From Lab to Gigafactory:

Pioneers for the Mass Production of Next-Generation Thin-Film Battery Materials

Cameron R. Gottlieb

Thin-film technology represents an emerging class of materials to supplant incumbent battery designs with lighter and higher-performance materials across the entire cell architecture. Although groundbreaking strides have been achieved in the laboratory, most developers fail to develop an economically sustainable model for commercial manufacturing at scale. This is the single greatest challenge in the commercialization of advanced battery materials.

AGC Plasma Technology Solutions is the industrial thin-film coatings unit of AGC Inc., a global materials company and the world's largest glass producer. It applies complex optical thin-film coatings to most of its glass products for various functions like thermal insulation and anti-reflection. Thin-film coatings are thin layers of materials that are applied to a substrate in a vacuum (low pressure) deposition process, where coating thicknesses are typically in the range of 1 nm to 50 µm. It is an environmentally-sustainable dry process which does not use solvents or water. The company have developed several advanced vacuum coating technologies over past decades, including magnetron sputtering, PlasmaMAX™ PECVD, and thermal evaporation, to optimize high-volume manufacturing of large area coated glass products.

The coating platforms were developed specifically for high-volume mass production of highly uniform materials on large area substrates, often larger than 3 meters in width.

The company provides industrial process equipment based on this coating technology to a range of industries that require high-volume (millions of square meters) mass production of advanced thin-film technologies. The coating platforms are deployed in customized process equipment used for coating both rigid (Sheet-to-Sheet) and flexible (Roll-to-Roll) substrates. Due to unprecedented demand growth expected for electric vehicles in the next decade, there will be a need to manufacture millions of square meters of battery materials annually with superior quality and cost-efficiency. The only proven industrial experience in manufacturing thin-films at this scale is found in the glass industry. Thin-film battery materials were therefore identified as an ideal application for coating technology.

Figure 1: AGC Production Facility (Osterweddingen, Germany)

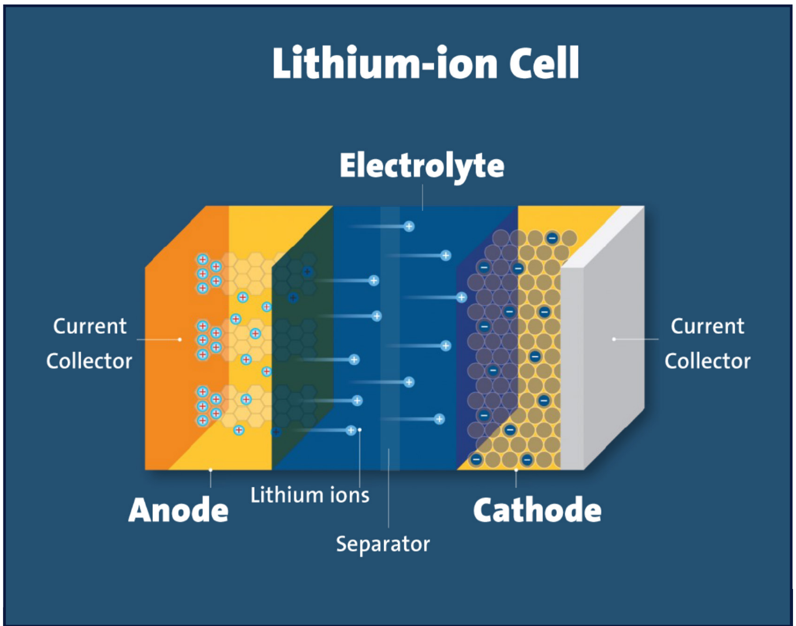

Figure 2: Basic Components of a Lithium-ion Cell[2]

Why thin-film batteries?

Thin-film battery materials offer substantial promise for the widespread adoption of electrified mobility by addressing three key challenges in the EV industry.

First, thin-film materials reduce range anxiety, the single biggest obstacle to driving positive consumer sentiment, by enabling a dramatic increase in battery performance. By replacing thick solid materials, thin-film coatings allow for substantial reduction in weight of the overall cell, which directly results in an increase in energy density and longer cycling life. Thinner materials also permit bendability as form factors of battery applications like wearables grow increasingly complex.

AGC
Your Dreams, Our Challenge

AGC Plasma Technology Solutions

Vacuum coating equipment for innovative thin-film battery materials

Scaling from lab to gigafactory

ROLL-to-ROLL EQUIPMENT

SHEET-to-SHEET EQUIPMENT

Coating Technologies

- Magnetron Sputtering
- Plasma Enhanced Chemical Vapor Deposition (PECVD)
- Thermal Evaporation

Battery Components

- Anode (Silicon, Lithium)
- Cathode (LFP, LCO, NMC)
- Solid Electrolyte (LiPON)

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Second, thin-film coatings offer a wide range of materials availability which is either unavailable or impractical with traditional battery materials and processing methods. The coating technologies are fully configurable for a wide range of process conditions and precursor materials, enabling novel solutions across the entire cell from the cathode and anode to the electrolyte, separator, and current collector.

An insufficiently addressed challenge in securing long-term capital investment in new battery technologies is the inherent uncertainty associated with the localization of critical raw materials in regions at risk of trade conflict with the US and EU. The process versatility afforded by thin-film technology allows cell developers to investigate new classes of coating materials and precursors which are not derived from geopolitically risky supply chains. In December 2023, China, the world's number one supplier of graphite, implemented export restrictions on the material as a response to US-led restrictions on semiconductor exports1. Graphite is used as the anode in every commercially produced lithium-ion battery in the world. There is therefore substantial risk for the global battery industry if a critical material is subject to the political vicissitudes of a single country. Thin-film technology allows for the development of better materials with higher performance that are derived from globally abundant sources.

Third, and most importantly, thin-film battery materials are scalable. Established Roll-to-Roll processing techniques allow cost-efficient mass production by coating thin-film battery materials onto flexible rolls of substrate material inside a coater within a small footprint. Roll-to-Roll coating equipment enables an automated one-step manufacturing process which occurs entirely inside the coater. A roll of substrate material (e.g., copper foil) is loaded into the coater. The coater is then evacuated to low pressure (vacuum) using pumps, whereupon the foil unwinds from one roller to another. A coating process applies materials to the foil in between rollers. Once complete, the coater is vented back to atmospheric pressure, where the finished roll of coated material is removed for integration into the battery cell. This precludes the need for traditional multi-step wet processing techniques, which command substantial manufacturing floorspace and create significant amounts of environmental waste.

Figure 3: AGC Roll-to-Roll Industrial Coater

Enhanced Chemical Vapor Deposition (PECVD) developed by AGC to substantially increase coating deposition speed of certain materials. PECVD uses a precursor material which is injected into the coating chamber as a volatilized liquid or a gas. Inside the coating chamber, precursor is injected directly into a high-density plasma which facilitates a chemical reaction of the precursor into a reactant which deposits onto the substrate as a coating. PlasmaMAX™ offers ultra-high-rate coating speeds (typically ~ 10x compared to magnetron sputtering) and high controllability of coating properties like porosity and morphology.

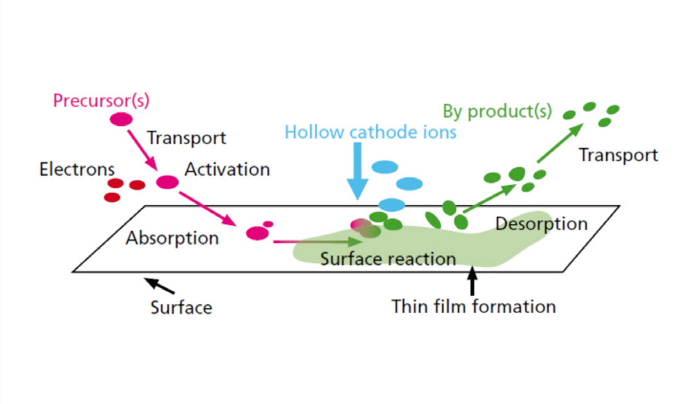

Figure 5: PlasmaMAX™ PECVD Coating Mechanism

Five decades of innovation in mass production of thin-film coatings

AGC developed three primary coating technologies for use in high-volume mass production of large area thin-film materials. All three are designed to be interoperable such that they can be combined inside the same coating chamber to allow one-step manufacturing of complex multilayer coatings.

Magnetron sputtering is a type of Physical Vapor Deposition (PVD) which creates thin coatings by accelerating ionized argon atoms into a solid target material. The momentum transfer of the argon ions into the target causes the ejection of target atoms, which ballistically move from the target surface onto a substrate surface. The company pioneered the use of magnetron sputtering for industrial glass coatings in the 1980s and developed several innovations for its use in high-volume manufacturing. A key benefit of magnetron sputtering is its wide coating materials availability and extremely high thickness uniformity control. Sputtering enables precise control of film properties like smoothness, crystal size, and dendrite growth.

Figure 4: PlasmaMAX™ PECVD Source

Thermal evaporation is a well-established vacuum deposition process for many decades in the production of materials like metallized plastic films. Coating materials in the form of solid pellets or granules are placed in an evaporation source, which is typically a boat made of a refractory metal like tungsten. A resistive heating element is used to heat the coating material under vacuum, whereupon it will sublimate and ultimately condense onto a substrate as a coating. Thermal evaporation has a relatively high deposition rate and is therefore useful for producing thick coatings in the μm range. The disadvantage of thermal evaporation is that there is limited range of coating materials and there is less controllability of film properties and thickness uniformity compared to magnetron sputtering and PECVD.

Building the world's first Gigafactory for 100% silicon anodes

AGC leverages its suite of advanced coating platforms combined with its unique position as the world's largest manufacturer of large area thin-film coatings to provide an accelerated path to mass industrialization of next generation thin-film battery materials. Innovative battery developers like GDI recognize the tremendous gulf between success in the laboratory and operational excellence in a mass production environment. The Tesla story illustrates this concept well. AGC's decades of industrial experience in the design, testing, and upscaling of large are thin-film coatings and its established global manufacturing footprint enable companies like GDI to fast-track the commercial deployment of truly game-changing battery technologies.

GDI and AGC signed a JDA in 2022 for the development of a 100% silicon anode produced using AGC's PlasmaMAX™ PECVD platform. While providing 30% higher battery range and 15-minute fast-charging capability, 100% silicon anodes can be produced entirely with a gas derived from the second most abundant element in Earth's crust.

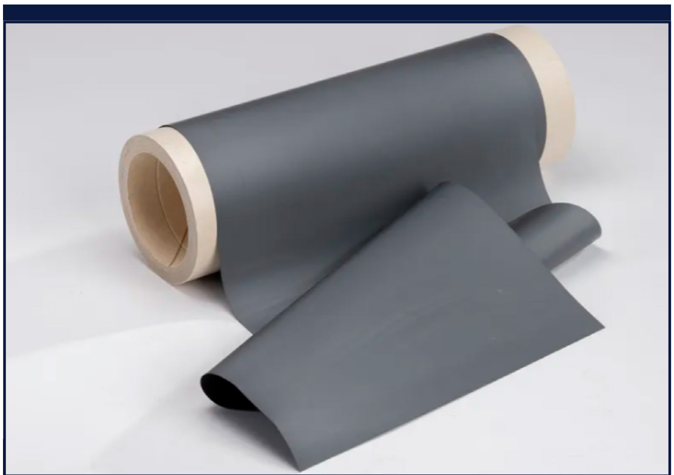

Figure 6: GDI 100% Silicon Anode Produced on AGC Pilot Coater[3]

GDI developed one of the most promising advances in battery technology in recent years, but a key challenge was how to turn that success into a commercial product. The technology used to initially develop the coating has a limited deposition rate to grow the silicon coating, which constrains overall production capacity. Considering expected demand of hundreds of millions of square meters of anode in the coming decade, coating technology is needed with the highest possible deposition rate, as well as dependable, stable, and uniform operation over long production campaigns. After successfully commissioning a pilot Roll-to-Roll coater for GDI's silicon anode production with a PlasmaMAX™ PECVD source, planning is now underway for installation of GDI's first manufacturing plant in Germany[4].

Figure 7: AGC Pilot Coater for GDI 100% Silicon (Lauenförde, Germany)

Another promising application for AGC coating technology is the production of lithium-based anode materials. Lithium, along with silicon, enables substantial improvements in battery performance. Lithium anodes today are created using thick solid lithium foil. This presents supply risk due to the scarcity and availability of lithium foil and adds excessive weight to the cell. A more efficient solution is thin-film deposition of lithium directly onto a current collector. This allows for precise control of the optimal amount of lithium, reduces overall weight for greater efficiency, and circumvents supply risks for lithium foil. AGC partnered with a European cell developer to integrate a lithium evaporation process into an industrial Roll-to-Roll coater.

AGC Plasma Technology Solutions (Louvain-la-Neuve, Belgium), a supplier of advanced thin-film coating equipment, partners with technology developers across the world to accelerate the mass adoption of electrified mobility by supporting the industrial scale-up of next-generation thin-film battery materials from the laboratory to GWh-scale mass production

Cameron R. Gottlieb

Business Development Manager, USA AGC

1) https://www.reuters.com/world/china/china-require-export-permits-some-graphite-products-dec-1-2023-10-20/

2) https://ul.org/research/electrochemical-safety/getting-started-electrochemical-safety/what-are-lithium-ion

3) https://www.gdinrg.com/

4) https://www.agc-plasma.com/news/agc-glass-europe-and-gdi-extend-collaboration-to-develop-and-industrialize-100-silicon-anodes-for-batteries-to-replace-graphite