Paper

Influence of the deposition process parameters on electronic properties of BN films obtained by means of RF PACVD

Piotr Firek, Aleksander Werbowy, Jan Szmidt, and Norbert Kwietniewski

Abstract—This work presents results of investigations of electronic properties of undoped boron nitride (BN) films produced on Si substrates in the course of radio frequency (rf) PACVD process with boron triethyl $(C_2H_5)_3B$ as the boron source. The influence of the deposition process parameters on thickness and electronic properties (resistivity ρ, dielectric strength E_{BR}) of BN films based on ellipsometry and *I-V* curve measurements at room temperature is studied. The obtained results show that proper selection of deposition process parameters allows BN layers with the required thickness and advantageous values of ρ and E_{BR} to be fabricated. BN becomes therefore an interesting material for microelectronics applications.

***Keywords*— III-nitrides, thin BN films, electronic properties, RF PACVD.**

1. Introduction

Dynamic development of microelectronics creates an increased demand for new materials. New areas of application emerge, where typical semiconductor devices run a risk of high-temperature and/or high power emission. Unfortunately, classic silicon-based devices are not capable of working in such operation regimes. One of the potential ways to overcome this problem is to develop fabrication technologies and applications involving the use of wide band-gap materials like diamond or III-group nitrides (GaN, AlN and in particular BN).

Cubic boron nitride (c-BN) with its unique properties, such as wide band gap (6.4 eV), chemical inertness, good thermal stability and thermal conductivity (∼1300 W/mK), is considered a prospective material for electronic applications in high-temperature and high-power electronics, particularly in combination with other wide band-gap materials [1, 2]. It is worth to emphasize that the expected working temperature of BN-based devices can reach even up to 900°C! [2].

2. Experimental details

Boron nitride films were produced on p-type Si ($\langle 100 \rangle$, $\rho = 6 - 8\ \Omega$cm) substrates using radio frequency plasma assisted chemical vapor deposition (RF PACVD) method [3–5]. Layers were synthesized from boron triethyl $(C_2H_5)_3B$ vapors carried by nitrogen N_2. Then circular, aluminum (Al) electrodes (diameter = 1 mm, gate area = $7.85 \cdot 10^{-3}$ cm^2) were evaporated on the top of the deposited layers. As a result metal-insulator-semiconductor (MIS) structures with BN thin films acting as the insulator were fabricated.

Table 1
Process parameters of RF PACVD deposition

Parameters	Voltage [V]	Time [s]	N_2 flow [cm^3/min]	$(C_2H_5)_3B$ flow [a.u.]
Value 1	70	30	10	200
Value 2	105	60	20	250
Value 3	140	90	30	300

Table 2
Thickness of the deposited BN layers

Process	Voltage [V]	Time [s]	N_2 flow [cm^3/min]	$(C_2H_5)_3B$ flow [a.u.]	Thickness $x/(x+i\cdot\text{period})$; $i = 1, 2, 3\ldots$ [Å]
1	70	30	10	200	391 / 2579
2	70	60	20	250	1770 / 2540
3	70	90	30	300	111 / 1567
4	105	30	20	300	2220 / 2568
5	105	60	30	200	513 / 2514
6	105	90	10	250	985 / 2538
7	140	30	30	250	1039 / 2455
8	140	60	10	300	1515 / 2506
9	140	90	20	200	474 / 2524
1^{bis}	70	30	10	200	633 / 2532

Deposition parameters subsequently used in the Taguchi-based process analysis method [6] are presented in Table 1, whereas the results of BN film thickness measurements are collected in Table 2.

3. Results

Applying Taguchi's method allowed the influence of input process parameters (self-bias potential, deposition time, flow rates of reactant vapors N_2 and $(C_2H_5)_3B$) on its output parameters – in this case thickness x, resistivity ρ and critical electric breakdown field E_{BR} (being the measure of dielectric strength) of deposited BN layers to be analyzed. The dependence of the film thickness on process parameters is illustrated in Fig. 1.

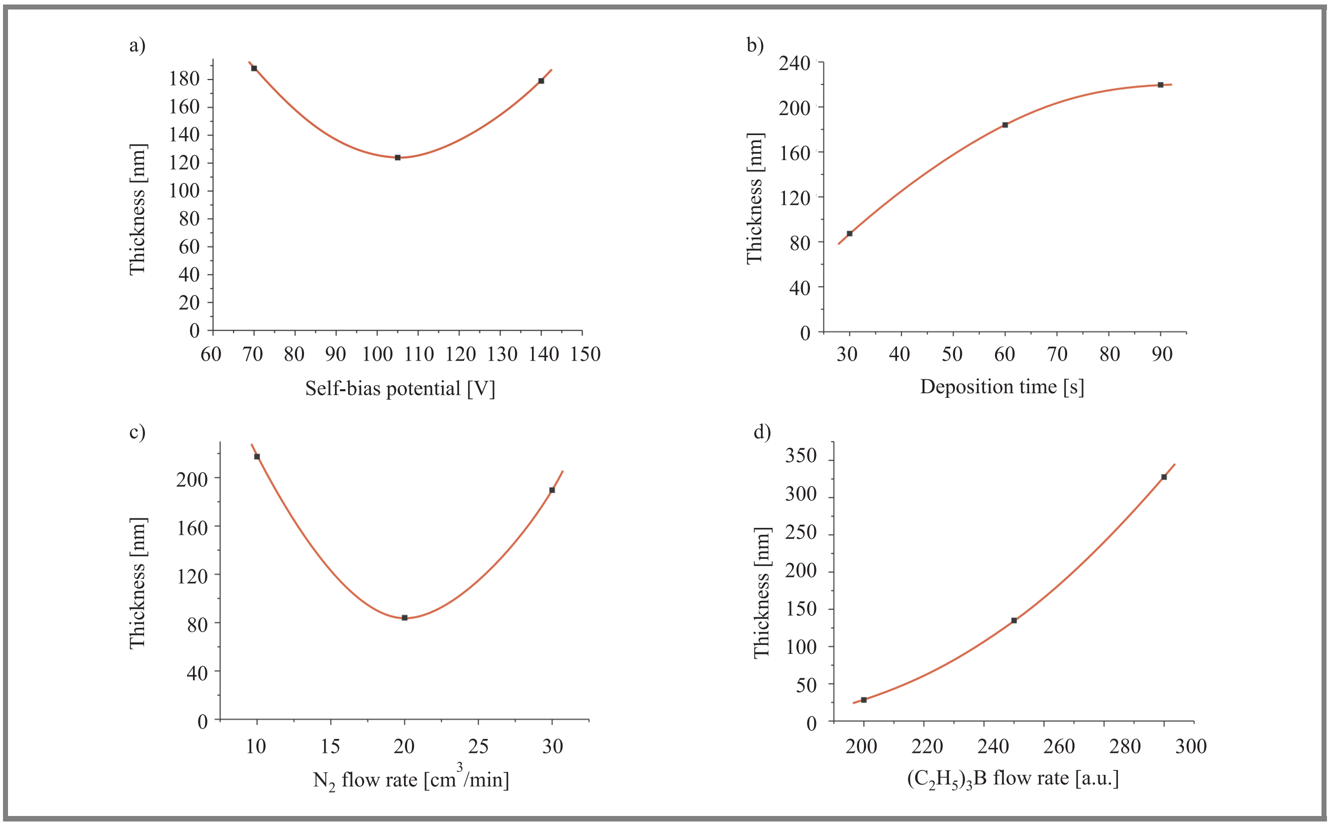


Fig. 1. Influence of the: (a) self-bias potential; (b) deposition time; c) N_2 flow rate; (d) $(C_2H_5)_3B$ flow rate on thickness of BN layers.

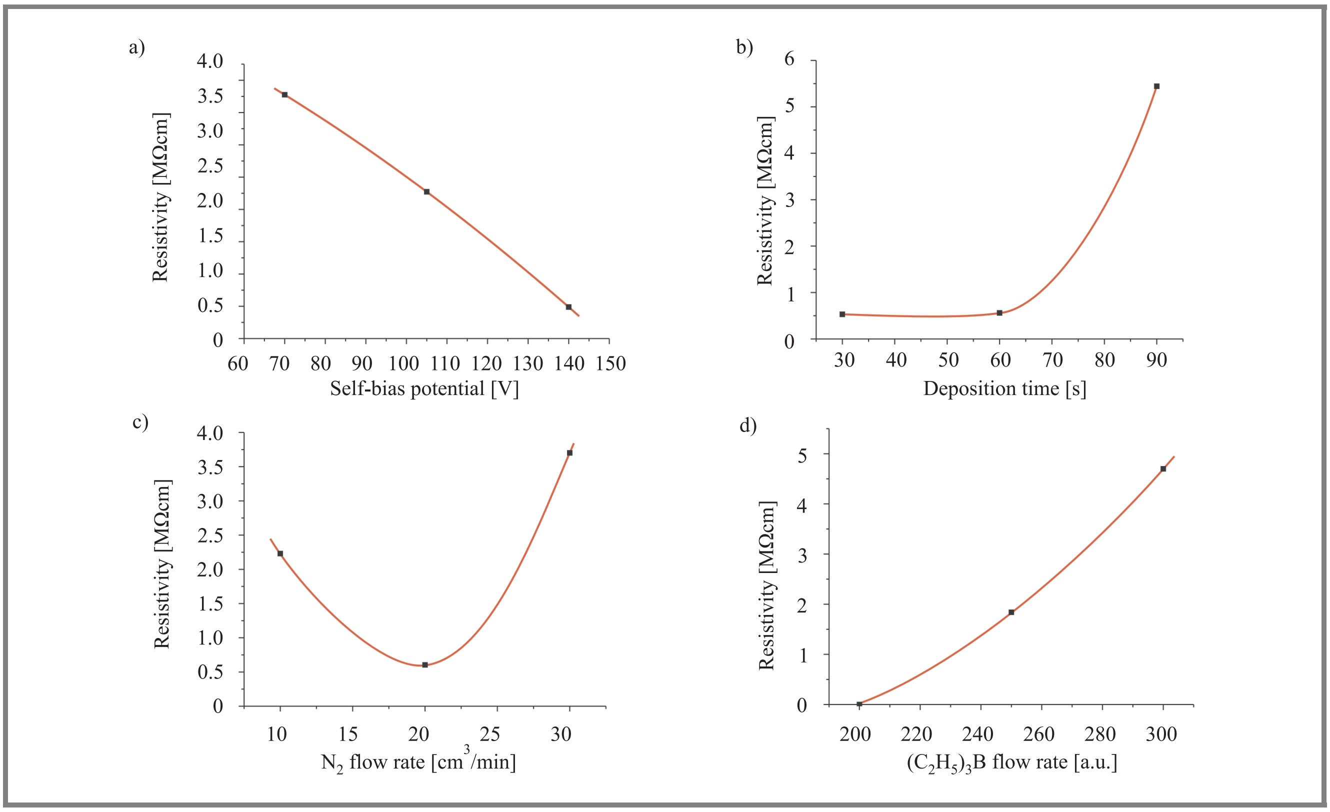


Fig. 2. Influence of the: (a) self-bias potential; (b) deposition time; c) N_2 flow rate; (d) $(C_2H_5)_3B$ flow rate on resistivity of BN layers.

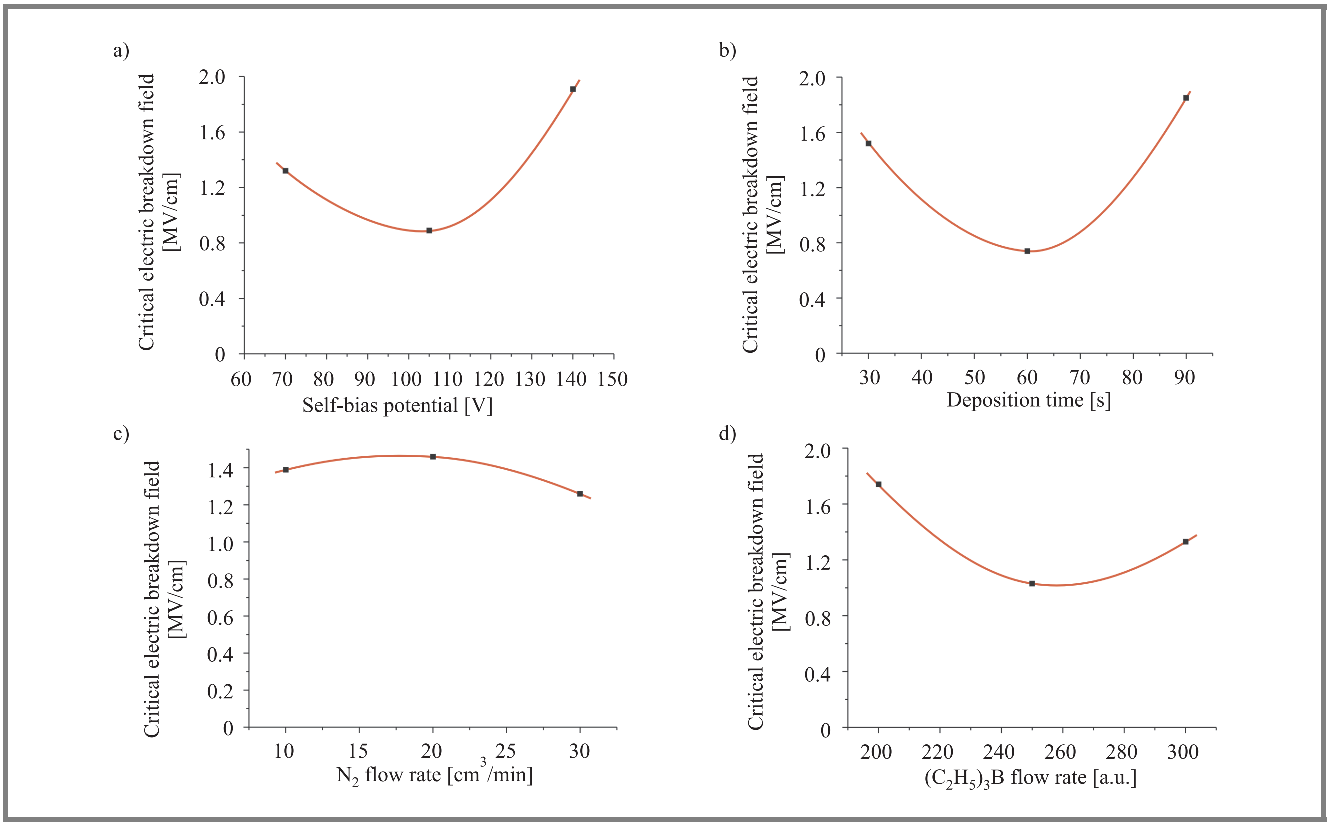


Fig. 3. Influence of the: (a) self-bias potential; (b) deposition time; c) N_2 flow rate; (d) $(C_2H_5)_3B$ flow rate on critical electric breakdown field of BN layers.

The obtained results show clearly that increasing deposition time results in thicker layers. The same is also observed when boron triethyl flow rate increases. On the other hand, the correlation between film thickness and self-bias potential, as well as nitrogen flow rate is more complicated. It suggests the presence of opposing phenomena during BN layer formation and needs further investigation.

Electrical characterization (current-voltage (I-V) measurements) of the fabricated MIS structures was performed to extract the resistivity ρ and critical electric breakdown field E_{BR} of BN layers. In order to determine the influence of the deposition process parameters on ρ and E_{BR} Taguchi's method was used again. The results are shown in Figs. 2 and 3.

As seen in Fig. 2, increasing self-bias potential (i.e., supplied power) leads to a decrease of the resistivity of BN layers. The opposite trend is observed in the case of boron triethyl flow rate growth.

As far as the dependence of deposition time on resistivity is concerned, the initial low value of this parameter might be attributed to the fact that for short growth times (therefore for thinner films) one has weaker control over the synthesis process, which usually results in inferior values of resistivity.

Obviously the nitrogen flow rate affects chemical composition of the layer and thus its parameters. At the same time nitrogen flow rate exerts influence on the pressure under which the coating is formed. The obtained results suggest however that higher resistivity is obtained when N_2 flow rate is increased to 30 cm^3/min.

In the case of the dielectric strength of BN films (Fig. 3) the character of its dependence on the deposition process parameters is more complicated as the obtained curves are not monotonic, showing minima or maxima instead. Nevertheless it can be seen that a certain set of process parameters (self-bias potential – 140 V, N_2 flow rate – 20 cm^3/min, boron triethyl flow rate – 300 arbitrary units) results in the highest value of critical electric breakdown field. On the other hand, Fig. 2 shows that ρ will not reach the required highest level with this combination of parameters. This indicates that it is necessary to find a trade-off between these parameters. Taking into account both resistivity and dielectric strength it appears that the best results are obtained with the following process parameters: self-bias potential – 70 V (substantial gain of with relatively small EBR loss), N_2 flow 30 cm^3/min (in spite of a slight drop of the dielectric strength, the resistivity increases almost twice). For the same reason using the maximum (300 arbitrary units) boron triethyl flow rate is the most advantageous.

4. Conclusions

The obtained results show that it is possible to achieve good electrophysical parameters of BN layers grown by means of RF PACVD. The method is relatively inexpensive and does not require substrate heating. Proper selection of process parameters allows the quality of the fabricated films to be controlled, although further efforts (in particular involving the use of more advanced Taguchi procedures) towards process optimization are required.

References

[1] S. N. Mohammad, "Electrical characteristics of thin film cubic boron nitride", *Solid-State Electron.*, vol. 46, pp. 203–222, 2002.

[2] P. Gielisse, "Wide bandgap materials in future electronic applications", in *Proc. XXIV Int. Conf. IMAPS*, Rytro, Poland, 2000, pp. 115–123.

[3] S. Mitura, E. Mitura, and A. Mitura, "Manufacture of amorphous carbon layers by r.f. dense plasma CVD", *Diam. Rel. Mater.*, no. 4, pp. 202–203, 1995.

[4] J. Szmidt, "Electronic properties of nanocrystalline layers of wide band gap materials", *Chaos, Sol. Fract.*, vol. 10, no. 12, pp. 2099–2152, 1999.

[5] S. Mitura, A. Mitura, P. Niedzielski, and P. Couvart, "Nanocrystalline diamond coatings", *Chaos, Sol. Fract.*, vol. 10, no. 12, pp. 2165–2176, 1999.

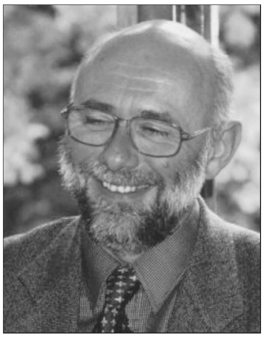
[6] G. S. Peace, *Taguchi Methods – A Hands – On Approach.* Reading: Addison-Wesley, 1993.

Piotr Firek was born in Rawa Mazowiecka, Poland, in 1977. He received the M.Sc. degree in microelectronics from the Faculty of Electronics and Information Technology, Warsaw University of Technology (WUT), Poland, in 2004, where he is currently working towards a Ph.D. degree. His research concentrates on fabrication, characterization, processing and application of thin and thick film materials (e.g., barium titanate, boron nitride, diamond) in microelectronic devices.

e-mail: pfirek@elka.pw.edu.pl
Institute of Microelectronics and Optoelectronics
Warsaw University of Technology
Koszykowa st 75
00-662 Warsaw, Poland

Aleksander Werbowy received the M.Sc. and Ph.D. degrees in microelectronics from the Faculty of Electronics and Information Technology, Warsaw University of Technology (WUT), Poland, in 1994 and 1999, respectively. His main research interests are nanotechnologies synthesis, characterization, processing as well as application of thin films of wide band-gap materials in microelectronics and nanoelectronics structures.

e-mail: werbowy@imio.pw.edu.pl
Institute of Microelectronics and Optoelectronics
Warsaw University of Technology
Koszykowa st 75
00-662 Warsaw, Poland



Jan Szmidt received the M.Sc. degree in the electronics from the Faculty of Electronics, Warsaw University of Technology (WUT), Poland, in 1976. From the same university, he received the Ph.D. and D.Sc. degrees in 1984 and 1995, respectively. In 1999, he became an Associate Professor. Since 2002 he has been an Associate Dean for Development of the Faculty of Electronics and Information Technology, Warsaw University of Technology. Since 2006 he has been a Head of Electronic Materials and Microsystem Technology Division, Institute of Microelectronics and Optoelectronics, WUT. His research interests concentrate on characterization of thin films for electronics, especially for microelectronics and nanoelectronics, as well as on their application in microelectronic and nanoelectronic structures.

e-mail: j.szmidt@elka.pw.edu.pl
Institute of Microelectronics and Optoelectronics
Warsaw University of Technology
Koszykowa st 75
00-662 Warsaw, Poland

Norbert Kwietniewski was born in Sandomierz, Poland, in 1980. He received the M.Sc. degree in microelectronics from the Faculty of Electronics and Information Technology, Warsaw University of Technology (WUT), Poland, in 2007. His research concentrates on fabrication, characterization, processing and application of wide band-gap materials (e.g., silicon carbide) materials in microelectronic devices.

e-mail: nkwietni@ite.waw.pl
Institute of Electron Technology
Lotników av. 32/46
02-668 Warsaw, Poland