Roll to Roll Co-Sputtering: Insights on Power and Control

David J. Christie, Advanced Energy Industries, Inc., Fort Collins, CO 80525

dave.christie@aei.com

Magnetron sputtering is used to deposit large scale multi-layer structures on flexible webs for an ever expanding set of applications. Pulsed power is used for reactive deposition of dielectric and semiconducting compounds, enabling deposition processes essentially impossible with direct current (DC). Target arcs are prevented by periodic discharge of insulative films deposited on the target. Reversing anode voltage enables continuous processing. New developments, key solutions, and opportunities are enabled by pulsed power capabilities. A family of pulsed power supplies has been developed specifically for driving dual magnetron sputtering (DMS) processes. In particular, they enable reactive co-sputtering in pulsed DMS systems by providing independent control of power delivered to each magnetron and process measurements specific to each magnetron.

It is possible to configure a sputtering system such that two different target materials are sputtered, with the power to each of the targets controlled independently, as shown in Figure 1. This is referred to as co-sputtering. When co-sputtering is performed in the presence of a reactive gas, it is called reactive co-sputtering. The motivation is creation of controlled mixtures of materials in the film deposited by the process. Reactive co-sputtering is appealing because it can deposit films otherwise unrealizable. It allows, for example, the creation of films with customized or graded indexes of refraction. For example, Al_2O_3 can be deposited with a refractive index of about 1.6 and TiO_2 can be deposited with a refractive index of about 2.4. If a co-sputtering arrangement is configured with one Al target and one Ti target, the ratio of Ti to Al can be controlled by controlling the power to each of the magnetrons. Therefore, in principle, it is possible to “dial” the refractive index anywhere between 1.6 and 2.4.

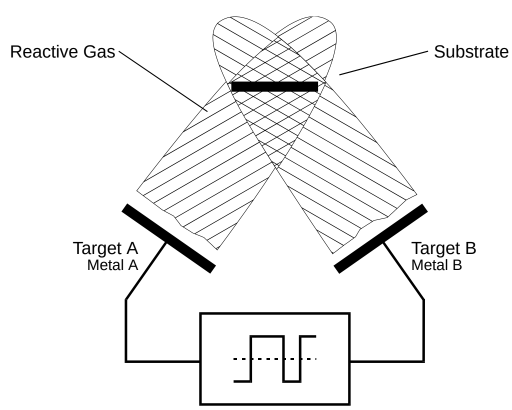

Figure 1. Pulsed dual magnetron reactive co-sputtering arrangement.

Co-sputtering, with a different material on each of the targets in a dual magnetron sputtering (DMS) system, enables thin film materials with properties not otherwise achievable. It is beneficial to understand the properties of a reactive co-sputtering process operating in the transition region between the metallic state (with a small fraction covered with compound) and the poisoned state (approaching unity coverage with compound) of the target. Insight into the requirements for control of deposition rate and composition can be gained. A static model can be used to find the equilibrium characteristics of the process, and build intuition about transfer characteristics impacting rate, stability and composition. When reactive co-sputtering processes are operated in the naturally unstable transition region they must be stabilized with output feedback. Published data can be used to model a representative reactive co-sputtering process. Reactive co-sputtering in roll to roll DMS systems is enabled by pulsed power supplies with independent control of power delivered to each magnetron and process parameter measurements specific to each magnetron.

Co-sputtering of two different materials was initially accomplished with ion beam sputtering or the use of RF or DC supplies to deliver power to sputtering targets in diode or magnetron configurations [1, 2]. The development of pulsed supplies which can reliably regulate the power delivered to each magnetron is a key enabling technology for reactive co-sputtering in a conventional dual magnetron sputtering (DMS) arrangement. Pulsed supplies inherently offer more flexibility in control of the process. They provide the capability of independently regulating the power delivered to each magnetron. This has some advantages for existing processes, and enables the implementation of co-sputtering processes. Independent regulation enables the creation of controlled mixtures of materials in the film when dissimilar materials are used for the magnetron targets in a co-sputtering arrangement. This allows the creation of films with customized or graded indexes of refraction.

Co-sputtering has mostly been reported on a small scale. A constant concern is scaling to large substrates, with sizes appropriate for architectural and automotive glass, as well as large web coaters. Results for large scale inline coaters, using DC power supplies, were reported in 1991 [3-5]. Several issues of scaling, such as uniformity and film quality, were addressed. Now high power pulsed supplies for DMS systems with capability for independent regulation of power to each magnetron enable large scale pulsed reactive co-sputtering in industrial roll to roll DMS systems [6-9].

A 20 kW pulsed current source system for DMS was introduced in 1996 [10-13]. In 1998, a 120 kW pulsed current source solution, capable of driving DMS or single magnetron processes, and targeting large area industrial coating processes was introduced to the marketplace [14]. A 200 kW pulsed current source supply was introduced in 2000, capable of driving essentially all industrial scale large area reactive DMS processes [15, 16]. These units are still in service for industrial large area glass coating. In 2013, a pulsed current source solution was introduced based on modularity. It is capable of delivered powers in excess of 200 kW, with granularity as small as 30 kW. Targeted at large area industrial processes, its primary application is DMS; it is capable of single magnetron operation in some specialized situations [6-9].

The potential of reactive co-sputtering has motivated several workers to address process models. Early work modeling co-sputtering processes focused on process voltage and current as model outputs [17]. The resulting model gave interesting results; however, the algorithms required for model computation were complex and challenging to implement. Almost ten years later, an extension of the Berg model was introduced which showed that the basic process curves look qualitatively like those for simple reactive sputtering [18]. Further work has refined the basic approach, effectively modelling equilibrium (static) process conditions [19].

A detailed investigation of co-sputtering, based on process modeling, has shown that more than one enabling technology is required. Pulsed dual-magnetron sputtering with independent regulation for each magnetron is the required base. However, a closer look shows that both the composition of the film and the deposition rate are in fact functions of the partial pressure of the reactive gas. This result indicates that control of the reactive sputtering working point (with at least implicit control of partial pressure) is also required in order to achieve high quality films of consistent composition. Both independent regulation of power to each magnetron, and reactive sputtering working point control, are required in order to set both the film composition (hence, index of refraction for an optical film) and deposition rate.

Summary

Co-sputtering for large area processes is enabled by pulsed DMS power supplies with independent regulation and monitoring for each magnetron. A detailed model of the reactive co-sputtering process provides insight into process characteristics, and shows that both power control and reactive sputtering working point control are required to gain control over film composition and deposition rate.

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