Innovative Solutions in Film Capacitor Vacuum Coating for advanced automotive Applications

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Abstract

Emerging markets for film capacitor due to expanding applications of these types create an increasing demand for an extended range of thin film products.

Capacitor manufacturers face new challenges in production and metallised films are about to substitute ceramic and electrolyte capacitors in various applications which are i.a. mainly driven by new requirements of automotive industry in the field of advanced hybrid car applications and other new features of cars in future.

Production systems for film capacitors must cope with the market developments and in the same time enable producers to remain competitive.
There is a need for multifunctional, flexible machines, able to perform multitasking within the production process, which can be achieved with advanced metallisers offered on the market.

Content

1 Introduction

New Markets for the Film Capacitor
As reported in earlier CARTS papers 2005 and still valid, further development of commercially available coating technology and the advancement in thin film capacitor applications over the last 5 years is opening up established market areas where until now only ceramic and electrolyte capacitors had a footing. This market is now ready for accepting the thin film capacitor with the many advantages they offer.
The film capacitor market is expanding due to interesting developments of the capacitor production processes, especially those provided by the metalliser. Improved metallising techniques are adding to the efficient use of new ultra thin dielectric substrates offering manufactures new design tools, production methods and a wider range of materials. Producers are now exploiting these innovations to produce high quality capacitors with advanced properties at reduced cost.

When using the latest production systems, such as the Applied Materials metalliser MULTIMET™, it's now within every producers capability to deposit layers of up to >60 nm (i.e. approx. <1.5 Ω/□) on all dielectric substrates from thickness 0,5 µm to 20 µm. Metallised coating takes place when the conductive material for the electrodes is deposited on thin dielectric substrate. This is done with extreme accuracy at speeds up to 20 m/s, depending on layer thickness and deposited material.

Polypropylene (BOPP)

One of the reasons for this huge increase in China and also India, are serious shortages and problems in electrical power supply. Demand for power factor correction capacitors is very high and contribute in high volumes for such unit's. Resulting from the Indian market need's, Tervakoski Films Group and Xpro India started a joint venture to produce high quality BOPP metallisation base film for capacitors for Indian domestic use and international markets. This production facility under the joint venture Terxpro Films Pvt Ltd is been told already to receive first customer approvals. Current facility is assumed to cover large share of Indian base film market.

At substituting other capacitor types because of better electrical properties e.g. the insulating resistance and self healing, make the BOPP film capacitor attractive for a big number of various applications and the price difference compared to the Electrolytic Capacitors (ELCO's) can be more than compensated, by offering and enabling better performance.

Figure 01: Example for ABB Power Factor Correction BOPP Capacitor (metallised).

Confirming this trend, Treofan as a leading global BOPP film manufacturer and supplier, is reporting about substrates below 3 µm, already available and tested in combination with high sophisticated pattern metallisations for e.g. replacement of ELCO's in automotive applications, such as the Hybrid Electrical Vehicles (HEV's). The trend to HEV's is obviously shown during the last Detroit Motor Show, as beside the leading Japanese manufacturer's now also more American and European companies start activities for catching up the Hybrid technology. Meanwhile ultra thin film BOPP of even 2.5 µm has been shown by Treofan and the trend to thinner substrates is evident. Treofan could increase it's output by 50% in the last 4 years and is planning further growth. Looking at the big BOPP capacities installed especially in China, in the next couple of years an over capacity for commodity products is expected, which results in the need for further new development of BOPP grades by the established producers. Beside Asia, Treofan recognizes significant higher demand in film from Europe and America, the demand for BOPP remains on a high level.

Further actual trends are reported by Kopafilm, another global supplier for BOPP capacitor grade film: Continuous improved electrical values of BOPP like Breakdown Voltage (BDV) of 700 V/µm and substitution of e.g. ELCO's in the motor run segment at using a 4 µm instead 5 µm BOPP.

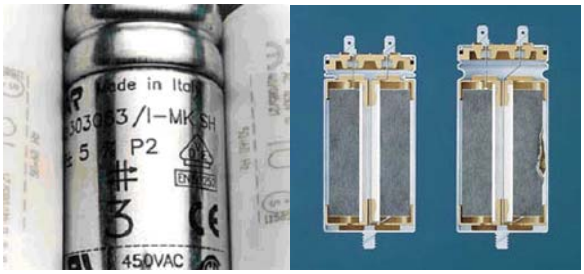

Figure 02: Example for Icar Motor Run BOPP Capacitor (metallised).

With constantly decreasing thickness down to 3 µm, the BOPP film capacitor get's suitable for applications, where ELCO's because of lifetime must be oversized and loose their advantage in lower price (at Voltage >550 V). Another special development, where metallised polypropylene capacitors are used successful, because other capacitor types can't compete, is the so-called NIF project (National Ignition Facility) in the USA:

Figure 03: Capacitor Module "1.7 Megajoule".

Here the Italian capacitor manufacturer Icar could pitch successfully against international competition, at designing a metallised BOPP capacitor, which is used in a number of 4000 pieces (each consists of 125 kg film), which are arranged in 200 unit's of 20 capacitors and have each 1.7 Megajoule.
This high quality Icar capacitor is produced with a Kopafilm BOPP (produced of ultra pure Borealis granulate), which was metallised on a MULTIMET™ and is used for the fusion technology, fuelled by water and lithium.

Polyethyleneterephthalat (PET)
As informed by film manufacturers of Polyethyleneterephthalat (PET), Polyester, market is remaining on a stable demand, with a clear trend to thinner substrates below 2.7 µm, the so called "Ultra Thin Film, UTF". The total monthly quantities supplied for PET film capacitor applications are at around 950 t. There's no increase in quantity to detect and as reported earlier, there's a switch to the thinner materials, which are around 50 t/month. Because of moving required PET quantities to China, Toray is following this trend and expands PET production capacity in China to cope with the increasing demand there.
It could be said, that all PET manufacturers offer different film types: Less shrinkage (for SMD applications), standard rough film and smooth film for further minimization of film capacitors.

Mitsubishi Polyester Film is aware of a substitution of ELCO's with PET capacitors and vice versa, which is always related to the different requirements on capacity, voltage-/impulse strength and the price.

A new technology, where Mitsubishi Polyester Film is cooperating in development, is in link circuit applications: Metallised PET capacitors, consisting of ≤4 µm, preferably 1-2 µm dielectric, are working as converters in different functions in the up to 250 V range very successfully. The PET SMD version, invented by Mitsubishi Polyester Film, supports applications requiring either long endurance at elevated temperatures or surviving temperature peaks.

Polyethylenenaphthalate (PEN)
Film manufacturer are reporting, the PEN is used in a smaller number of applications, where in automotive applications like the High Intensity Discharge lamps (HID lamps) the high heat resistance of >150°C gives an advantage against PET and is less expensive than the Polyphenylenesulphide (PPS).

Polyphenylenesulphide (PPS)
Toray has enhanced their PPS film production capacities with a new plant in 2005. The increasing demand for PPS is obvious: Beside the bigger quantities for PPS in technical applications for the LCD display market, especially PPS SMD types in mobile phones respectively all applications, where high reliable chip capacitors are used when minimum capacity variation, high heat resistance (>170°C) and good response time at high frequencies are mandatory and getting more important. The summary of best electrical and thermal properties, make the slightly larger and more expensive PPS capacitor as competitive alternative to existing MLCC's.

2 Requirements

Metallisers must offer more to Capacitor Manufacturing
With the a.m. increasing demands for an extended range of thin film products, capacitor manufacturing plants must provide the designer and the production engineer with necessary tools and the required flexible capabilities.

Multifunction and flexible machines now offer the designer, the production engineer as well as the quality controller more facilities to perform multi tasking within the production process. By having a number of these inherent functions the metalliser offers overall support for optimising each function within the capacitor production process. The design, production and the quality control of film capacitors is becoming progressively more efficient to meet the increasing scope of film capacitor applications, like the increasing number of applications for the future cars.

3 Film Capacitors used for new Automotive Applications:

There are mainly 6 areas, in which film capacitors play an important role for fulfilling future requirements in automotive applications in the car of the future:

a) High Intensity Discharge Xenon lamps (HID)
b) Passive Keyless Entry systems (PKE)
c) Tire Pressure Monitoring Systems (TPM)
d) Driver Information and Car Entertainment
e) Integrated Starter Alternator (Mild hybrid)
f) Full Hybrid Vehicles

The a.m. applications will allow to manufacture cars, which have reduced fuel consumption, less emission resp. air pollution and offer it's driver a high level of safety and comfort. Meeting these requirements, advanced electronic systems, which work reliable in the new cars of the future. So following demands have to be fulfilled by future automotive applications:

- Longer component life time (10 years or 100,000 miles),
- higher operating temperature (150-170°C under the engine hood),
- higher vibration frequencies,
- higher operating voltages (dual voltage system 14-42 V).

In the following paragraphs, the single new applications for automotive applications will be described:

a) High Intensity Discharge Xenon lamps (HID)
Application: High brightness of 3-4 times of halogen lamps, high visibility which is daylight similar, high efficiency with approx. at 35 W half consumption compared to halogen, 3 times longer life time with up to 2000 h (which is 3 times of halogen)
Solution: 3 film capacitor types possible: For the "Ballast" a 400 V DC type with a capacitance range of 0.33 µF to 0.56 µF and a 250 V DC type with 1 µF to 1.5 µF is used together with a 1000 V DC type and 70 to 120 nF in the "Ignitor"
Film capacitor types: For Ballast PET leaded and PEN Film chip are used, for Ignitor a PEN stacked / naked / leaded

Figure 04: Comparison "Xenon and Halogen".

b) Passive Keyless Entry systems (PKE)
Application: Driver can enter the car by simply pulling the door handle "hand free system using a electronic card", starting the engine by just pushing a button
Solution: Several transmitters (antennas) are located in each door and inside car. One capacitor for each transmitter means up to 8 film capacitors per car (this application requires a high capacitance stability, working at high frequencies)
Film capacitor types: Capacitance range 2200 pF to 0.033 µF with 400 to 1000 V DC type

c) Tire Pressure Monitoring Systems (TPM)
Application: The system senses temperature and pressure of each tire and informs driver in case of pressure loss or reaching a certain temperature level
Solution: A central receiver is in communication with a transmitter near each tire, which receives the signal from a sensor (each tire has a sensor inside). One film capacitor on the resonant circuit of each transmitter means 4 capacitors per car (this application require same high capacitance stability, working at high frequencies as "PKE" application)
Film capacitor types: Capacitance range 2200 pF to 0.033 µF with 400 to 1000 V DC type

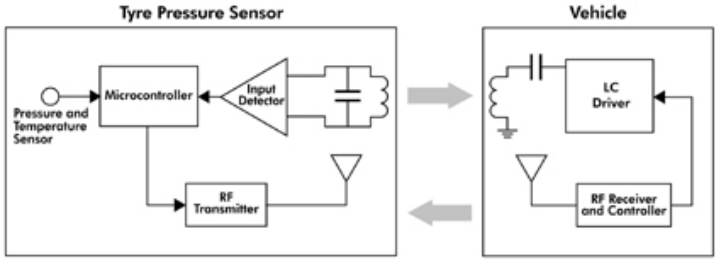

Figure 05: Electric scheme, 1 capacitor for each transmitter.

d) Driver Information and Car Entertainment
Application: Various applications like audio entertainment, navigation system, any kind of information system
Film capacitor types: Film chip capacitors in PET, PEN and PPS dielectric

Figure 06: Car speedometer with navigation display.

e) Integrated Starter Alternator (Mild hybrid)
Application: Using this technology, fuel consumption can be reduced by 15-20% at lower emissions. Conventional components can be replaced and the system start's / stop's automatically e.g. at stop and go traffic. Inboard Voltage at 42 V possible

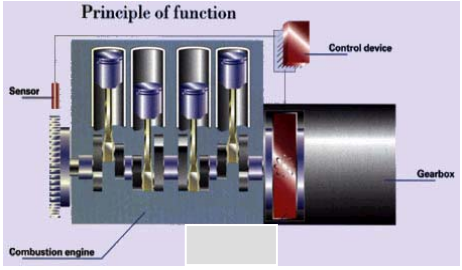

Figure 07: Principle of function "Mild Hybrid / ISA".

Solution: The Integrated Starter Alternator (ISA) combines the function of starter and alternator in single intelligent electric motor. Filtering/DC-link capacitors are used
Film capacitor types: High temperature PET capacitors are used in a naked stacked construction with special connection (SMD version for reflow soldering available), capacitance range 10 µF to 330 µF with 63 to 250 V DC

f) Full Hybrid Vehicles
Application: Hybrid vehicles combine an electric motor with a gasoline engine. Compared to the mild hybrid, the electric motor can run the car completely independent for a certain time, powered by a battery
Solution: The power sources can be combined in two different ways. In both ways (series or parallel hybrid system), the electric motor is linked by an inverter to the battery

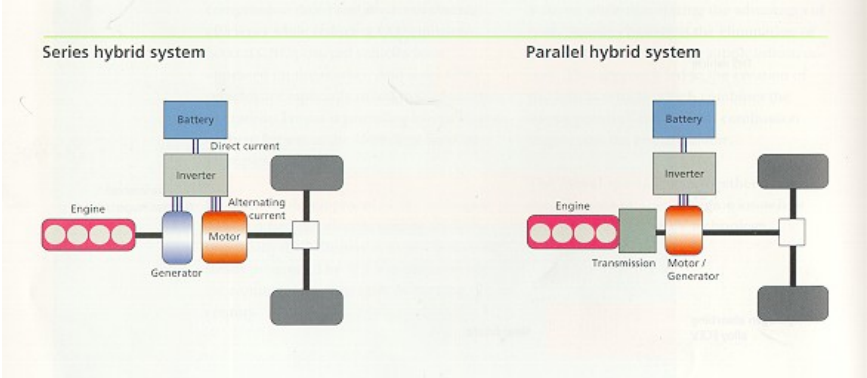

Figure 08: Series and parallel hybrid systems (DC link capacitor between battery and inverter).

Film capacitor types: For the DC link capacitor, film technology is preferred over electrolytics. As dielectric Polypropylene is used, rated capacitance 1000 µF to 2000 µF at a rated Voltage of 750 V DC. Solution of the Arcotronics Nissei Group is the patented Spider Cap technology: High ripple current (rated ripple current 110 Arms at 10 kHz), high reliability with self healing properties, no capacitance loss over product life (i.e. capacitance stability over product life) and low ESL / ESR values (Inductance <30 nH)

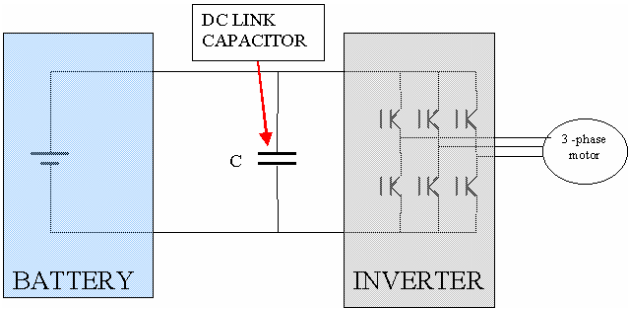

Figure 09: DC link capacitor between battery and inverter.

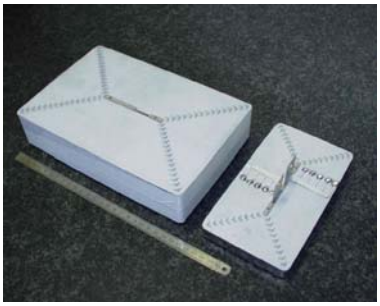

Figure 10: DC link film capacitor “Arcotronics Nissei Group Spider Cap”.

4 Design & Production Support for Metallisation of Film Capacitor Materials

Design

As a design support function the metalliser must offer the capacitor designer increased flexibility to fulfil design ideas to create the desired products and especially the a.m. requirements to the film capacitor for new automotive applications.

For example, capacitor designers are able to use an increased variety of materials. Electrode materials including copper, zinc alloys, silver and aluminium can be applied to ultra thin substrates comprising most dielectrics on the market. Dielectric thickness between 0.5 and 20 µm can be handled by precise winding systems. The process can easily be controlled to deposit metal layers up to 60 nm, so finished metallised films might achieve resistivity values of below 1.5 Ohms / sq.

Dielectric	Thickness	Resistivity	
		Al	Al/Zn
	[µm]	[Ω/□]	[Ω/□]
BOPP	<3.0-20.0	<1.5->30.0	<2.5->40.0
PET	(0.5), 0.7-12.0	<1.5->10.0	<2.5->10.0
PEN	1.4-6.0	<1.5->5.0	-
PPS	1.2-6.0	<2.5->5.0	-
PC	(1.5-9.0)	-	-
Paper	5.0-20.0	<5.0->40.0	<7.5->30.0

Table 01: Examples of metallised Film Combinations.

Production

Although one of the most critical and complex steps during the capacitor production is the vacuum metallisation process, the metalliser must also perform a number of parallel functions, which support and even eliminate further down stream steps.

The MULTIMET™ provides these features by using specified exchangeable modules with a highly developed vacuum plant, winding and control system. Capacitor production engineers are offered the combined capabilities of the metallising process and to perform subsequent production steps almost automatically.

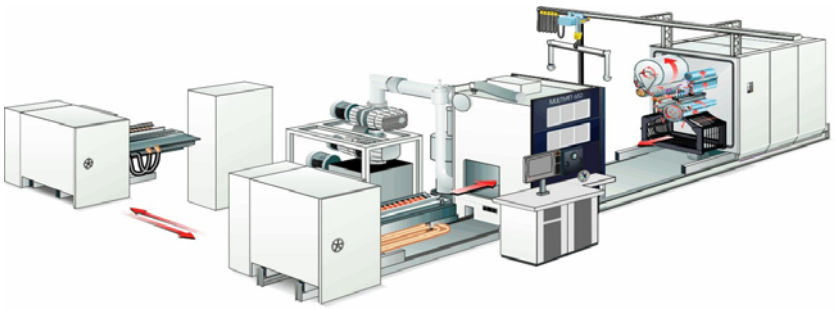

Figure 11: Schematic of Film metallising System.

Additionally the metalliser combined with associated production equipment offer film already prepared in the forms of stripes and patterns, for the subsequent steps in the production of the finished capacitor.

While keeping the design parameters of the capacitor stable at the optimised production rates, the creation of precision patterns, in almost any form, is performed. This pattern forms are used for the insertion of fuse links between the electrodes as well as forming insulated metal free zones.
By developing these special patterns on the substrate, small metallic bridges can be created to improve the capacitor reliability and lifetime. The bridges act as fuses and will operate in cases of insulation breakdown causing short circuits between the electrodes (i.e. the film layers). The metallic bridges are dimensioned in such a way, that an interruption occurs in cases of increased current. In this way, the faulty area is automatically insulated in a localized small zone. The total capacity of the capacitor is decreased only very

slightly so the capacitor can continue operating in the circuit and that the function will remain. Patterns are also used to increase accuracy of metallised film capacitors in masking exact area's for high defined capacities.

Factors offered by the prepared film, for the subsequent steps in the production of the finished capacitor, include precision stripes and patterns of deposited material and an increased layer thickness: Forming of the relatively thicker edge (heavy edge) is allowing the production step of side contacting at the edges of the capacitor sleeves after e.g. winding easier and more reliable. Beside this, electrical properties can be influenced positively.
Thus improving manufactured quality, limiting the rejects and better the electrical performance of capacitors.

Reliability and Quality Support
The quality controller is able to use sensing and measuring systems to maintain layer uniformity and thickness. These provide intelligible data, used inside and outside the process. When performing metallisation using a vacuum evaporation process, measured values during and after process will:

- Indicate the quality of product (according to required specification),
- display the process values for the machine operator -process engineer,
- enable optimal operation of a real-time process control.

Data offered by the MULTIMET™ includes continuous in-line readings of layer resistivity in Ohms/square and Optical Density measurements as well as masked insulating geometries. These values are necessary to achieve the desired features of a single coating and subsequently an efficient layer at its optimum quality.

5 Advanced Metallising Systems

The metallising system comprises advanced mechanized plant and process technology as well as an accurate process control system. Each of these three facilities provide the capacitor manufacturer with a range of tools to enhance the complete capacitor production plant.

The metallising steps in the production of capacitors offer many production optimisation facilities, which ultimately determine the resulting quality, reliability and the highly competitive price of the end product.

Design of a modern Web Coating System
During the production of film capacitors, one of the most important and complex process steps takes place during the vacuum metallisation.

As a consequence, for the whole vacuum coating system, the quality standards are very high when coating specially produced substrates.

Because of progress in vacuum coating technology at Applied Materials, it's possible to find solutions for the rising number of complex requirements in the field of high vacuum web coating.

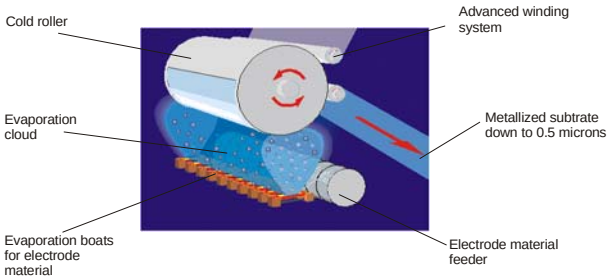

Figure 12: Schematic of Evaporation Process.

It is a rapidly changing market, which demands highly flexible equipment for varying products and applications, combined with low production costs. To meet these requirements, a web coating system has to provide highest production speed at high quality and minimum maintenance and downtime.

The Applied Materials MULTIMET™ metalliser and pattern coating system meets all this demands by offering the range of critical functions within the system.

Machine Operation

Coating roll material in a vacuum web coater takes place in a batch process. Conditional to this, productivity is not only depending on the process speed, but also on the down times in-between the several coating runs. To achieve low down times, the web coating system is easy and user-friendly to handle. All machine and process functions are controlled by the best available technology, which makes it possible to monitor the large range of parameters. In this way, most crucial operations are controlled automatically.

With the advanced control systems operation is simplified which also minimises the risk of error. The operator interface is simple and the process visualisation includes all necessary tools to maintain a stable process while producing the best quality for advanced film capacitors.

Robust design and easy access to all relevant machine components - particularly the access to the process modules - enable short down times. The rectangular design of the MULTIMET™ vacuum chamber gives open access to the evaporator also at locked module.

Figure 13: Total View Film Capacitor Coater.

Advantages of the easily removable module (change is possible within reload a new substrate roll), enable simple maintenance and cleaning. A bright, smooth surface of the vacuum chamber in combination with a good shielding of the evaporator source and even surfaces, allows a trouble-free machine preparation.

Process Visualisation

The operator panel (touch screen) and the control panel show comprehensible input and output elements. Additional the operator receives detailed alarm messages from an error reporting system. Process parameters can be stored in recipes and recalled again at any time.

Figure 14: Process Visualisation MULTIMET™.

Vacuum

Pressure for evaporation in the separated coating chamber must reach ≤4 x 10^{-4} mbar. This pressure is achieved in less than 5 minutes. A multi stage pumping station is installed, for pre-evacuation, in which phased mechanical pumps ensure a rapid reduction of pressure level. After having the sufficient pre-vacuum, a diffusion pump for creating the high vacuum is hooked up. For removing moisture and other volatile components in the winding chamber, a cold trap (coil) is installed. The combination of this mechanical, diffusion and physical pump units, ensures the required pressure is reached in a minimum of time. The short pump down time together with an excellent cost/benefit ratio are achieved by a correct layout design and the corresponding selection of suitable pumps and their optimised positioning at winding- and coating chamber.

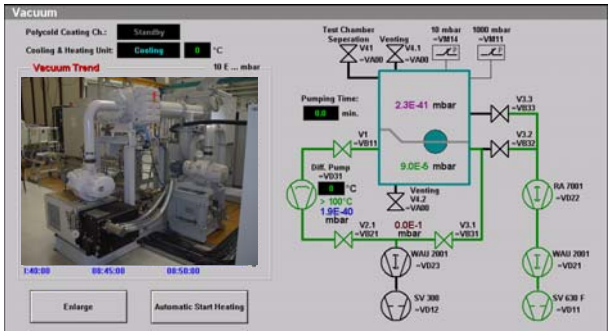

Figure 15: Vacuum Scheme MULTIMET™.

It is important that all chosen components for the vacuum pump system interact seamlessly. As the process is taking place under vacuum, a maximum level of care is required: Both in selecting suitable vacuum measuring instruments and sensors as well as in the design of vacuum feed throughs.

Winding System

The winding system has to guide the very thin substrate through the process and to rewind it without damaging it (down to e.g. 0,5 µm PET or 3 µm BOPP).

In principle, there are separate drive units for the „Unwinder“, „Coating drum“, „Tension roll“ and „Re-winder“. For precise regulation of the web tension at the coating drum without influence by the rewinder, separate traction between the coating drum and rewinder is necessary. This is realised by the „Tension roller“. The best contact of the substrate to the coating drum is achieved with good rewinding quality.

Ultra thin Film Handling (UTF)

To handle and coat sensitive substrates such as ultra thin film on the PET side (film thickness down to 0.5 µm) and the upcoming down gauging on the BOPP side (<3.0 µm is available), it was necessary to adapt the drives for this purpose. To achieve highest flexibility for the MULTIMET™ users, a system was installed, which offers the quickest change of drive unit's possible. So in a single machine, substrates from 0.5 up to 20.0 µm can be processed. Another important item is the arrangement of guide rollers, which must assure short unguided distances of the substrate.

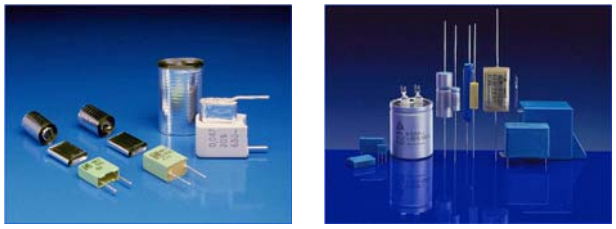

Figure 16: Various Film Capacitors.

Together with the development of the oil masking system and the further development of the winding system for ultra thin films, the Applied Materials patented segmented spreader roller is significant.

Figure 17: Patented Spreader Roller for UTF.

This development brought the breakthrough in coating technology to handle ultra thin substrates. Such a system, which offers excellent flexibility, is required because of the wide range of film coating applications. The system, which consists of several single idle metal rollers, spreads the substrate being coated in such a way, that it leaves the rollers flat and smooth without any additional stretching. In this way the film is adjusted and no over expansion taking place.

Positioned in front of additional processes like oil masking, the spreader roller system improves the dimensional accuracy of the stripes and patterns. An additional idle roller is no longer necessary. Another advantage is that static charging avoided, as the whole winding system is build of metallic material.

Coating Modules

The 1st capacitor materials were usually coated with a single Aluminium layer. Ongoing development and changing demands to the capacitor industry resulted in further layer systems, being deposited in one machine. So today, beside the still important single Al layer, Aluminium-Zinc mix coatings also play an important role. Depending on the philosophy of the capacitor manufacturer, with the MULTIMET™ Silver and/or Aluminium can be coated for pre-seeding of the Zn main layer. It's also possible to deposit e.g. copper as an alternative. The most common used mixed layer is an Aluminium-Zinc combination.

To offer oriented solutions, which meet the requirements in the best and economic way, the modular concept of the MULTIMET™ was developed. Depending on the process required, different modules are used which are quick to change:

- Standard Aluminium (Silver/Copper) - Zinc module (for mixed coatings)
- Aluminium high rate evaporator module (with Applied Materials patented staggered boat system for single Aluminium coating)
- Further developed and for ultra thin film designed Aluminium high rate module UTF especially for PET, PEN and PPS applications

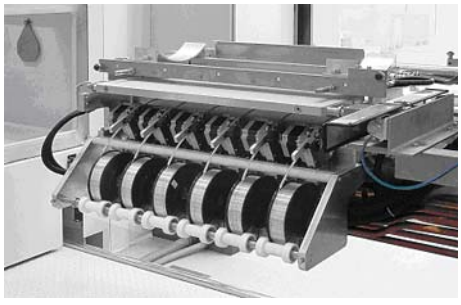

Figure 18: UTF Coating Module for Al.

- Combined Module (for mixed Aluminium, Silver/Copper-Zinc Coatings or normal rate single Aluminium layer)

Figure 19: Combined Al - Al/Zn Module.

Advantages of the modular system lie not only in the flexibility and easy access for maintenance, it also keeps the system open for new development in coating technology.

All evaporator modules consist of an evaporator source, which is located in the separated process chamber. The supply units for the single modules are mounted outside the chamber and accessible at any time.

Masking Systems for unmetallised Structures

Beside the revolving circular masking tapes between the substrate and the evaporator source, the Applied Materials patented oil masking system has become an accepted process. Depending on the demands of the capacitor design, both systems are available with the MULTIMET™. This commercially available machine concept offers enormous technical progress in the field of structures and deposited layers for these applications.

During the oil masking process, a special oil is evaporated and desired patterns are imaged on the substrate, which are creating the thin film metal layer with corresponding insulating / fuse areas.

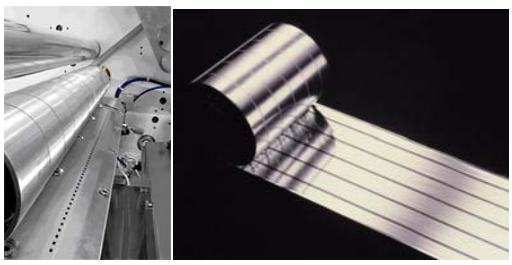

Figure 20: Longitudinal Oil Masking System.

After evaporating and transferring the oil, it condenses in specified positions on the film. During the metallising process, the condensed oil is vaporized by the energy from the metallising process and in that way a localised protective gas cushion is created, which inhibits the metallisation in a defined local area. Accurate defined sharp structures down to 0.1 mm are creatable by this Applied Materials technology.

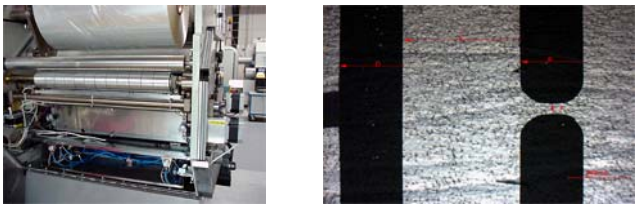

Figure 21: Inline Pattern Masking System PatVap™
/ Example for Variety of possible Pattern.

High accuracy of imaged structures is achieved, which is crucial for the proper function in the specifically designed pattern film capacitors.

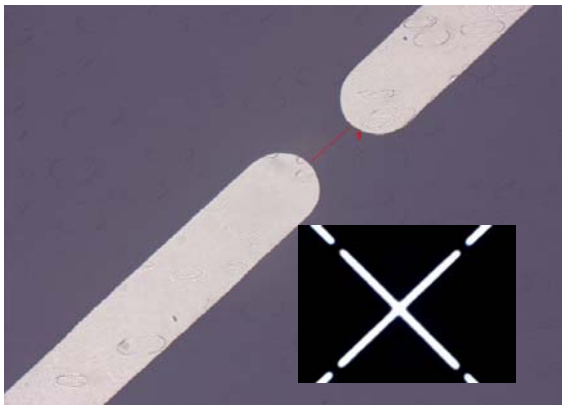

Figure 22: Accurate coated Al/Zn Pattern Fuse: 0.274 mm (desired value 0.300 mm), BOPP.

The applied oil layer has a thickness in the nanometer range and this only few atoms can be transported over guide rollers, without the oil image being smeared or separated. The quantity of the vaporized oil can be treated in a way, so that almost no oil remains, which can adversely affect the metallised film.

A precise pattern masking like PatVap™ together with the corresponding coating modules for various electrode materials in required dimensions on ultra thin BOPP, are the key technologies for the demanding film capacitor application, used for the Hybrid Electrical Vehicle's . Beside pattern metallisation on 2.8 to 3.2 µm BOPP in combination with Aluminium/Zinc, also unmetallised geometries on ultra thin PET film <1.5 µm and pure Aluminium are requested and possible with the MULTIMET™ and it's PatVap™ system.

Masking Systems for reinforced Edges

With at MULTIMET™ available coating modules, all recently requested combinations of reinforced (heavy) edges are possible:

Figure 23: Coated BOPP Substrate with "Heavy Edge" and Free margin.

The reinforced edge, or so-called „heavy edge", can have a selected width in millimetres and a factor of e.g. 3.0 lower resistivity (i.e. thicker metal layer) in comparison to the normal active layer.

Reinforcement Combinations			
Heavy Edge	Active Layer	Coating Module	Ratio
Al	Al	Al	e.g. 1:2 to <1:5
Zn	Al/Zn[1)]	Al/Zn	e.g. 1:2 to 1:3
Zn	Al	Combined	e.g. 1:2 to <1:5

1) Al pre-seeding

Table 02: Heavy Edge Coatings.

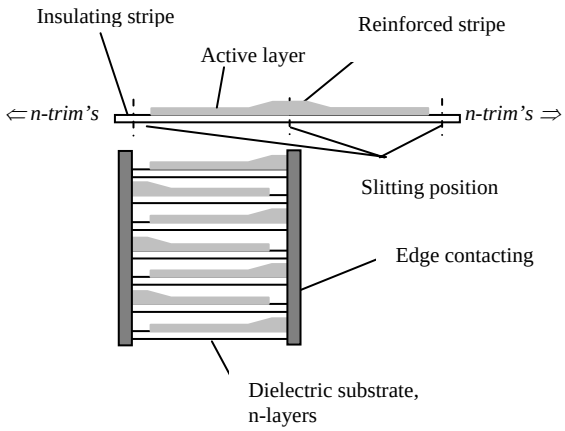

Figure 24: Scheme of possible Film Capacitor design.

Plasma generated Web Charging/Discharging

To increase coating speed at thicker getting layers on down gauged, more sensitive substrates, also in combination with pattern metallised structures, a additional process feature can be used: At using a plasma generated electron / ion source, it's possible to achieve improved web behavior during deposition process on the coating drum: An attractive force of the film on the coating drum is created by electron bombardment of the plastic film.

The below shown Applied Materials solution, combines with it's simple operation by only adjusting Voltage and Gas flow, a maintenance friendly system (no filament changing necessary), which can also be positioned flexible in various positions, inside of machine.

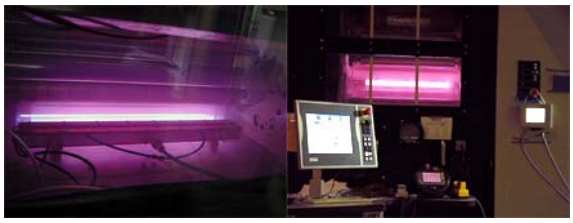

Figure 25: MULTIMET™ WEB Charging / Discharging Unit.

The reliable operation is achieved at the relatively higher background pressure of winding chamber. It requires no additional pumping system and also no complicated beam deflection system, no hot spots are caused. Using the system, e.g. coating Al layers with <1.5 Ω/□ on UTF PET 1.4 µm at web speed 10 m/s are achieved in stable conditions, as well as pattern metallisation on BOPP 3.0 µm with 15 m/s (8-10 Ω/□ Al/Zn). More process parameters are shown in Table 03.

Coating speed / Layer thickness with CEAS ™				
Substrate	Thickness	Layer		Speed
		Active (Al)	Reinforced (Zn)	
	[µm]	[Ω/□]	[Ω/□]	[m/s]
PET	1.4	<1.5	-	10
PET	1.2	1.5	-	10
BOPP	3.5	<0.9	-	6
		1.15	-	8
		1.4	-	10
BOPP	3.0	>10	<3	15
BOPP	2.5	8-10	<3	11

Table 03: Achieved process parameters with CEAS™: Increased web speed of 30-50% possible.

The thermal contact of the electrostatic charged foil to the cooled coating drum is considerably improved by this electron charging unit. By bombarding the uncoated plastic substrate with electrons, they can be implemented into the plastic. The penetration depth x(mm) of electrons can be calculated by following Equation 01:

$$x(mm) = 0{,}1 * E_0^{1,5} / r$$

E_0= acceleration voltage (kV)
r = Material density (g/cm³)
r = 1,41 g/cm³ for PET
0,91 g/cm³ for OPP

Equation 01: **P**enetration depth x(mm).

At 10 kV the penetration depth into PET is around 2,2 µm and the number of reflected secondary electrons is low, which result in a good charging effect, see Figure 26.

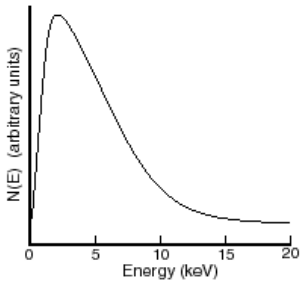

Figure 26: Secondary electrons created by electron bombardment.

After the coating process is finished the foil has still electrostatic charge on the surface. This charge has to be removed before the foil is wound up and further processed. For this purpose a linear plasma source is used. The working principle of this charging / dis-charging process is shown in Figure 27.

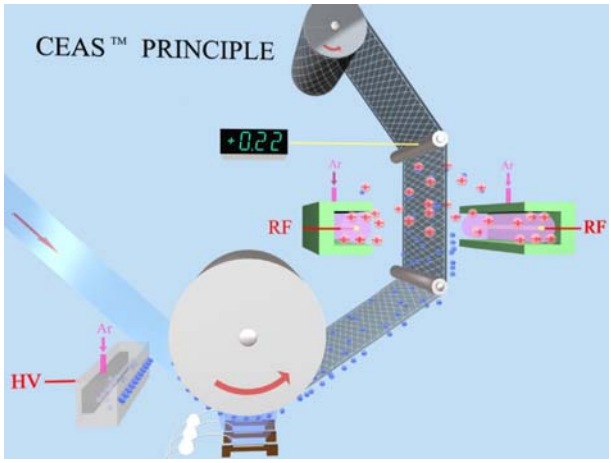

Figure 27: MULTIMET™ WEB Charging / Discharging Unit.

Advantages CEAS™:

- Easy and Simple operation by changing voltage / gas flow with CEAS™
- The attractive force can strongly be influenced by increasing the penetration depth with higher electron energy
- No filament exchange necessary (low running costs)
- No hot spots and no complicated beam deflection system
- Flexible positioning inside machine
- Reliable operation at high background pressure without additional pumping system
- CEAS™ for best pattern coating and UTF coating (stable work at defect in substrates)
- Dis-charging of substrate by linear plasma source

Plasma Pre-treatment

The TreatMag™ inline plasma source is a pretreatment tool for thin film coating applications. The origin of this system has been the use in the high throughput web coating systems TOPMET™ and TOPBEAM™, mainly used initially on flexible packaging materials for already more than 10 years now.

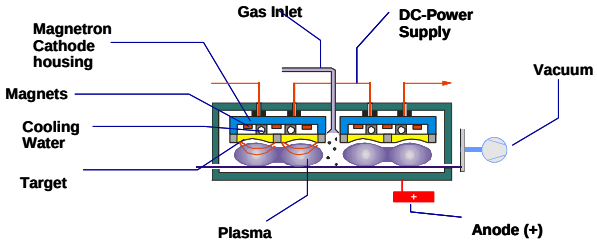

Figure 28: Working Principle Plasma Pre-treatment.

The TreatMag™ improves the overall thin film properties and helps to produce film, which meets the demands of high quality capacitor producers and is used successful since several years also in MULTIMET™ already. Main advantages of the TreatMag™ technology are improved metal adhesion and substrate surface cleaning before deposition. Therefore it‘s possible to realize stable metallising preconditions at the substrates. For reaching this effects, different process gases in combinations with adapted power adjustment and target types make it possible, to find the optimum setup for the many different substrate types.

6 Quality Support

Online Process Control

Different monitoring systems are available for online control and measurement of the deposited layers and structures.

Layer Thickness

The metallised film layer thickness can be measured by two independently working „**L**ayer **M**onitoring **S**ystems LMS): One system gauges the surface resistivity of the coated layer between two measuring rollers and for the coating width an integrated value is displayed in a Ω/□-Value (Ohm/Square, LMS-C). Second method is the laser beam system LMS-P, which is measuring the **O**ptical **D**ensity (OD) of the coated layer.

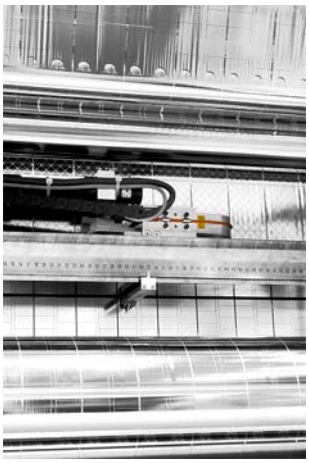

Figure 29: Online Layer Measurement.

The LMS-P („P“ for „Pattern“) allows by a transversal positioning unit, to measure OD at exact positions in specified areas, which provides useful information about the layer thickness distribution across the web width. This especially applies in the case of coating patterns e.g. longitudinal free stripes.

Pattern Structures
To have the opportunity to control online the accuracy of the imaged unmetallised structures (e.g. created by the approved inline PatVap™ system), an online optical measurement via a video system can be installed parallel at the LMS-P drive unit („LMS-Video“).

At below shown additional visualization display, the actual measuring positions are shown, and in case of a variation to a set tolerance the operator is informed by an error message, so that the necessary adjustment can be made.

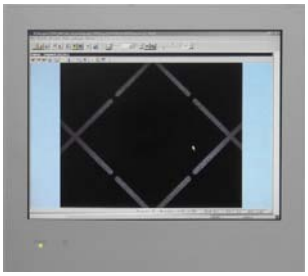

Figure 30: Online Pattern Measurement LMS-V.

Production Data
A high volume of data is generated by the MULTIMET™ during the process. With today's powerful PC's this information is now used for a wide range of data evaluation. The production data is automatically stored and - if required - printed, and the relevant parameters are easy to store and manage.

In Addition, a **P**roduct **I**nformation **M**anagement system is available (PIM system). With this tool various kind of statistics/reports can be easily generated and the whole process can be monitored by an external PC system. The data are stored in a database and the backup to a storage medium is also possible. Search and statistical features are integrated.

7 Conclusions

Film capacitors are a considerable alternative to commonly produced caps like Ceramics or Electrolytics.
The further exploitation of new applications will require advanced thin film capacitors, especially in new applications in the automotive industry.
New coating technology for capacitor design and production like UTF handling, various heavy edge combinations and precise pattern masking on ultra thin film substrates are already commercially available as an advanced thin film capacitor production system.
Capacitor manufacturers will profit from the expanding market for thin film and pattern metallised capacitors by using advanced vacuum web coating metallisers like the MULTIMET™. It meet's this requirements and some producers are already exploiting these innovations to produce high quality capacitors with advanced properties at reduced cost with a multifunctional and flexible system, which offers production-, design and quality support for each of it's users.

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- Toray, Japan (www.toray.com)
- Treofan, Germany (www.treofan.com)

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