Latest Developments In Metallisation & Vacuum Deposition

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Introduction.

Vacuum metallization continues to grow as an industry and with the growth there are developments in both the equipment and the deposition process. In addition to the normal course of development there are, in some parts of the world, other changes over the horizon that are needed to meet new legislation. In this paper I will detail the current status of pattern metallization including in-register pattern metallization, transparent barrier coatings for packaging and high-tech applications, energy reduction options for metallizers as well as vapour jet sources which may be the preferred deposition source for the future.

Energy and the environment.

In complying with environmental requirements a life cycle analysis (LCA) of the metallized film can be done. One of the aspects of doing an LCA is to carry out an energy audit. One of the things to come out of this type of activity is that metallizing, although it can be demonstrated to have some advantages, is not particularly energy efficient.

The resistance heated sources are not an efficient way of evaporating the Aluminium. The broad view is that the energy used in resistance heated boat metallizers is split three ways, one third into the cooled end connectors, one third radiated away from the sources and one third used to evaporate the aluminium metal (1) of which much of this energy also ends up in the cooling liquid in the deposition drum.

Similarly in the sputter deposition systems the magnetron sputter cathodes are not particularly efficient and 75% of the applied power can disappear into the water as heat.

The sources radiate heat in all directions. It ought to be possible to reflect the heat back to the sources and so reduced the radiation losses from the back surface of the sources. It has always been argued that this is an area that gets very dirty and so the reflectance would soon be lost and thus the benefits would only ever be marginal. However this argument lacks substance, it really requires some experiments to be done to and measurements to be taken to determine the amount of energy that could be saved. The costs could then be calculated and an informed decision made on whether the effort of providing and keeping reflectors clean was a cost effective activity.

Energy recovery

It has always been viewed that energy is cheap and this has encouraged us all to be wasteful of it. Heat from the exhaust water from any vacuum deposition process as a source of heat energy is erratic and classed as low-grade heat. As it may be erratic in quantity and temperature it is easier to pour the hot water down the drain. In more than one case a recirculating water system has been installed, at great expense, including a cooling tower just for the one vacuum deposition machine. Despite the fact that one of the machines was sited in a region where snow could be present for six months of the year it was never considered as an option to use the heat from the machine to pre-heat the building heating or hot water system.

Contrast this with the solar collector industry, which takes sunlight and converts the energy to pre-heat water (2,3), which is now established and growing quickly. This too can be considered to be an erratic source of heat as it depends on the local climate and number of sunshine hours as well as it only working during daylight hours. Therefore it too produces an erratic quantity and temperature of heated water. If anything a production metallizer has a more predictable output with the period and quantity of heat fairly accurately known. Thus apart from occasional unforeseen downtime this would represent a regular source of available heat throughout both day and night. This ought to make this a more easily utilised source of pre-heating than the rooftop solar collectors.

Therefore it ought not to be beyond the intelligence of the metallizing industry to make better use of the exhaust hot water by recovering an amount of the heat and thus making an energy saving in the process.

Deposition efficiency improvement.

It could be considered that the largest loss of energy in an aluminium metallizer is due to the poor collection efficiency of the aluminium. Often only 50% of the aluminium is collected on the web. A simple energy improvement would be to collect more aluminium on the web. One option for this would be to increase the deposition drum diameter. The down side of this is that the capital cost of the whole machine increases as well as the energy cost to pump a larger system and an increased energy cost in the increased quantity of material that goes into the larger system.

A second option is to use a high collection efficiency source. In my view the arguments for using this type of source only get stronger as the energy cost rise. The high collection source uses full width evaporation sources that are distributed around the deposition drum. As each source only has to contribute a proportion of the deposition they can be located closer to the drum and so the deposition losses are reduced. As there are several sources around the deposition drum the heat load is better spread and so the machine can also run faster than conventional machines.

A production machine was made for a different material and the collection efficiency was >95%. If this were carried through to the aluminium deposition the energy cost per unit area would be almost halved using this type of source (4).

Sidrabe have for years produced special resistance evaporation sources that could be fed from the ends that look capable of being used for distributed sources. (5). Also the in-line web coaters in Japan have used coated ceramic boats with lifetimes of over 100 hours (6). Both of these developments would suggest that it is possible to use long lifetime boats for aluminium and that designing a distributed sources is feasible There are indications that jet vapour sources are now being developed for use in depositing some solar cell materials and it could be expected that these will be applied to metallizers in due course.

Jet Vapour evaporation sources.

Of the aluminium evaporated only a proportion of it is condensed onto the polymer substrate. These sources have been developed for other reasons and for are targeted at a different application but never the less will be applicable to aluminium metallization. Jet vapour sources use a material source that provides a vapour into an enclosed volume from which the vapour exits through a narrow slot. As the vapour exits through the slot the vapour is accelerated and undergoes adiabatic expansion where the vapour is accelerated but cooled. The substrate passes very close to the nozzle and so the collection efficiency can be greater than 99%. The deposition efficiency of the aluminium deposition is substantially improved using this process. Not only does the enclosed source lose less energy but the collection efficiency means the energy is shared by much more coated material lowering the cost per unit area. The jet source can be oriented in any direction and so the sources can be distributed around a deposition drum spreading out the heat load to the substrate. This will give further opportunities to increase the deposition speed for thicker coatings than are currently possible but without the corresponding problems of tramlines (railroad lines).

This type of source is not all ‘good news’ as the enclosed nature of the source means that it has to be operated differently. Generally the whole metal inventory for a single deposition run is placed in the source from the start. Cooling of the source is more difficult than for the high loss resistance heated sources. So the status of these jet vapour sources is that they are being developed for other applications and, once developed and debugged, could be adapted for aluminium metallization.

Pattern metallization

Many applications where it is required that metallization is carried out only onto selective areas of the substrate. This is known as pattern metallization. There are several ways that this can be achieved. Of the methods two can be done inside the vacuum system as part of the metallization process.

The earliest method was to use a metal mask that is in the form of a continuous belt that is brought into contact with the substrate across the deposition zone. The belt passes around the sources and this can stress the deposited material on the belt so that it breaks off and this keeps the belt clean and the pattern dimensions reasonably accurate.

The currently favoured method is to vaporize a suitable oil and condense it onto a patterned gravure roll that prints the pattern either directly onto the web or via an intermediate roll onto the web. The quality of this process depends on several factors including the quantity of oil transferred, the hardness and surface quality of the gravure roll, the balance of un-metallized to metallized areas and well as the coating thickness. The problem with this technique is that as the oil evaporates the size of the oil drop can reduce in size and so the edge sharpness can be lost. The quantity of oil is the critical parameter. The oil is not a on the surface as a flat parallel layer but has a curvature and so as the oil is evaporated the width of the line is reduced and so the line edges may not be as sharp as with an in-contact mask, particularly if almost all the oil has been removed. If, however oil is left on the surface it will transfer via the first front surface roll to other parts of the aluminium deposition contaminating the surface. Methods have been developed to manage this. The oil chosen can vary depending on whether the film is to have food contact approval or not.

The latest development in this process has been made by General Vacuum who offers systems containing winding control that can deliver in-register pattern metallization. This technique allows the pattern metallization to be positioned in-register with other devices on the web such as printed patterns or designs or holographic images. This in-register metallization allows more flexibility in the order the coatings have to be deposited.

The images that can now be produced enable a variety of products to be produced by this technique. This includes simple capacitor films, antenna for radio frequency identification as well as different forms of microwave heating. The microwave heating can include attenuation as well as coupling and focussing. Patterns can be used to produce areas of weakness that on heating will fail and reduce the conductivity thus limiting the heating effect. In this way the temperature can be limited preventing the food being overheated or even burnt.

The next technology that may be applied to vacuum systems is ink jet printing processes. This could be used in two different ways. One is to use the ink jet heads to print on the oil in finer detail than by the gravure printing and then to metallized in the same way to produce metallized patterns. This potentially offers the option of changing the pattern being printed either during the metallization process or between deposition runs but without having to change the gravure roll.

The second option is to use the ink jet print heads to directly print on the metal layer. This requires making an ink jet print head that can contain and work with molten metal. Difficult though this sounds it has been done, both in atmosphere and more recently in vacuum (7). The aim was to deposit copper circuits and antenna directly.

This process has completed the proof-of-principle work and plans have been drawn up for scaling up to pilot production size of equipment.

Transparent barrier coatings.

Transparent barrier coatings are one of the higher growth markets across Europe and volumes are increasing in the USA too. Substantially little has changed in the deposition techniques over the last few years. There are three processes that are the major ones used to deposit the coatings, electron beam deposition or chemical vapour deposition of silica and the post oxidation of aluminium into alumina (8-12).

Coupled to this are the benefits of the research done into the mechanisms to explain why the barrier materials do not perform as well as might be expected (13-16). Key to improving the barrier is cleaning the substrate of any debris to minimise the number of pinholes in the coating. One major difficulty is seeing the pinholes in transparent coatings. It is easy to ignore what cannot be seen. If you are in any doubt have a look at the pinholes in metallized films and typically the same size and density of pinholes will be in the transparent coatings. Where it is essential to improve the barrier performance, such as for the ultra barrier coatings for encapsulation electronic devices such as organic light emitting devices, a polymer layer is deposited immediately prior to the barrier coating. This pre-layer produces a very clean, smooth layer that will cover up any remaining debris and gives the best possible opportunity to produce a defect free coating (17,18). Sometimes there is a second polymer coating added over the top of the barrier layer which helps protect the barrier layer from damage and partially plug any remaining defects.

Conclusions.

Although at time it can feel as if within the metallizing industry there are not many developments and they are slow to appear it can be seen from the above there are some significant developments that are being worked on. In particular the jet vapour source look as if it would have the greatest impact on the metallizing process particularly if it can change the material efficiency to > 95%.

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