Durable AlN and Al_2O_3 Optical Films Deposited by Low Duty Cycle Pulsed Magnetron Sputtering

J. Kohout, T. Schmitt, R. Vernhes, O. Zabeida, J.E. Klemberg-Sapieha, L. Martinu

Department of Engineering Physics, Thin Film Research Center-GCM, Polytechnique Montreal, P.O. Box 6079, Station Centre-Ville, Montreal, Quebec H3C 3A7, Canada

POLYTECHNIQUE MONTRÉAL
LE GÉNIE EN PREMIÈRE CLASSE

Background and objective

•Transparent Al_2O_3 and AlN materials are praised for their high hardness, toughness and durability and may find utilization in numerous applications such as touch screens of portable devices or ophthalmic lenses.

•However, deposition of Al-based films is challenging due to severe arcing during the sputtering process and high intrinsic stress in the films.

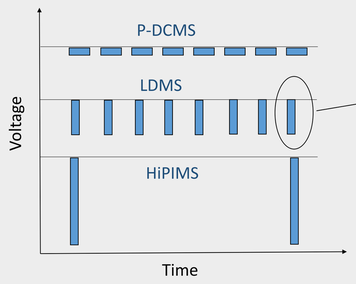
• Inspired by our earlier work on HiPIMS, we aimed to eliminate arcing in the reactive magnetron sputtering of Al target and to prepare transparent low-stress AlN and Al_2O_3 films at deposition rates using low duty cycle pulsed magnetron sputtering with very short pulses (t = 10 µs).

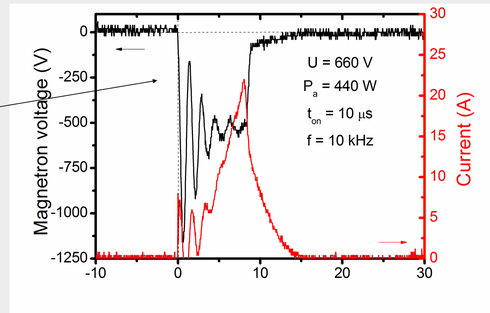
Experimental

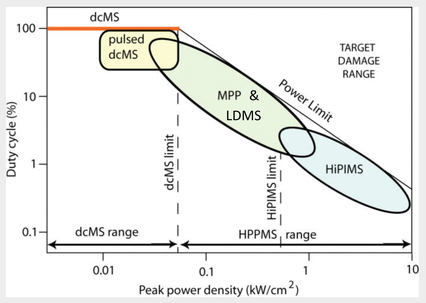
Significant magnetron voltage oscillations during the whole 10-µs pulse → stabilization of the discharge and elimination of arcing. Frequency of the voltage oscillations around 500 Hz well above upper limit of conventional pulsed power supplies → possible benefits for reactive sputtering of highly dielectric materials (e.g., metal oxides).

Deposition conditions

- *Al target, 4 " diameter*
- *Average target power: 200 – 1200 W*
- *Total pressure: 3 – 20 Tor*
- *rReactive gas/Ar flow ratio:* 1:20
- *Frequency: 10 kHz*
- *Duty cycle: 10 %*
- *Substrates: B270 , Si <100>*
- *Target to substrate distance: 90 mm*

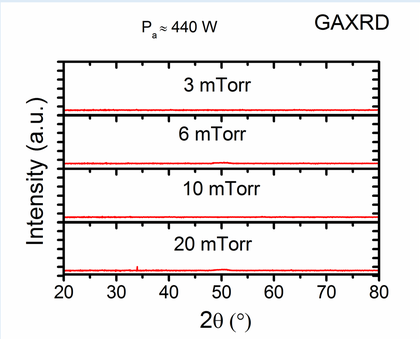


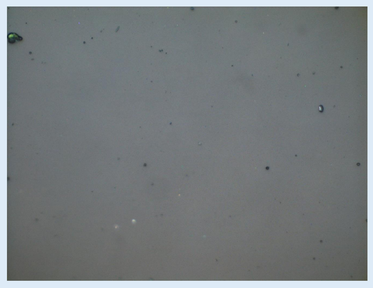




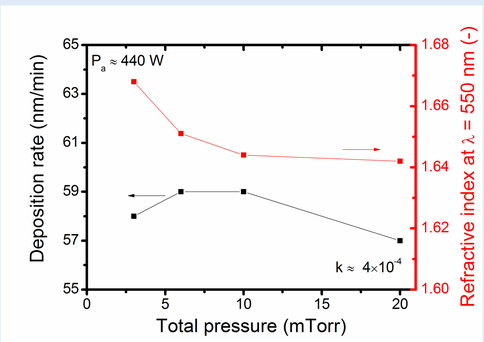
Adapted from [1]

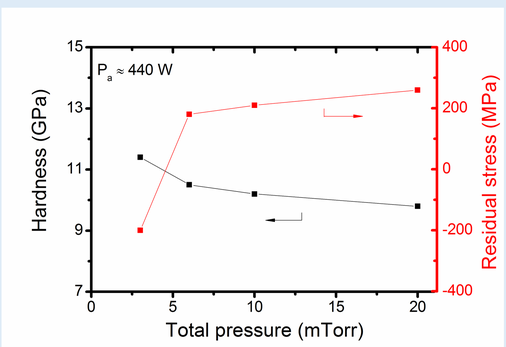
Al_2O_3 films



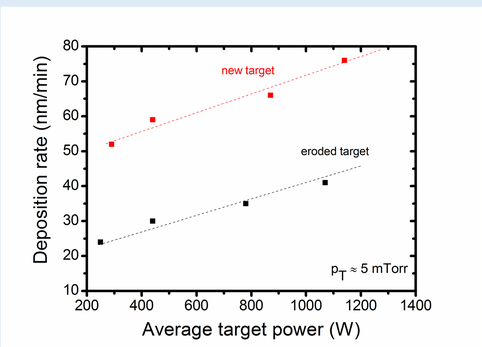


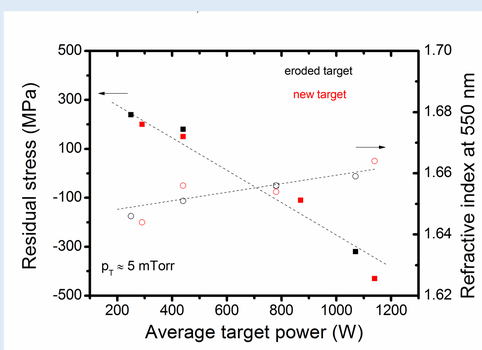
•All studied Al_2O_3 films were X-ray amorphous. No macroparticles were observed on the surfaces due to the elimination of arcing even at long deposition runs.





• The deposition rate was almost 60 nm/min regardless of the total pressure. A monotonic decrease in refractive index from 1.67 to 1.64 was observed (lower densification of the films at higher pressure)
• The hardness of Al_2O_3 decreased from 11.5 GPa to 10 GPa with the increasing pressure (again lower density of the films) and the residual stress switched from compressive to tensile (decrease in the total energy delivered to the films).

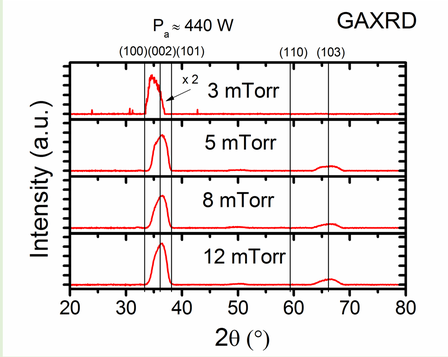


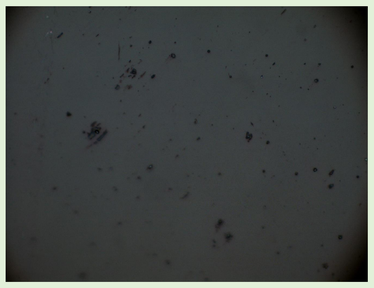


•The deposition rate increased with the increasing target power and was with the new target significantly higher (by 80-100 %) than with the eroded target (due to geometrical effect and/or effect of changed magnetic field).

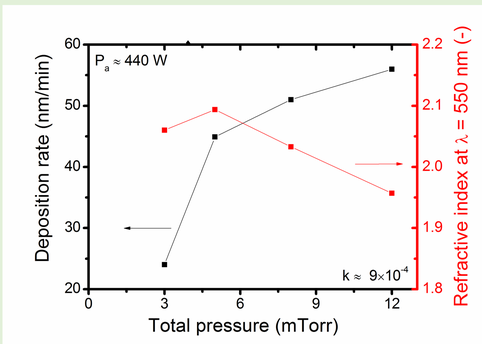
• Properties of the films seem to be largely unaffected by the level of target erosion.

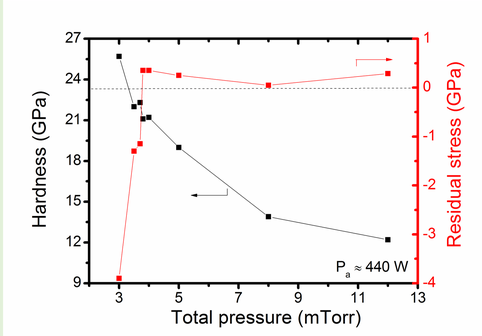
AlN films





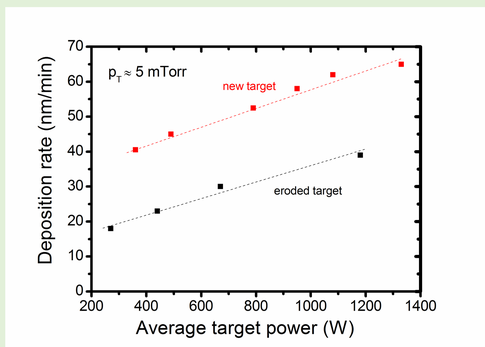
•GAXRD measurements revealed crystalline AlN films with predominant (002) orientation (i.e.,c-axis AlN) for all studied pressures. In the case of the 3 mTorr AlN film, the (002) peak shifted significantly to lower angles (high compressive stress). Similarly as for the Al_2O_3 films, no macroparticles were observed (elimination of arcing even at long deposition runs).

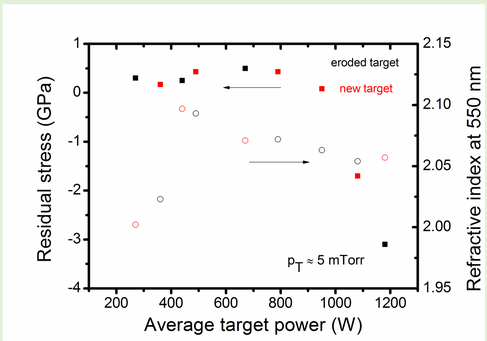




Continuous decrease in hardness with the increasing pressure due to higher porosity and oxygen incorporation was observed.

• Very sharp switch from tensile to compressive residual stress at total pressure of 4 mTorr.





The deposition rate was systematically significantly higher in the case of new target for the given average target power (geometrical effect of the eroded target and/or effect of different magnetic field and higher voltage).

• The residual stress and also the refractive index followed the same trend in the both cases.

Conclusions

• The LDMS deposition technique inspired by HiPIMS and based on the utilization of very short oscillating pulses at high repetition frequency is an effective way to stabilize the reactive magnetron sputtering process of Al and to avoid arcing.

• Dense and transparent Al_2O_3 and AlN films with interesting optical and mechanical properties were prepared at relatively high deposition rates (up to 60 nm/min).

• The possible benefits of this approach for reactive deposition of other dielectric materials are now being investigated.

References

[1] Gudmundsson JT, Brenning N, Lundin D, Helmersson U. High power impulse magnetron sputtering discharge. J. Vac. Sci. Technol. A 2012;30:030801.

[2] J. Kohout, E. Bousser, T. Schmitt, R. Vernhes, O. Zabeida, J. Klemberg-Sapieha and L. Martinu, "Stable reactive deposition of amorphous Al2O3 films with low residual stress and enhanced toughness using pulsed dc magnetron sputtering with very low duty cycle", Vacuum, 124 (2016) 96-100.

[3] AlN paper to be published