New Roll-to-Roll Sputtering System for Wide Film and Application Examples

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A new roll-to-roll sputtering system for wide film substrate is now under development; it is characterized by the connection of unit chambers in the horizontal direction. The new model is an improvement over previous models and is easily disassembled for shipping and assembled for installation; and it has kept the "open chamber concept" of previous models in the way in which the process chamber with sputtering source dynamically moves to the back of the equipment, which allows easy access to the coating zone. It also has sufficient degassing capability, thanks to a specialized degassing chamber unit. This system makes a suitable coating process for touch-panel displays or heat reflective film, etc., where the substrate film is wider. The other R2R coating system models are also introduced.

Introduction

Products having resin films with various functions imparted by vacuum coating are widely used in our daily lives. For example, a package material for snack food or retort food includes a substrate film of polypropylene (PP) or polyethylene terephthalate (PET), with a coating of aluminum (Al) and/or silica (SiOx) deposited on the substrate film so as to suppress the transmission of atmospheric water vapor and oxygen and to prevent deterioration of food quality and extend the expiration date. Conventionally, many food-package materials have had aluminum coating deposited on their surfaces. Lately, package materials with a transparent film deposit of silica and imparted with a function of visibility are also found.

Smartphones and tablet terminals with touch panels have been spreading rapidly in recent years. These touch panels also include resin films with vacuum coating. More recently, in particular, projected capacitive touch panels are being widely used; these panels allow multiple pointing input and gesture functions, for example, moving the fingers to enlarge and shrink pictures. A transparent electrode component disposed on the operation surface of such a touch panel comprises a hard-coated PET substrate having an optical adjustment layer, index matching (IM) layer and indium-tin-oxide (ITO) film layer deposited on it. The layers are patterned for multi-wiring by etching. A patterned monolayer of ITO film, however, can be slightly visible. Hence an optical adjustment layer is formed on the ITO film layer so as to make the pattern less visible.

Coating on flexible substrate often involves the use of a system called "roll-to-roll" (hereinafter "R2R"), which has high productivity. In a R2R, a substrate film rolled in the shape of a hollow cylinder is mounted as-is in the system. The unwound film is guided by cylindrical rollers to be continuously processed at each step and is finally wound up again into a hollow cylindrical roll as a film-deposited product.

With the recent trend of large touch panels, the substrate width has been increasing from 400 mm to 500 mm. Large R2R sputtering systems that were designed to accommodate a substrate width of 1,300 mm (for three 400 mm wide pieces) are now being required to accommodate a substrate width of 1,600 mm (for three 500 mm pieces). Large-area applications, such as films affixed to window glass to block the sunlight, require a product width of 1,600 mm or greater, so the systems are required to accommodate a substrate width of 1,600 mm for that application, too.

Kobe Steel developed and launched the sales of a unique R2R sputtering system, type W35-S, for functional films having a substrate width of 350-700 mm.[1)] This R2R sputtering system has a vacuum chamber with a unique structure, making the system compact while facilitating easy access to its coating zone. moreover, a large R2R sputtering system, type W50-S, has been added to the lineup to accommodate substrates 1,300 mm wide. This system has a coating zone that is openable (open chamber concept), which facilitates access to the coating zone.

A new large R2R sputtering system model, type W60-S, is being developed in anticipation of the future demand for increasing the substrate width to 1,600 mm. Type W60-S exploits the open chamber concept, which is original to Kobe Steel and facilitates easy access to the coating zone, while resolving problems associated with type W50-S, such as requiring a tall housing and large amounts of time for disassembling and installation. This paper gives an outline of the new model, type W60-S, and its applications, as well as Kobe Steel's lineup of R2R systems.

1. R2R sputtering system, type W50-S

Type W50-S is a large R2R sputtering system for wide films that is based on Kobe Steel's conventional model. This system has a process chamber that mounts sputtering sources and a box-shaped base chamber that mounts a coating drum, in which the process chamber is fully openable to the base chamber (open-chamber concept.) This construction allows easy access to the coating zone and achieves excellent workability for cleaning and changing masks, as well as sputtering targets, while the process chamber is open. **Fig. 1** illustrates the construction of a R2R sputtering system, W50-S type, and **Fig. 2** shows the base chamber of the model W50-1300S system for 1,300 mm wide substrates.

The process chamber is equipped with several turbo molecular pumps (TMPs) so as to realize stable film coating in coating zones that are evenly evacuated. The system includes four coating zones, and the spaces in between the coating zones are also evacuated by TMPs to ensure favorable gas-separation characteristics. An upper chamber is stacked above the base chamber and mounts substrate rolls with large diameters, a degassing zone where the films are degassed by a span-heating method employing plate heaters set between idler rollers, and a monitor for checking film qualities such as film resistance and transmittance before the substrate is wound up.

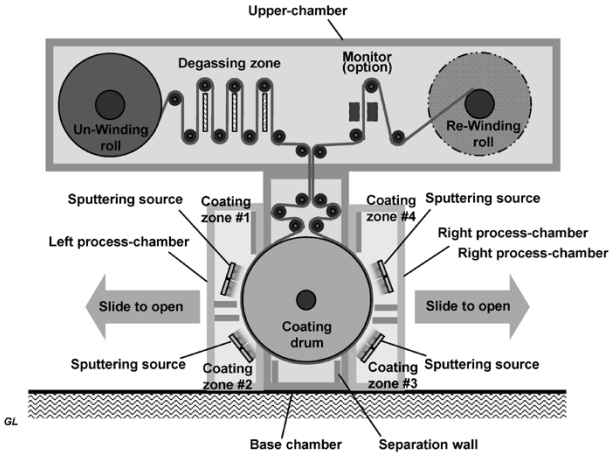

Fig. 1 Schematic of sputtering R2R model W50-S system

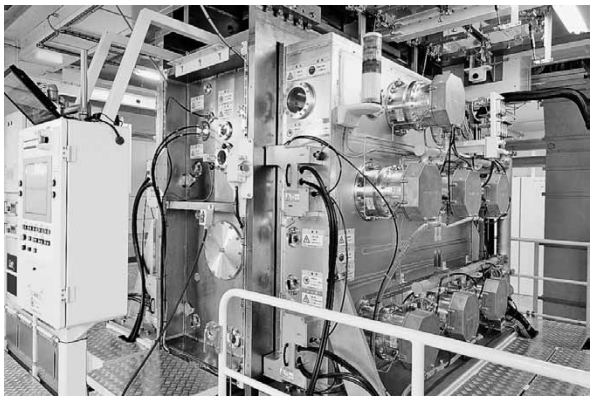

Fig. 2 Base chamber of sputtering R2R model W50-1300S

In the type designation, "W50" represents a R2R apparatus that has chambers, including an openable process chamber stacked, "1300" represents the compatible substrate having a nominal width of 1,300 mm, and "S" represents sputtering.

Thanks to the stacked structure of chambers, the system has the advantages of requiring a small installation footprint and possibly has only the upper chamber being inside a clean room. The other side of the coin is that the system is tall and requires tall housing. Moreover, the upper chamber, being a heavy load, must be disassembled before transportation and be assembled again at the installation site, which poses the problem of taking large amounts of time for disassembling, assembling and installing.

2. Features of new R2R sputtering system, W60-S type

The W60-S is a new type of R2R sputtering system based on the "open-chamber concept" while resolving the above described issues of the W50-S type. The advantages of the W60-S type R2R sputtering system are as follows:

(1) The process chamber is constructed so as to be openable, allowing easy access to the coating zone;
(2) the continuous degassing function, based on the span-degassing method, is unitized and integrated; and
(3) the unit chambers are connected horizontally, facilitating disassembly, transportation, restoration and expansion of the system.

Fig. 3 illustrates the basic configuration of the W60-S type R2R sputtering system. This sputtering system comprises chamber units, each designed to be within a dimensional limit imposed due to transportation, being connected in the horizontal direction. Substrate rolls are loaded and unloaded in a unitized un-winding (UW) chamber and a unitized re-winding (RW) chamber. The degassing mechanism is incorporated in a unitized degassing chamber, which is horizontally coupled with the UW chamber. The coating zones in the base chamber have openings, one on the left side and the other on the right side. The left and right process chambers, having a dovetail on their opening faces, open left and right for approximately 40 cm to avoid interference with the coating drum and

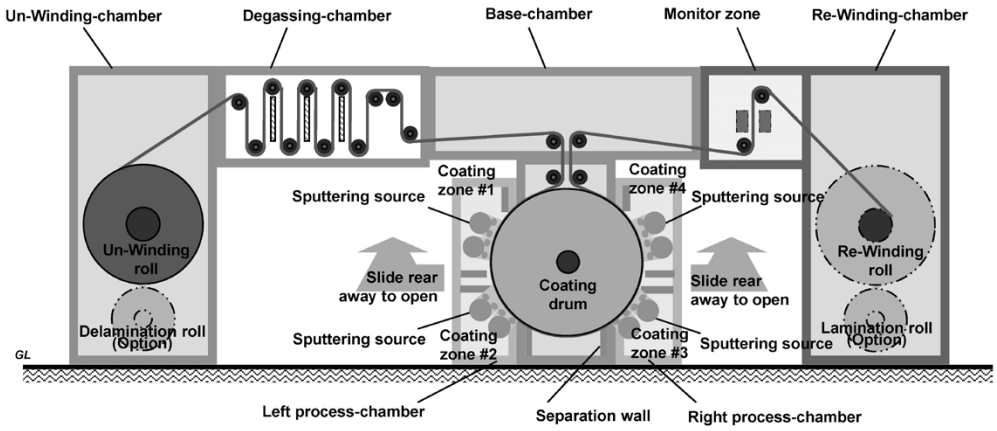

Fig. 3 Schematic of sputtering R2R model W60-S system

Table 1 Main specifications of W60-1600S model

Item	Specifications
Type of chamber structure	Unit chamber horizontal connection
Method to open coating zone	Sliding away of process chamber
Substrate	Plastic film (PET/PEN/PI etc.)
Film thickness	23-200 μ m
Film width	Max. 1,620 mm
Effective width	Max. 1,530 mm
Max. roll diameter	800 mm
Film tension	70-600 N
Film transfer speed	0.5-25 m/min
Diameter of coating drum	1,300 mm
Temperature of coating drum	-15 to 75℃
Number of coating compartments	4 sets
Number of sputtering sources	Max. 2 sets for each compartment
Type of sputtering source	Rotary magnetron or planner magnetron
Power supply	DC/DC pulse/MF-AC
Gas separation	Over 1/100
Type of degassing	Span heating between idler rollers
Degassing length	4 m
Minimum space for installation	15 (width)×19(depth)×5.5m(height)

move largely toward the back so as to expose the coating zones. This structure facilitates the changing of masks and cleaning of the coating zones. The sputtering targets, remaining in the retreated process chamber, can easily be changed. With this chamber structure, the W60-S type R2R sputtering system allows the chambers to be connected horizontally while securing accessibility to the coating zones, and facilitates installation. Thus the system can be introduced more easily than conventional models.

In addition to the conventional planar sputtering sources, the W60-S type accommodates rotary magnetron (RM) sputtering sources. The RM sputtering sources can achieve high target yields and are being adopted widely. A RM sputtering target unit for a nominal 1,600 mm-wide substrate may have a length exceeding 2,000 mm and weigh as much as 100 kg. Hence the W60-1600S model is adapted to support both ends of the target units and equipped with a dedicated hoisting accessory so as to ease the handling of the long target. Another feature is an increased expandability. The unitized UW chamber and RW chamber, for example, can optionally accommodate special rollers for unwinding and rewinding laminated films. The coating drum temperature is controlled by circulating medium, enabling film deposition at low to mid temperatures (-15 to 75 ℃).

Table 1 outlines the specifications of the W60-1600S model accommodating the substrate width of 1,600 mm.

The design development has been completed for the new W60-1600S model and for the W60-1300S model designed for 1,300 mm wide substrates. The base chamber, having a new design (for, e.g., the chamber structure, chamber open/close mechanism, door open/close mechanism, coating drum, pressure bulkhead and RM sputtering sources), has an

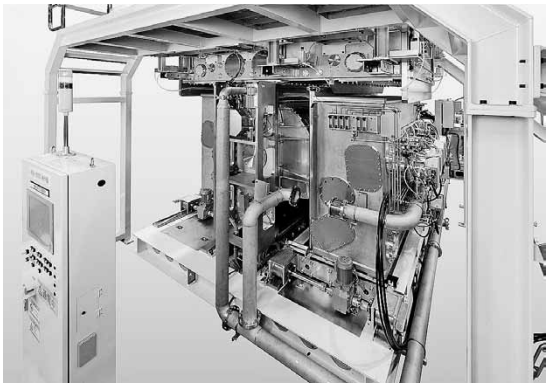

Fig. 4 Base chamber of sputtering R2R model W60-1600S

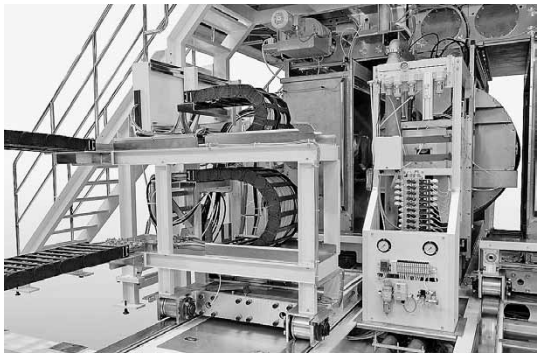

Fig. 5 Base chamber of sputtering R2R model W60-1600S

important effect on system performance. Hence a prototype W60-1600S base chamber has been built and evaluated for its basic performance, including pressure-separation performance, temperature-control function and the uniformity of the deposited films. **Fig. 4** and **Fig. 5** show the base chamber being tested and modified at the Takasago Works of Kobe Steel.

3. Fully equipped degassing function

The features of Kobe Steel's large R2R sputtering systems include a fully equipped degassing function. The degassing process involves a span-heating method, in which films are radiation-heated by plate heaters set between free rollers. The degassing length of 4,000 mm ensures sufficient degassing.

Kobe Steel constructed a dedicated degassing apparatus to propose, through some tests, the optimum process conditions for the span-heating degassing method using plate heaters. **Fig. 6** shows a degassing system (type W35-550D) with open/close doors on four sides. This system is to be connected with a box-shaped chamber designed for nominal 550 mm wide substrates. Thanks to the openable doors, this chamber structure facilitates the cleaning of rollers, plate heaters and the like. The maximum diameter of mountable substrates is ϕ400 mm. The chamber is evacuated by a dry pump.

An indium tin oxide (ITO) film used for a touch panel requires an index matching (IM) film, an optical adjustment layer that compensates for the difference in optical characteristics so as to prevent so-called "skeleton emergence," the problem of ITO wiring patterns showing up after the patterning. Here, comparisons were made between ITO films deposited with and without degassing. The substrate material was LightNavi® CW1300L/NP-50, a 50 μm-thick PET substrate with an IM layer, available from NOF Corporation. Un-balanced magnetron sputtering (UBMS), having a high plasma-assist effect,[2] was performed to deposit ITO films having a thickness of 23 nm. Sheet resistance and total light transmittance were measured before and after annealing at 150 ℃ for 1 hour to evaluate the effect of degassing. The results are shown in **Table 2**. It was revealed that the degassing eliminates residual

Fig. 6 Degassing R2R model W35-550D

Table 2 Comparison of typical ITO-film characteristics with and without degassing treatment

Condition		Sheet resistance (Ω/sq)	Total light transmittance (%)
With degassing treatment	As deposited	464	86.5
	After annealed	151	89.0
Without degassing treatment	As deposited	567	87.7
	After annealed	683	88.6

moisture and oligomers in the substrate, which are factors that inhibit the crystallization of the ITO film during annealing treatment, and enables favorably low sheet resistance with a high transmittance.

Resin substrates incidentally contain moisture. This makes degassing treatment important for other applications. For example, when depositing an oxide film, SiOx, a large amount of released moisture disables the control of oxygen taken into the film and destabilizes the quality of the film. Hence, the degassing treatment prior to the vacuum coating is extremely important in order to maintain constant conditions of film deposition.

4. Application examples of large R2R sputtering system

A large R2R sputtering system has been described using the example of ITO film deposition on wide substrate. There are other cases where similar systems are used. The following introduces the application examples of metal film deposition (thin films for metal mesh, metal wiring films) used in touch panel and optical film deposition.

4.1 Metal film for touch panels

(1) Thin film for metal mesh

Large touch panels used for tablet terminal and digital displays must maintain transparency while keeping their sheet resistance as low as several tens Ω/sq or less. For large-screen applications of 15" or greater, however, the reduction of ITO film resistance is approaching the physical limit. Electronic information devices such as displays and tablet terminals are also required to be flexible. Thus ITO films, which are prone to crack during bending and folding, are required to be replaced by other transparent conductive films with flexibility.

To resolve the issues associated with ITO films, metal mesh films,[3] in which metal films with a thickness of several hundred nanometers are patterned into fine mesh, have been implemented as new transparent conductive films in the last several years. The methods of depositing these metal films include vacuum processes such as vapor deposition and sputtering, as well as printing processes such as gravure offset and ink jet. These processes have pros and cons in terms of the need for photolithography, workability of the mesh, selectivity of wiring materials and production cost.

Fig. 7 shows a multi-layer film used for typical metal mesh sputter-deposited on a PET film. An intermediate adhesion layer is provided between the PET film substrate and metal conductive layer so as to improve their adhesion and has a minimum required thickness of 10 nm or less. The material selected for the intermediate adhesion layer is commonly an oxidation-resistant alloy in the same alloy system as the metal conductive layer so as to prevent the diffusion of the metal conductive material into the PET film and to inhibit oxidation. The topmost black layer suppresses the optical reflection from the conductive layer surface to obscure the meshed wiring and to mute the color intrinsic to the metal conductive layer. Metal oxide and/or nitride is/are mainly used as the material. As in the case of the intermediate adhesion layer, the black layer is required to have adhesion to the conductive layer, mesh-patternability (etchability) as well as continuous patternability with the conductive layer. These factors are taken into account in selecting the material for the black layer.

Fig. 8 is a micrograph of a metal-mesh film. This metal-mesh film was made from a multi-layer film including a metal conductive layer, as shown in

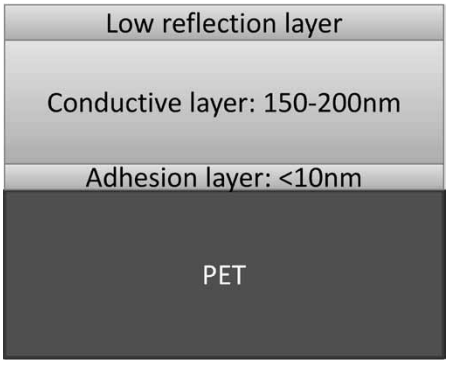

Fig. 7 Cross-sectional view of multi-layer thin film for metal mesh

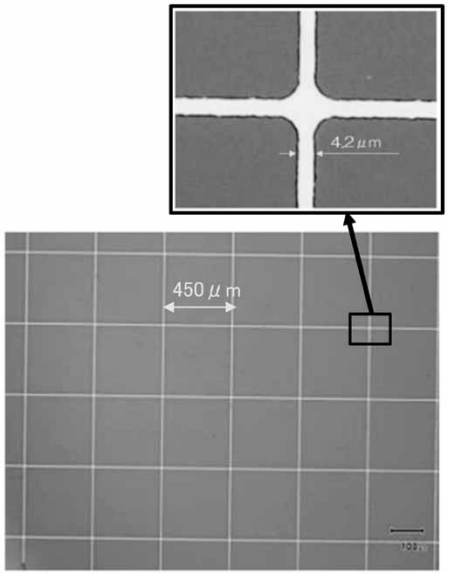

Fig. 8 Microscope photograph of Cu multi-layer after mesh patterning

Fig. 7, deposited on a PET substrate using the W35-350S system (the system details will be described later.) This multi-layer film was then patterned by photolithography. This sample includes a metal conductive layer of pure copper (tough pitch copper having a purity of 99.9% or higher), an intermediate adhesion layer of copper alloy and a black layer of copper alloy oxide. This photolithographic mesh pattern has a linewidth of 4.2 μm and line spacing of approximately 450 μm. The total light transmittance after the mesh patterning is 89.6%, satisfying the transparency required for touch panels.

(2) Metal film for wiring

Fig. 9 is a cross-sectional schematic drawing of a multi-layer film for wiring an electrostatic capacitance type touch panel. The multi-layer consists of, in sequence, a PET film substrate, an IM/ITO layer, an intermediate adhesion layer similar to the one used for the multi-layer film for metal mesh, and a metal conductive layer. The topmost protection layer serves to protect the metal conductive layer from oxidation, deterioration and fingerprints.

4.2 Optical film

Well-known examples of optical films include the films affixed to the glass windows of, for example, ordinary homes, office buildings and commercial facilities to improve interior air-conditioning efficiency and exterior appearance. Window films are heat reflective, transmitting visible light with a wavelength of 400 to 800 nm and reflecting light with wavelength of 800 nm or longer. These films are being widely used for the above purpose.

Fig.10 is a cross-sectional schematic drawing of a heat-reflecting film experimentally made by the W35-550S system (the system details will be described later) The W60 - 1600S, a large system with four coating zones, also has a to-and-fro deposition capability which enables the deposition

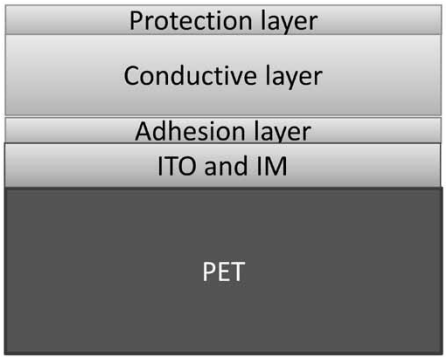

Fig. 9 Cross-sectional view of metal multi-layer on ITO for touch panel

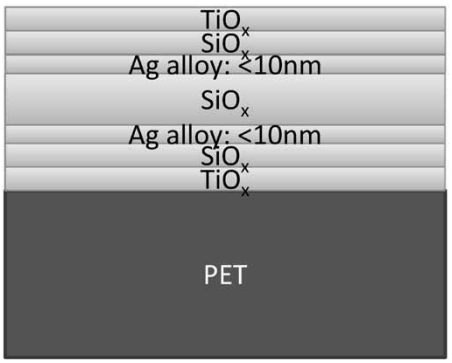

Fig.10 Cross-sectional view of heat reflective film

of this film structure. The multi-layer film comprises 7 layers of optically designed thin films deposited on a PET film substrate and includes a TiOx layer having a high refractivity, a SiOx layer having a low refractivity and a heat-reflecting layer of silver alloy. This arrangement is compatible with the total light transmittance for visible light of 67.8% and infrared light reflectivity of 68.2% (wavelength 1,100 nm.)

5. Lineup of R2R systems

5.1 Other large R2R systems

A degassing system, W30-1600D, dedicated to the R2R system, employs the span-heating method and accommodates the substrate width of 1,600 mm. This system is used for the pretreatment of sputter coating. Type W30 is designed conventionally, chambers being opened and closed, while the film transferring arrangement is fixed. This model is useful as an apparatus auxiliary to pre-existing systems whose productivity is bottlenecked by the degassing process and/or whose degassing function is relatively poor. The degassing zone has a length of approximately 4,000 mm. The apparatus accommodates substrate rolls of up to ϕ700 mm. **Fig.11** shows this degassing system.

A large chemical vapor deposition (CVD) system,[4] which is uniquely designed as a W60

Fig.11 Degassing R2R model W30-1600D

type by Kobe Steel, is also in the lineup. This is a coating system based on Kobe Steel's original method of coating SiOx. This system includes a pair of electrode rollers, which transfer resin substrates while depositing a dense film of SiOx by the mid-frequency (MF) magnetron discharge. The system has been applied to high-barrier films on resin substrates and low-refractive SiOx layers for the ITO films of touch panels. **Fig. 12** shows the W60-1300C.

5.2 Small R2R systems

A R2R sputtering system W35-S comprises a box-shaped chamber having a left door and a right door; a film transfer arrangement supported at its two ends by the front and rear walls of the box-shaped chamber; an anode layer source (ALS), a pretreatment source (optional) and a dual magnetron sputtering (DMS) source mounted on the left door; and a UBMS source mounted on the right door. The hinged door fully opens the chamber, making the system compact and allowing easy access to the coating zones. Here the type designation W35 indicates a R2R system having a box-shaped chamber with pivoting openable doors as described above.

Fig.13 shows the W35-350S system for a nominal 350 mm wide substrate with a door opened, while **Fig.14** shows the construction of the system. Opening the doors as shown in Fig.13 facilitates access to the sputtering source and to the coating masks, eases the loading of film substrates and collects all the work spaces in one spot. In conventional systems, the film transfer mechanisms are pulled out. The newly developed system eliminates the need for space to pull them out, which almost halves the installation footprint. Moreover, the film transfer rollers are supported at both ends, providing stability.

The W35 types can incorporate a CVD function in the lower part of the chamber. The CVD dedicated system is designated as W35-C, while the system combining CVD with sputtering is designated as W35-CS. The system can also incorporate various other functions. **Fig.15** shows an example in which an RM sputtering source (optional) is mounted

Fig.12 CVD R2R model W60-1300C

Fig.13 Sputtering R2R W35-350S model

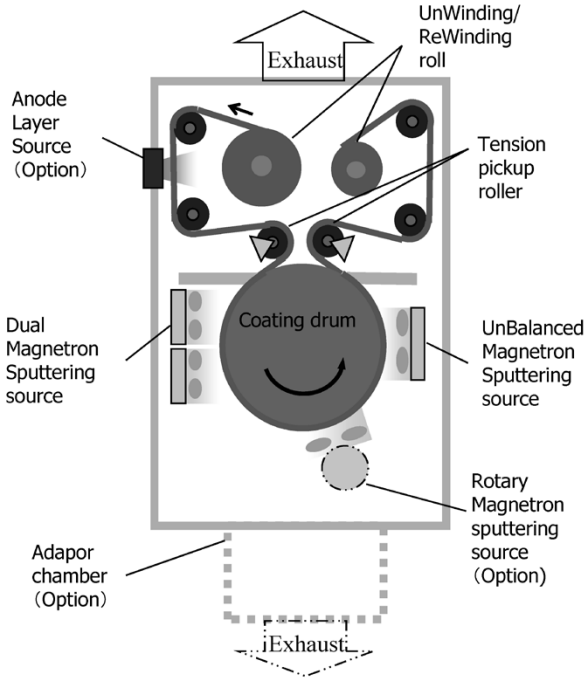

Fig.14 Schematic of sputtering R2R model W35-S system

Fig.15 Rotary magnetron sputter source in W35-550CS system

on the bottom of the chamber. The RM sputtering system employs a fixed magnet unit and a rotatable hollow cylindrical target. It has the advantage of a higher target utilization rate of about 80%, compared with 20 to 40% for the planar system. Kobe Steel adopted RM sputtering sources that are supported at both ends by the chamber interior walls.

This series has gained a fine reputation as small R2R systems and has been widely used, not only as experimental equipment, but also as production equipment for substrates that are 700 mm wide or narrower. The equipment lineup also includes the W40 types in which the coating zones of the W35 type are separated by a bulkhead structure and differential evacuation. Kobe Steel owns a system combining sputtering with CVD, W35-350CS and W35-550CS, which it exploits for various sorts of development and sample tests.

Conclusions

The R2R systems of Kobe Steel feature a unique structure to improve accessibility to various processing zones for facilitating cleaning and the changing over of shields/masks to stabilize product quality. The newly developed model of the large R2R sputtering system comprises unit chambers that can be connected horizontally so as to improve expandability, dismountability and mountability, enabling a quick response to the rapidly changing market. The system lineup is being expanded. Kobe Steel will strive to respond to customers' needs by integrating various technologies developed by the machinery business division and corporate research laboratories.

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