Available online at www.sciencedirect.com
ScienceDirect
Diamond & Related Materials 17 (2008) 768 – 771
DIAMOND AND RELATED MATERIALS
www.elsevier.com/locate/diamond

A MIS transistor using the nucleation surface of polycrystalline diamond

J.C. Madaleno [a,*], L. Pereira [a], G. Lavareda [b], G. Cabral [c], N. Carvalho [b], A. Amaral [d], E. Titus [c], M.C. Coelho [c], J. Grácio [c]

[a] *Physics Department, University of Aveiro, 3810-193 Aveiro, Portugal*
[b] *Materials Science Department, New University of Lisbon, Portugal*
[c] *Centre for Mechanical Technology and Automation, Mechanical Engineering Department, University of Aveiro, 3810-193 Aveiro, Portugal*
[d] *Physics Department, Technical Superior Institute, Lisbon, Portugal*

Available online 12 November 2007

Abstract

In this work, the nucleation surface of a polycrystalline diamond film was used for the first time to fabricate a MISFET structure using standard photolithographic procedures, with a channel length of 100 μm. The resulting structure works as an enhancement-type p-type MOSFET. The I_{ON}/I_{OFF} ratio is about three orders of magnitude. The saturation of the current is clearly observed, with I_{DS} currents of about 20 nA for V_{DS} of 20 V. The smoothness of the nucleation surface allows a higher control of the electrodes, as well as their size decrease. The results show that, even though in an early stage, this investigation opens the door for a new generation of devices built on free-standing diamond films.

Keywords: Polycrystalline diamond; MISFET; Surface electronic properties

1. Introduction

Diamond films have some unique properties, such as a high thermal conductivity and chemical inertness, which make them attractive for mechanical and electronic applications. The high thermal conductivity and high bandgap (5.5 eV) make them an ideal candidate for high-power electronics.

Both homoepitaxial and polycrystalline diamond have been used to fabricate electronic devices. The use of homoepitaxial diamond involves some kind of doping. While some devices have already been built on boron-doped diamond [1], some researchers have used the highly conductive layer (HCL) that is formed after the exposition of diamond crystals to hydrogen plasma [2,3].

Polycrystalline diamond has also been used to build superficial MISFET devices [4] and high-power diodes [5] with some excellent characteristics, as a high rectification ratio (>200) and a breakdown voltage of 500 V.

While homoepitaxial diamond is a very expensive material and is available in a very limited area, polycrystalline diamond can be easily grown in large silicon wafers, by the standard chemical vapour deposition (CVD) methods. However, it has some additional problems. Its intrinsic polycrystalline nature, with structural defects that arise from the grain boundaries, is responsible for the creation of states of energy that may degrade the electrical behaviour of the devices [6,7]. The surface roughness may also become a problem in larger films, promoting the oxide disruption in metal-oxide based devices.

The fabrication of devices using the nucleation surface of diamond films comes as a new approach that has recently been demonstrated [8]. The surface roughness of the film is no longer a problem since the roughness of the nucleation surface follows the roughness of the substrate used.

In this work, a surface MISFET structure was built on the nucleation surface of a polycrystalline diamond film. The

* Corresponding author. Centre for Mechanical Technology and Automation, Mechanical Engineering Department, University of Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal. Tel.: +351 234 370 830; fax: +351 234 370 953.
E-mail address: jcmadaleno@ua.pt (J.C. Madaleno).

0925-9635/$ - see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.diamond.2007.10.037

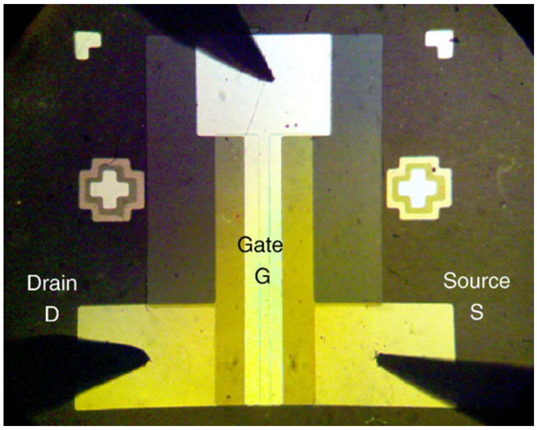

Fig. 1. Photo of the measurement setup.

resulting structure works as an enhancement-type p-type MOSFET.

2. Experimental

The diamond film was grown on n-type silicon substrate in an AsTex PDS-18 MPCVD system.

The growth parameters were 4000 W, 110 Torr, 400 sccm H_2 and 1 sccm CH_4. After deposition, the Si substrate was removed in a HF solution. The film's thickness is approximately 170 μm, allowing it to survive the necessary steps to evaporate the contacts.

Aluminum contacts were evaporated as source (S), drain (D) and gate (G) by standard lithographic procedures. a-SiN_x was used as the gate insulator. The thickness of the drain/source and gate contacts was 2000 Å and 1400 Å, respectively. The insulator thickness was 3000 Å. The channel length and width were 100 μm and 2.2 mm, respectively.

The device was characterized with a semiconductor parameter analyser Agilent 4155C and Alessi microprobes, at room temperature in the dark.

3. Results and discussion

The top view of the device is shown in Fig. 1.

In Fig. 2 the current/voltage (I–V) behaviour of the source and drain electrodes without any applied gate voltage can be seen. The aluminum electrodes, evaporated directly on the nucleation surface, behave as ohmic contacts. The small asymmetry in the characteristics is related probably with a slight heating of the electrode when the current starts to flow, increasing the resistivity of the material and producing an extra decrease of the current.

The resistivity of the diamond, taken from this curve, is 1.1×10^{10} Ω·cm.

In Fig. 3 we can see the output characteristics for negative bias. Field effect is seen for negative V_{GS}, revealing a p-channel, what is consistent with the literature [9]. There is no current for $V_{GS}=0$ V, and the device is an enhancement-mode MISFET. The I_{ON}/I_{OFF} ratio is close to 3. I_{DS} saturates for higher V_{DS}.

I_{DS} increases linearly with V_{GS} (as seen in Fig. 4) and does not show the usual quadratic dependence commonly observed in MISFETs. This effect is currently under study.

The transconductance g_m is related to the field effect mobility μ_{FE}:

$$g_m = \left.\frac{\partial I_{DS}}{\partial V_{GS}}\right|_{V_{DS}=20\ \mathrm{V}} = \mu_{FE}\cdot C_i\cdot\frac{W}{L}\cdot V_{DS}. \quad (1)$$

W and L are the channel width and length, respectively, and C_i is the insulator capacitance. Using this equation, it is possible to estimate the mobility from the V_{DS} *vs.* I_{DS} plot. From Fig. 5, we obtain an extremely low mobility of 1.4×10^{-4} $cm^2\cdot V^{-1}\cdot s^{-1}$.

Even though the device shows the basic principle of a field effect transistor, the characteristics of the devices are weak. The current measured for $V_{DS}=-20$ V and $V_{GS}=-20$ V is only 15 nA and the channel resistivity is extremely high (1.1×10^{10} Ω·cm). This may be due to the high quality of the film

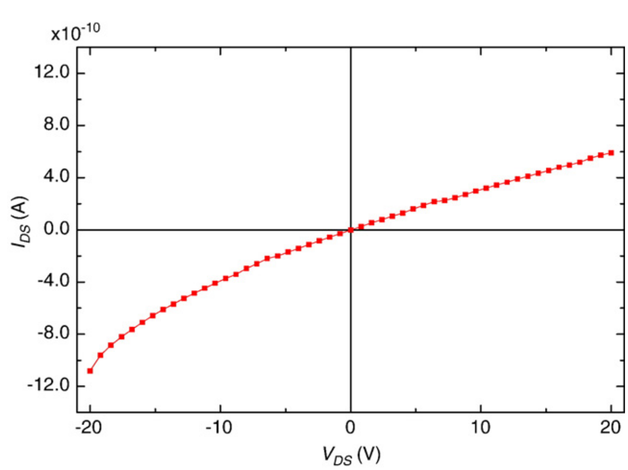

Fig. 2. Current/voltage behaviour of the source and drain electrodes without any applied gate voltage. The voltage sweep starts at −20 V.

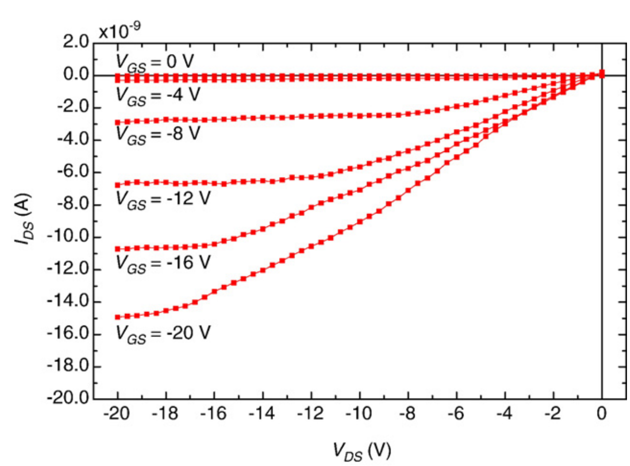

Fig. 3. Output characteristics for negative bias. V_{DS} swept between 0 and −20 V with a −0.4 V step; V_{GS} swept between 0 and −20 V with a −4 V step.