Emission pattern of an aluminium nitride target for radio frequency magnetron sputtering

G Gálvez de la Puente1,2, S Zitzlsberger1, J A Guerra Torres2, O Erlenbach2, R Weingärtner1,2, F De Zela2, A Winnacker1

1 Department of Materials Science 6, University of Erlangen-Nuremberg, Germany.
2 Dpto de Ciencias, Sección Física, Pontificia Universidad Católica del Perú, Perú.

E-mail: rweingartner@pucp.edu.pe

Abstract. Thin amorphous aluminium nitride films, (a-AlN) have been produced by radio frequency magnetron sputtering at rf power 120W from a highly pure AlN target. The target is mounted below the substrate holder such that its position can be adjusted inside the vacuum chamber. The emission pattern is determined by means of thickness distribution of the deposited material obtained from optical transmission measurements. Holding a set of the process parameters constant and only varying the target-sample distance a three dimensional emission pattern of the AlN target was determined. The deposition rate and emission pattern for 120W and 180W (studied before) were compared. This comparison allows us to consider the target and shielding dimensions of our magnetron to predict the thickness and the sputtering rate distribution for any process parameter and sample target geometry.

1. Introduction
The wide-bandgap semiconductors Silicon Carbide, Aluminium Nitride (AIN) and Gallium nitride are of increasing interest in research and development due to their potential for example in optoelectronic device applications [1, 5]. In addition, it is highly desirable to control the bandgap of a semiconductor which can be achieved with semiconductors solid solutions. For instance, the bandgap of the pseudobinary amorphous compound (SiC)1-x(AlN)x covers the range from 2.2eV to 3.5eV by varying the composition x from zero to one [6]. Amorphous SiC and AlN have the advantage to be produced rather simply and inexpensively without the drawback of losing those important properties. Further, the indirect character for optical transition in a-SiC is absent, so that applications in optoelectronics seem promising [7]. In the case of a-AlN applications in the ultraviolet region are possible, due to the wide bandgap of 5.6 eV [8]. Unfortunately, the production of wide-bandgap semiconductors like the above mentioned is difficult due to their large sublimation point and incongruent evaporation process. The rf sputtering method overcomes the above mentioned problems and in addition bandgap engineering is possible by changing the composition [9-11]. To be able to predict a composition of a solid solution using dual magnetron sputtering it is necessary to control the sputtering rate for a certain target material, sample-distance, rf-power, gas pressure and other process parameters [9, 12]. In this context, we present more results about the emission pattern of an AlN target of our rf magnetron

1 Av. Universitaria 1801, Apartado Postal 1761, Lima 32, Perú.
2 Martensstrasse 7, 91058 Erlangen, Germany.

Published under licence by IOP Publishing Ltd
sputter system in terms of the sputtering rate distribution. This has been performed by evaluation of
the film thickness at different target-sample distances using optical transmission data.

2. Experimental details

2.1. Sample Preparation
Amorphous AlN films were produced using radio frequency dual magnetron sputtering. High pure
aluminum nitride bulk disk of 51 mm diameter was used as target. The target was mounted below the
substrate holder. Substrates were placed at distances 40 to 60 mm from the AlN target (see schematics
in figure 1). The base pressure of the vacuum chamber was better than $9 \times 10^{-7}$ mbar. The sputtering
process took place in an argon atmosphere of purity 5N, pressure $8 \times 10^{-3}$ mbar at argon flow rates of
50 sccm. Rf power of 120W (at 13 MHz) for the magnetron for the AlN film production was used. The
sputter times were between 20 min and 180 min for the deposited samples. Soda-lime glasses served
as substrate and were kept by water cooling below 10°C during the sputtering process. Further details
of the sputtering process can be found in [9]. The amorphicity of the films have been checked by XRD
measurements (no figure).

2.2. Transmission measurements and thickness determination
Absorption spectra of the thin films in the wavelength range from 200 to 1100 nm by 1 nm steps and
absorption coefficients up to 240000 cm$^{-1}$ were recorded using a double beam photospectrometer
model Lambda 2 UV/VIS/NIR of Perkin Elmer. In order to obtain the absorption coefficient, the
refractive index and the film thickness from transmission data, we applied a slightly improved self-
consistent method of Swanepoel [13] described in [9]. An adjustment of the measured transmission
and simulated transmission in figure 2 is shown. The errors obtained for the absorption coefficient,
thickness and refractive index were less than 5% and were mainly caused by film inhomogeneities and
low number of interference fringes in the transmission spectra for thickness determination.

Figure 1. Geometrical arrangement of the substrate and magnetron. Schematic assembly of
one magnetron. As example, two target sample distances are shown. The expected film
thickness distribution is indicated

Figure 2. Measured transmission spectrum and simulated transmission spectrum of a
semiconductor film with a thickness of 988 nm and Cauchy parameters $p = 2.112$ and
$q = 26000 \text{ nm}^2$. For comparison the simulated curve is shifted by
-20 below the measured transmission curve.
3. Results and discussion

In order to predict the thickness distribution it is essential to know the emission pattern of the magnetron. Therefore, determine the deposition rate at any distance from the target for certain process parameters must be determined, i.e. the target-sample distance at the center of the magnetron symmetry axis and (at a fixed target sample distance) the radial distance from the target symmetry axis. A series of film preparations for our magnetron with AlN target was performed.

3.1. Thickness and deposition rate of the samples

The deposition rates for rf power 120W were determined from the sputter time and the film thickness measurements described before. It decreases with increasing radial distance (figure 3) and can be described empirically with a power law function [9]. It was reported for rf power 180W (figure 4) in [12].

![Figure 3](image1.png)
Figure 3. Deposition rate for an AlN target at 120 W. Thickness of 50 nm is almost the lower limit for our thickness determination method. It occurs around 30 mm radial distance.

![Figure 4](image2.png)
Figure 4. Deposition rate for an AlN target at 180 W. The thickness of the film shows a radial decrease outwards from the center of the sample [9].

3.2. Emission pattern

In Figure 5 and 6, the resulting emission patterns of our rf magnetron with AlN target at rf power of 120 W and 180 W [9] are shown.

![Figure 5](image3.png)
Figure 5. Emission pattern for our rf magnetron with AlN target powered at 120 W.

![Figure 6](image4.png)
Figure 6. Emission pattern for our rf magnetron with AlN target powered at 180 W [12].

Constant contours for deposition rates as a function of the magnetron target geometry, i.e. as a function of the target sample distance and the radial distance from the symmetry axis of the target are
shown by the same gray scale. The lowest contour line (<50 nm/h) is almost the lower limit for our thickness determination method. For film thickness determination we need at least a film thickness of 500 µm which is still achievable for reasonable sputter process times. In the case of the AlN-target at rf power 120W seems a maximum deposition rate at the central axis at a approximately distance of 35 mm, similar to the rf power 180W. Both rf powers, show a strong directional emission characteristic with outer limits mainly defined by the target and the shielding geometric dimensions. For both rf powers, 120W and 180W, the contours of constant emission rates increase towards the target centre. Furthermore, there is also a steep decrease beyond 25 mm in deposition rate with increasing radial distance. It can be explained from the generated limit to the emitted material from the target duo to the shielding of our magnetron described in [12].

4. Summary
Thin amorphous AlN films by rf dual magnetron sputtering at rf power 120W were produced. The emission pattern of our rf magnetron with AlN bulk target has been determined by means of thickness distribution of the produced films at different target sample distances and sputter process parameters. The deposition rates and emission patterns at rf power 120W and 180W were compared. The emission pattern shows a strong directional behaviour for rf power 120W as for rf power 180W. Independently of the rf power value, the outline of the emission pattern seems to be limited by the geometric dimensions of our target and shielding.

5. References
[1] Roussel P, Scot A, Milligan J and Newey J 2003 Comp. Semicond. 9 20
[2] Grandjean N, Ilegems M, Suski T, Butté R 2009 Phys. Stat. Sol.C 6/S2 S289
[3] Weingärtner R, Erlenbach O, De Zela F, Winnacker A, Brauer I, Struck H P 2006 Mater. Sci. Forum Vols. 663 527-529
[4] Weingärtner R, Erlenbach O, Winnacker A, Welte A, Brauer I, Mendel H, Struck H P, Ribeiro C and Zanatta A R 2006 Op. Mater. 28 790
[5] Aldabergenova S B, Osvet A, Frank G, Struck H P, Taylor P C and Andreev A 2002 J. Non-Cryst. Sol. 709 299-302
[6] Weingärtner R, Guerra Torres J A, Erlenbach O, Gálvez de la Puente G, De Zela F and Winnacker A 2010 Mater. Sci. Eng. B 174 114-118
[7] Dmitriev V A 1990 Amorphous and Crystalline Silicon Carbide III 56 Springer 3
[8] Gurumurugan K, Chen H, Harp G R, Jadwisienczak W M and Lozykowski H J 1999 Appl. Phys. Lett. 74 3008
[9] Gálvez de la Puente G, Torres Guerra J A, Erlenbach O, Steidl M, De Zela F, Weingärtner R and Winnacker A 2010 Mater. Sci. Eng. B 174 127-131
[10] Torres J A, Winterstein A, Erlenbach O, Gálvez de la Puente G, De Zela F, Weingärtner R and Winnacker A 2010 Mater. Sci. Forum Vols. 645-648 263-266
[11] Erlenbach O, Gálvez de la Puente G, Torres J A, De Zela F, Weingärtner R and Winnacker A 2010 Mater. Sci. Forum Vols. 645-648 459-462
[12] Gálvez de la Puente G, Erlenbach O, Torres Guerra J A, Hupfer T, Steidl M, De Zela F, Weingärtner R and Winnacker A 2010 Mater. Sci. Forum Vols. 645-648 1199-1202
[13] Swanepoel R 1983 J. Phys. E: Sci. Instrum. 16 1214.

Acknowledgements
This research is funded by the Deutsche Forschungsgemeinschaft (DFG) and the Bundesministerium für Zusammenarbeit und Entwicklung (BMZ) under contract number WI393-20-1,2, WI393/21-1,2,3 and is supported by the German Academic Exchange Service (DAAD) under contract number D08-09227.