UWS Academic Portal

A comparison between DCMS, HiPIMS and a novel 'HiPIMS+Kick' deposition for piezoelectric thin-films

Rogan, Mhairi; O'Donnell, John; Hrebik, Jason; Franzer, Nick; Belan, Rob; Gibson, Des; McAughey, Kevin L.; Hughes, David A.

Published in:
2019 IEEE International Ultrasonics Symposium, IUS 2019

DOI:
[10.1109/ULTSYM.2019.8925581](https://doi.org/10.1109/ULTSYM.2019.8925581)

Published: 31/10/2019

Document Version
Peer reviewed version

[Link to publication on the UWS Academic Portal](#)

Citation for published version (APA):
Rogan, M., O'Donnell, J., Hrebik, J., Franzer, N., Belan, R., Gibson, D., McAughey, K. L., & Hughes, D. A. (2019). A comparison between DCMS, HiPIMS and a novel 'HiPIMS+Kick' deposition for piezoelectric thin-films. In *2019 IEEE International Ultrasonics Symposium, IUS 2019* (pp. 2616-2619). [8925581] (IEEE Conference Proceedings). IEEE. <https://doi.org/10.1109/ULTSYM.2019.8925581>

General rights

Copyright and moral rights for the publications made accessible in the UWS Academic Portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

Take down policy

If you believe that this document breaches copyright please contact pure@uws.ac.uk providing details, and we will remove access to the work immediately and investigate your claim.

“© © 2019 IEEE. Personal use of this material is permitted. Permission from IEEE must be obtained for all other uses, in any current or future media, including reprinting/republishing this material for advertising or promotional purposes, creating new collective works, for resale or redistribution to servers or lists, or reuse of any copyrighted component of this work in other works.”

A comparison between DCMS, HiPIMS and a novel ‘HiPIMS+Kick’ deposition for piezoelectric thin-films

Mhairi Rogan
novosound ltd.

Motherwell, Scotland
mhairi.rogan@novosound.net

John O'Donnell
Kurt J. Lesker company
Hastings
johnno@lesker.com

Jason Hrebik
Kurt J. Lesker company
Hastings
jasonh@lesker.com

Nick Franzer
Kurt J. Lesker company
Hastings
nickf@lesker.com

Rob Belan
Kurt J. Lesker company
Hastings
robb@lesker.com

Des Gibson
*Institute of Thin Films, Sensors
and Imaging,
Scottish Universities Physics
Alliance
School of Computing, Engineering
and Physical Sciences,
University of the West of Scotland,
Paisley
Des.gibson@uws.ac.uk*

Kevin L. McAughey
novosound ltd
Motherwell, Scotland
kevin.mcaughey@novosound.net

David A. Hughes
novosound ltd.
Motherwell, Scotland
Dave@novosound.net

Abstract—High power impulse magnetron sputtering (HiPIMS) has been shown to improve optical and semi-conductor thin-film coatings through increased density [1], crystallinity and more control over deposition parameters [2]. Here, HiPIMS and, a new technique, HiPIMS + ‘Kick’ are investigated in relation to deposited piezoelectric coatings and compared with a standard DCMS coating. To assess improvements for acoustic generation, these films have been characterized using SEM and XRD techniques for material parameters, simulations have been done to model acoustic output and further work is to be done to find d_{33} parameters.

Keywords—thin-films, materials, HiPIMS

I. INTRODUCTION

Current ultrasonic imaging relies on ceramic materials such as lead zirconium titanate (PZT) and PVDF. These ceramics have a complex manufacturing process, particular for high frequencies, as well as relatively low Curie temperatures, limiting their operation above 250°C. Piezoelectric thin films, such as aluminium nitride (AlN) and zinc oxide (ZnO) have long been desirable for ultrasonic imaging transducers due to their ability to operate at high frequencies and temperatures, being fully flexible and having a cheap, simple manufacturing process. Until recently, however, thin films have been unable to compete with standard transducer materials such as PZT and PVDF since their acoustic properties are much lower [3]. These properties include d_{33} , which is 3.4pmV^{-1} for AlN [4] compared to values as high as 513pmV^{-1} [5] for more conventional

piezoelectric materials. This work focuses on whether use of the newly developed high-power impulse magnetron sputtering (HiPIMS), which vastly increases the quality of optical coatings [REF], can similarly increase the acoustic output of piezoelectric thin films. Deposited thin films were characterized using scanning electron microscopy (SEM) and x-ray diffraction (XRD) to examine the crystal structure, while simulations were used to predict the effect of the change in material properties on the ultrasonic behavior of the thin films. In order to develop a more complete understanding on the effect of the HiPIMS deposition on films for ultrasonic applications additional experimental work is required to confirm the effects observed in simulations.

II. EXPERIMENTAL SET-UP

The proprietary material comprises a flexible substrate which is coated with a piezoelectric thin film; namely Wurtzite zinc oxide, through reactive magnetron sputtering. A comparison was made between depositions using three different methods; a conventional DC power supply, a HiPIMS supply and a novel HiPIMS+kick. HiPIMS+kick uses the same premise as HiPIMS but includes an additional positive voltage ‘kick’ to further increase density and reduce stresses in deposited material. The films obtained from the different sputtering procedures were characterized through SEM and EDX. All

Fig. 1. XRD spectrum of proprietary material deposited by HiPIMS (top) and HiPIMS+Kick

depositions were done with the support of Kurt J. Lesker using a PVD75 system and MAGkeeper sputter cathodes. The power supply used was a Starfire Industries Impulse PSU. Depositions were done at a sputtering pressure of 5 mTorr, with 30 sccm of Ar and 6 sccm of O₂ using a 99.99% purity ZnO target. A calibration step was undertaken pre-deposition to calculate the time necessary to deposit approximately one micron of ZnO. For the HiPIMS and HiPIMS + Kick depositions, the pulse width was 40μs at 1196Hz. The positive “kick” had a voltage of 100V, width of 50μs and delay of 4μs. Characterization of the deposited films was then characterized at the Institute of Thin Films, Sensors and Imaging at the University of the West of Scotland.

III. RESULTS AND DISCUSSION

A. XRD

Initial results, as seen in figure 1 above, show that both HiPIMS and HiPIMS+kick deposited crystalline ZnO with strong c-axis growth. XRD shows that each deposition has resulted in a clear, sharp (002) Wurtzite peak, however, some interfering layers can be seen in the data, corresponding to

TABLE I. Thicknesses and deposition rates for each sample

Sample	Thickness (nm)	Deposition rate(μmh ⁻¹)
DCMS	970	0.070
HiPIMS	863	0.055
HiPIMS + Kick	917	0.037

(101) ZnO. Figure 1 shows a peak at the corresponding 2θ-angle 34.4° for zinc oxide, with the HiPIMS+kick method resulting in a more intense peak although this could be due to this film being thicker than the HiPIMS sample.

B. SEM

Thicknesses were measured using SEM images and, as can be seen in Table 1 below, HiPIMS and HiPIMS + Kick reduce the deposition rate. For all three depositions, sputter time was estimated to deposit 1μm of material. Thicknesses of three samples were measured; DC = 970nm, HiPIMS = 863nm, and HiPIMS+kick = 917nm. The relationship between the physical and crystal properties of the film, such as thickness, stoichiometry and crystal structure are also related to the ultrasonic performance of the film, particularly the d₃₃ value. This allows the suitability of the HiPIMS deposition method for producing piezoelectric films for ultrasonic transducers to be assessed, and for refinements in the deposition process to be made.

Although it was expected that the HiPIMS deposition would show a reduced deposition rate to DCMS due to increased self-sputtering within the HiPIMS plasma [5], it was hoped that the positive kick during the HiPIMS + Kick run would bring the deposition rate back up to close to the DCMS. This was not the case, and in fact, the HiPIMS + Kick run had around half the deposition rate that DCMS had and 2/3 of the HiPIMS rate, as can be seen in Table 1.

C. Simulations

Simulations were performed to compare the acoustic output of DCMS and HiPIMS deposited ZnO. For these simulations, a simple, air-backed transducer facing into water was modelled. The simulations investigated the acoustic output of films with varying crystal density, efficiency and stiffness due to this being directly proportional to the expected increase in elasticity. As can be seen in Fig. 3., the response of the acoustic output to the changes in material properties had significant

variations, with the increase in density having no real effect, Fig. 2. SEM micrographs of (a) HiPIMS deposition, and (b) HiPIMS+Kick

while the increase in piezoelectric coefficient has a positive

Fig. 3. Simulation results showing how acoustic output varies with differing material properties.

impact and the increase in stiffness has a negative effect.

By considering all the responses of all three changes it can be seen that the decrease in acoustic performance due to increased stiffness is the dominant effect, suggesting that, although HiPIMS is expected to improve the crystallinity of deposited thin films, this is not a positive change for an acoustic thin film.

These simulations showed that this increase in stiffness reduces the acoustic output of our films linearly which can be explained using the relationship below,

$$k_{33}^2 = \frac{e_{33}^2}{\epsilon_{33}C_{33} + e_{33}^2} \quad (1)$$

Where k_{33} is the coupling coefficient, e_{33} is the piezoelectric constant, C_{33} is the stiffness and ϵ_{33} is the dielectric constant of the material along the c-axis. Equation (1) clearly shows that, as the stiffness of a material increases, the conversion of energy from one form to another reduces, and in these simulations this effect is dominant over the improvements expected in the piezoelectric efficiency.

IV. CONCLUSION

Although HiPIMS depositions have shown improvements for optical and semi-conductor coatings such as Tantalum on Silicon [6] due to increased crystallinity, density and lower residual stress [7], it is unlikely that HiPIMS or HiPIMS + Kick are the future of acoustic coatings. This is due to increased elasticity reducing the acoustic output of piezoelectric films, although further investigation is required to correlate the simulated performance of HiPIMS thin films to experimental results.

ACKNOWLEDGMENT (Heading 5)

novosound ltd. and University of the West of Scotland would like to thank Innovate UK for

REFERENCES

- [1] Lefki, K., and G. J. M. Dormans. 1994. "Measurement of Piezoelectric Coefficients of Ferroelectric Thin Films." *Journal of Applied Physics* 76 (3): 1764–67.
- [2] Marc-Alexandre Dubois, Paul Muralt. 1999. "Properties of aluminium nitridethin films for piezoelectric transducers and microwave filter applications." *Applied Physics Letters* 74 (20) 3032
- [3] Hudai Kara, Rajamani Ramesh, Ron Stevens, Chris R. Bowen. 2003. "Porous PZT ceramics for receiving transducers." *IEEE Transactions on ultrasonics, ferroelectrics, and frequency control*. 50 (3) 289-296
- [4] Samuelsson, Mattias, Daniel Lundin, Jens Jensen, Michael A. Raadu, Jon Tomas Gudmundsson, and Ulf Helmersson. 2010. "On the Film Density Using High Power Impulse Magnetron Sputtering." *Surface and Coatings Technology* 205 (2): 591–96.
- [5] Ait Aissa, K., A. Achour, J. Camus, L. Le Brizoual, P-Y Jouan, and M-A Djouadi. 2014. "Comparison of the Structural Properties and Residual Stress of AlN Films Deposited by Dc Magnetron Sputtering and High Power Impulse Magnetron Sputtering at Different Working Pressures." *Thin Solid Films* 550 (January): 264–67.
- [6] Sarakinos, K., J. Alami, and S. Konstantinidis. 2010. "High Power Pulsed Magnetron Sputtering: A Review on Scientific and Engineering State of the Art." *Surface and Coatings Technology* 204 (11): 1661–84.
- [7] Ait Aissa, K., A. Achour, O. Elmazria, Q. Simon, M. Elhosni, P. Boulet, S. Robert, and M. A. Djouadi. 2015. "AlN Films Deposited by DC Magnetron Sputtering and High Power Impulse Magnetron Sputtering for SAW Applications." *Journal of Physics D: Applied Physics* 48 (14): 145307.