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NCD LAYERS OBTAINED IN RF PE CVD PLASMA PROCESS AS AN DIELECTRICAL CHEMOSENSITIVE MATERIAL IN MIS END CHEMFET STRUCTURES

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A b s t r a c t. The aim of this work was to study the NCD layers as chemosensitive films for liquid organic compounds. Diamond layers were obtained in RF PA CVD (13.56 MHz) plasma deposition process on Si p-type <111> substrate. NCD layers act as a dielectric in Al/NCD/Si (MIS) and gate in ChemFET structures. The change of electrical properties of NCD layers caused by acetonitrile and methanol, dielectic organic nonwater solvent was observed.
The layers were characterized by means of C-V and I-V measurements performed by HP 4061 station and KEITHLEY 237 SMU, their surface investigated using AFM, while thickness and refractive index values were obtained ellipsometrically (Gaertner L 1160).

K e y w o r d s: NCD, ChemFET, RF PA CVD.

INTRODUCTION

Diamond is a wide band gap material which possesses unique combination of electrical, optical and physical properties. Therefore diamond and diamond films seem to be useful for many electronic applications [1, 2].

Since the discovery of natural semiconducting diamond [3] a number of diamond electronic devices made of natural diamond have been produced on the laboratory scale.

Recent improvements in the process of growing large single-crystal diamonds by high-pressure high-temperature (HPHT) synthesis, and continuing research on the production of semiconductor diamond films by chemical vapour deposition (CVD) [4] have led to renewed interest in developing diamond devices. The diamond devices are expected to work at high temperature and high frequencies in a hostile environment.

CVD-diamond was firstly obtained in 1956 in homoepitaxial process (on diamond seeds) [5]. Nowadays CVD deposition is carried out in the course of homo and heteroepitaxial processes on different substrates (GaAs, SiC, Si, glass) which are used in electronic applications [6-7].

Research on diamond film deposition led to elaboration of improved plasma activated CVD process - the Radio Frequency PA CVD [8]. RF PA CVD processes are now widely applied in diamond layers synthesis. It was demonstrated that the NCD film (nanocrystaline diamond) can be achieved by using CH_4 environment alone [9].

By controlling general parameters (pressure, electrode autopolarisation, temperature) of RF plasma activated CVD process one can obtain different phase composition of the carbon material. Depending on the type of hybridisation (sp, sp^2, sp^3), carbon films of varying electrical properties (dielectric, semiconductor or conductor properties) can be produced. Existence of carbon polymers besides nanodiamond particles in the layers, may result in their unique electrochemical properties. Several authors suggest the use of NCD layer as a chemosensitive part of sensors [10]. The process of NCD films synthesis was described by Mitura [11] while their electrical properties were shown by Szmidt et al [12].

The layers obtained as a result of RF PA CVD process demonstrate reproducible properties which depend on the set deposition parameters. In our study, NCD layers were obtained in the process presented in Table 1.

Table 1. The main parameters of obtaining NCD layers in two-stage process.

PARAMETER	ETCHING	DEPOSITING
Gas	CH_4	CH_4
Pressure	1 Pa	50 Pa
Negative self-bias voltage	600 V	400 V
Time	600 s	100 s

In this paper we proposed the construction of chemosensitive OpenGateFET with NCD layer as a typical gate thin film. Sensors with diamond chemosensitive layers are still under research.

EXPERIMENT

NCD layers were obtained on silicon in the course of RF PA CVD process which allows also deposition of thin DLC layers on semiconductor materials (Si, GaAs, SiC), as well as on metals and metal alloys.

Surface morphology of the layers was examined using AFM (Fig.1) while refractive index values and their thickness - by ellipsometry.

The refractive index was 2.1 – 2.3, what indicates if compared with the refractive index of diamond (2.42), that the layers were of NCD type. It was confirmed by the AFM method (see also [13]).

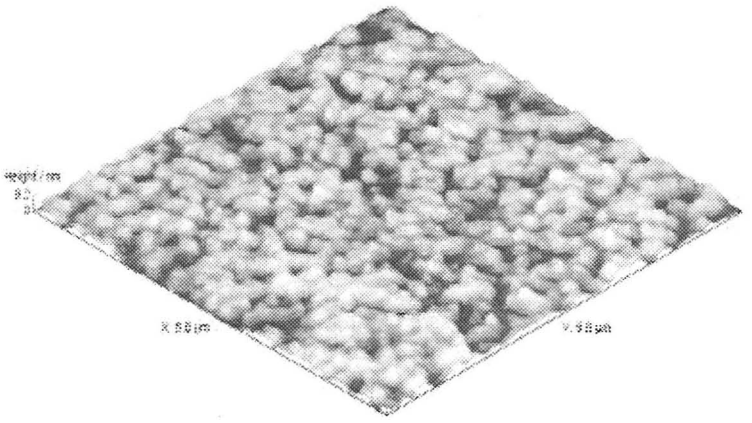

Fig. 1. Morphology of NCD layer observed by AFM method.

Electrophysical measurements were carried out on MIS type structure. The NCD film was produced on Si <111> type p substrate by RF PE CVD (13,56 MHz) process.

The HP 4061 station and KEITHELEY 237 SMU apparatus were used in order to determine the high frequency capacitance–voltage (C-V) (Fig.2) and current–voltage (I-V) characteristics of Al/NCD/Si structures (Fig.2).

In the course of the measurements, an organic compound was applied in the region of Al/NCD interface. Two non-ionic, anhydrous organic solvents were used for this purpose: acetonitrile (99.9 % purity) and methanol (99.9% purity).

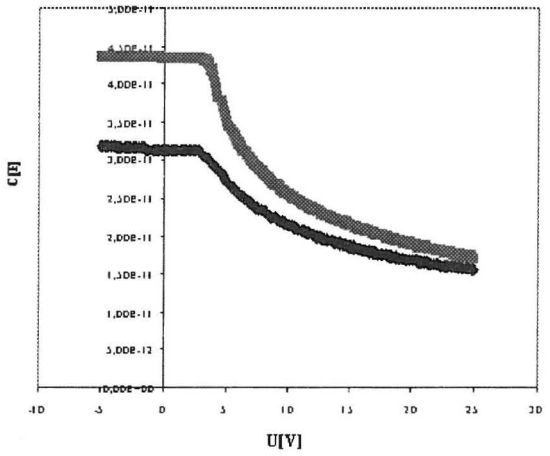

Fig.2. Typical change of electric properties of dielectric NCD layer in MIS (AL/NCD/Si) structure.

We constructed ChemFET on Si <111> p-type substrate (ρ = 9 Ωcm) with nanocrystalline diamond dielectric gate (200 x 200 μm). The KEITHELEY 237 SMU apparatus was used for the monitoring of drain – source current (I_{ds}) under varying polarisation of drain (V_{ds}). Because of ChemFET type sensor element, we did not polarize the gate [14].

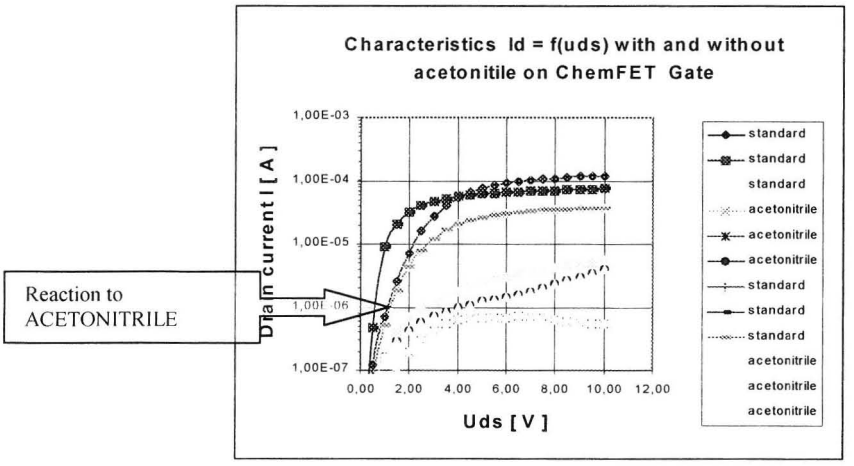

Fig.3. Influence of acetonitrile on I-V characteristics of investigated ChemFET.

In the course of the measurements, an organic compound was applied onto an open gate of FET structure. The influence of organic compound (acetonitrile) on electrical properties of transistor was significant in several cases (Fig.3).

RESULTS

In our research we observed that dielectric constant of NCD film (2.4-2.8) in MIS structures was subject to changes under the influence of organic chemical compounds. Changes were different for acetonitrile and methanol (Fig. 2). Chemosensitivity of NCD dielectric films in MIS structures suggests, to use diamond films as a dielectric gate in FET structures.

Measured characteristics of ChemoFET structure give evidence of existing channel in the FET structure. That channel was induced by charges existing in NDC layer and in NDC/Si interface. The influence of an electron affinity cannot be excluded as well.

The transconductance of FET channel changed when organic compound was applied. All changes were reversible because of volatility of acetonitrile. The modulation of ChemFET channel was significant in most cases (Fig. 3).

Our researches give evidence of chemical sensitivity of NCD layers in MIS and Open Gate FET structures. Electrochemical properties of NCD films can be used in construction of Chem FET.

CONCLUSIONS

In our researches, chemical sensitivity of NCD films to organic compounds is clearly shown. Using RF PA CVD process we easily obtained nanocrystaline diamond layer on typical electronic substrate – the silicon. This allowed us to construct ChemFET devices for nonionic organic compounds.

LITERATURE

1. **Gildenblat G. Sh., Grot S.A., Badzian A.**, *Proc. IEEE*, 79 (1991) 647.
2. **Okushi H.**, *Diam.Relat.Mater.*, 10 (2001) 281-288.
3. **Custers J.F.H.**, *Physica*, 18 (1952) 489-96.
4. **Okano K., et al**, *Japan. J. Appl. Phys.*, 1988, **27** L173-5.
5. **Eversole W.**: *USA Patents*, 3030187, 3030188 (1962).
6. **Geis M.W., Angus J.C.**, *SCI. Am.*, October, p 84 (1992).
7. **Angus J.C., et al**, *Phil. Trans. R.Soc.London A*, p.342 (1993).
8. **Mitura S., Klimek L., Haś Z.**, Thin Solid Films, 147 (1987) 83.
9. **Mitura S.**, J.Crystal Growth, 80 (1987) 417.
10. **Denisenko A. et al**, *Diam and Relat.Mat.*, 10 (2001) 667-672.
11. **Haś Z., Mitura S., et al**, *Thin Solid Films*, 136 (1986) 161.

12. **Szmidt J., Jakubowski A.**, *International Conf. On Thin Films ICTF-6*, Stockholm, Sweden, 1984.
13. **Lourdin P., Mitura S., Mitura E., et al**, *J.of Chem.Vapor Dep*, vol. 4-Jan 1996.
14. **Voigt H., et al**, *Sens.and Actuators*, B 44 (1997) 441-445.

WARSTWY NCD OTRZYMANE W PROCESIE PLAZMOWYM RF PE CVD JAKO MATERIAŁ CHEMOCZUŁY I DIELEKTRYCZNY W STRUKTURACH MIS END CHEMFET

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S t r e s z c z e n i e. Celem pracy było badanie warstw NCD, otrzymywanych w RF PA CVD (13.56 MHz) plazmowym procesie osadzania na Si p-type <111>, jako chemoczułych materiałów dla ciekłych związków organicznych. Warstwy NCD działają jako dielektryk w Al/NCD/Si (MIS) i bramka w strukturach ChemFET. Obserwowano zmianę własności elektrycznych warstw NCD powodowanych przez acetonitryl i metanol, dielektryczne niewodne rozpuszczalniki. Warstwy charakteryzowane były przez pomiary C-V i I-V wykonane na stacji HP 4061 i KEITHLEY 237 SMU, powierzchnię badano używając AFM, a grubość i wartości współczynnika refrakcji elipsometrycznie (Gaertner L 1160).

S ł o w a k l u c z o w e : warstwy NCD, ChemFET, proces RF PA CVD.