensitivity parameter of our sensors we made use of cathalythic properties of Pt nano-dots deposited by the DC-plasma sputtering method. The effect can be easily seen from the dependences presented in Figure 4 where the sensitivity towards H_2 increased 6 times after 20 sec deposition and 3 times for the case of CO.



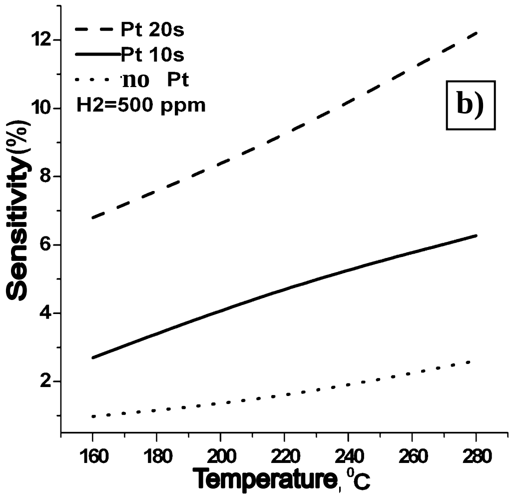


Fig.4. Improvement of sensitivity parameter towards CO (a) and H_2 (b) after Pt sputtering.

III. . CONCLUSION

We demonstrated the possibility of the Surface Charge Lithography for the fabrication of electronic devices based on GaN nanowalls and nanowires. There are still open questions regarding buffer layer shortcutting effect and quality of interface between metal contacts and FIB treated GaN surface.

ACKNOWLEDGMENTS

This work was supported by the Academy of Sciences of Moldova under the State Programme on Nanotechnologies and Nanomaterials. VP would like to thank the Alexander von Humboldt Foundation for the financial support. AS would like to thank Great Western Research for funding.

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