Slot sources:
a replacement for resistance heated boats in aluminium metallizers?

Charles A. Bishop
C.A.Bishop Consulting Ltd.
Middlesbrough, N.Yorks. TS8 0AQ. UK

Key Words: One key word here; Second key word here; Third key word here; Fourth key word here (10-pt type/12-pt leading)

ABSTRACT

Aluminium metallizers have a row of resistance heated evaporation boats sited beneath a chilled deposition drum. Each boat has aluminium wire fed into it that forms a molten pool from which the aluminium evaporates. This process has low material efficiency and there is a significant ongoing cost in replacing the evaporation boats after every 12 – 15 hours deposition time.

As metallizers get ever wider the number of boats required increases pro rata. Some polymer producers are looking at metallizing mill rolls of widths in the range 6m – 12m. To metallize at this width they would like to change from the large number of evaporation boats to a single full width slot source.

Slot sources are not new having been used for many years for the deposition of zinc and other low temperature metals & alloys. More recently they have been developed for the deposition of polymers such as for organic light emitting devices (OLEDs) [1]. Potentially slot sources can deliver improved deposition uniformity and higher material efficiency with reduced power consumption. However the opportunities to gain the benefits from slot sources for aluminium metallizing will only be achieved if some materials and process problems can be overcome. In this paper I will highlight the benefits that are on offer and the current limitations.

INTRODUCTION

Currently the higher rate metallizers are capable of running at 1000m/min. Depositing onto a 40km roll this gives a deposition time of approximately 40 minutes and with a turn around time of approximately 20 minutes with a productivity of around 1 roll per hour.

This process has been optimised over several years to minimise the pumpdown time and the time to bring the system back to atmospheric pressure. Work has also been done to minimise the time needed to exchange shielding, system cleaning and source replenishment. In some systems a second set of deposition sources could be indexed into position allowing the first set to be cleaned and replenished during the next deposition cycle.

Increasing the deposition speed to, say, 2000m/min would improve the productivity. However without a similar improvement in the other parts of the process the productivity would become dominated by the turn around time. At a deposition speed of 2000m/min the deposition time as a percentage of production cycle would be around 50%.

There can always be some improvement on the pumpdown time but this tends to be at a high cost. The other option is to reduce the cleaning and replenishment time. Reducing the amount of material that coat the shields either reduces the need to clean or the frequency with which they need to be exchanged, thus saving time.

Additionally aluminium metallizers have poor deposition efficiency. If the deposition efficiency could be improved there are several savings to be made. There would be the choice of either reduced power consumption for equivalent deposition, or increased deposition rate for the same power as one saving. Also if the material efficiency were to be improved there would be reduced material costs. Other benefits include the reduction in waste material disposal costs. As the shielding receives much less deposition it requires less cleaning saving both in labour costs and turn round times.

It is estimated that with resistance-heated sources 33% of the power is lost as conduction to the water-cooled bus bars and 33% as radiant heat. Using a radiant heated source and a surrounding radiation shield a much more power efficient slot source design is possible. In Europe, not only would there be a reduced power cost but also there would be benefits in reduced payments of Climate Control Levy because of the energy savings.

46th Annual Technical Conference Proceedings (2003) ISSN 0737-5921

In the past there have been efforts to improve the deposition uniformity [2,3] and to extend the boat lifetime but still the deposition efficiency has remained at < 50%.

Where slot sources have been used the material efficiency has been increased and in some cases this can be in excess of 95%. The move to slot sources has the potential to make huge step change to the deposition of Aluminium giving both cost savings and product quality improvement.

The move to using a slot source is not without some risks and it requires some thought in order to maximize the benefits and minimize the problems.

SLOT SOURCE DESIGN

Basic design

Figure 1 shows a schematic of a slot source. The retort limits the escape of the vapour and there is a rise in pressure of the vapour. The vapour exits from the slot or chimney. The build up of vapour within the retort helps to even out any local evaporation rate variations. It also means that the vapour can be directed and does not have to simply evaporate directly upwards.

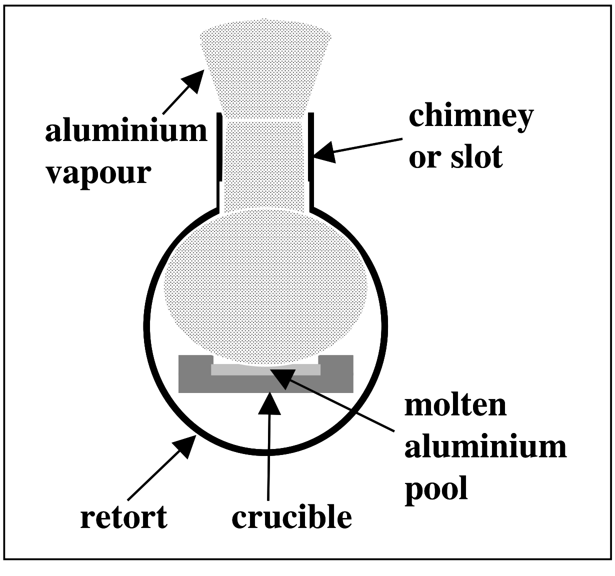

Figure 1. A schematic of a slot source

The pressure difference between the vacuum and within the retort depends upon the evaporation rate, the molten surface area and the slot dimensions. A narrow slot, a high rate of evaporation and a large area of molten metal and the vapour jet from the slot will be very strong narrow and directional. Reducing the rate and/or widening the slot will broaden the vapour plume and widen the deposition profile as shown in figure 2.

The efficiency of the source, uniformity of deposition, positioning of the heater elements, speed of heating and cooling and design shape and size of slots can all be modelled [4].

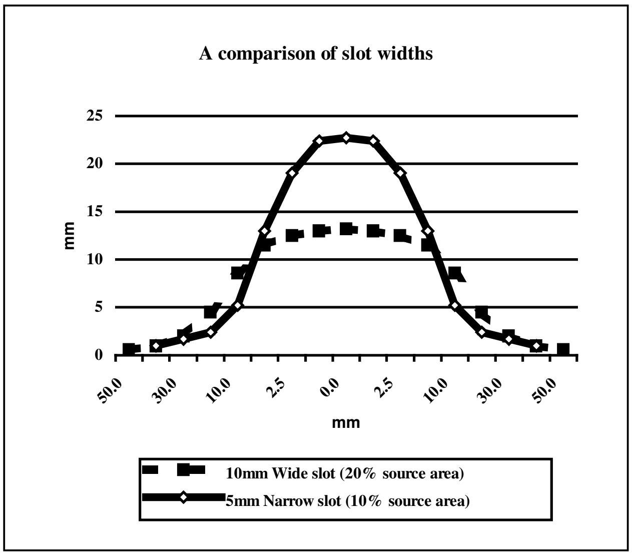

Figure 2 A change in the deposition profile with change in slot width for the same power input.

Number of sources

There is a choice of using individual sources, a single source with multiple outlet slots or multiple sources within a single insulated box.

One of the ways that source becomes more material efficient is that the source can be moved closer to the deposition drum and thus there is less scattered material that does not fall on the passing substrate. In moving the source closer to the deposition drum if the same mass of depositing material were to condense on the web but in a shorter deposition zone the thermal rise in the substrate would be increased. So to get the benefits of the improved material efficiency it is preferable to divide the deposition between several sources and so extending the deposition zone and gaining the benefits of greater cooling.

It is possible in this way to have more than 50% of the deposition drum circumference used as the deposition zone. A schematic of this is shown in Figure 3.

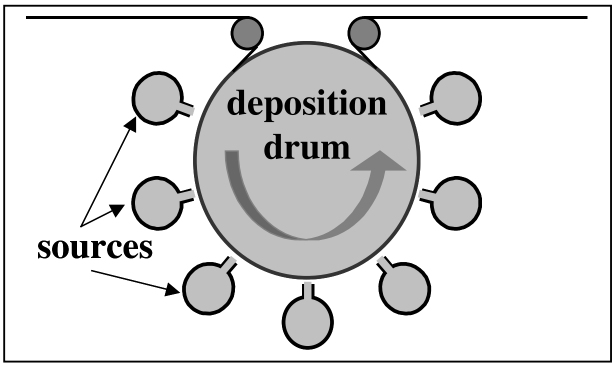

Figure 3 A schematic of several sources using almost 75% of the deposition drum circumference for the deposition zone.

Insulation

It has been estimated that 33% of the power put into resistance heated boats is lost as radiant heat. As 50% of this heat is lost towards the substrate it is a major source of substrate heating.

Sources can be insulated to minimise the radiation heating of the substrate and also to minimise the overall radiation heat loss. This becomes increasingly important as the source to substrate distance is reduced. This in turn speeds up the heating of the sources. By having multiple sources enclosed in a single insulated container allows for more efficient and faster heating [5]. The heat lost from one source contributes to the heating of the adjacent source.

The insulation can be achieved by use of radiation shielding or by use of insulating materials such as ceramic fibre blankets or blocks. The blocks and blanket material needs to be conditioned once but is then stable and does not significantly increase the outgassing of the system or slow down the pumpdown time.

The problem can occur in the cooling cycle. Once the power is removed the same radiation shielding that made the heating more efficient has the problem of slowing down the cooling of the source. If this is not managed well it can be a rate-limiting step in the process.

To overcome this problem one system was built that used a forced gas quench to more rapidly lower the source temperature to allow operators to more quickly replenish the source [6].

Materials

Molten aluminium is corrosive and is known too creep or migrate up crucible walls. Crucibles have been designed to have a higher temperature rim to ensure the migrating aluminium is evaporated and does not escape the confines of the crucible [7].

The crucible lifetime is one of the unknowns of slot sources for aluminium. Boron nitride, titanium diboride and an intermetallic of the two materials have all been used to make crucibles. As the intermetallic boron nitride/titanium diboride is currently used for the resistance heated boats there is no reason to think the boats will last any less time than the current application.

Carbon has also been used but is usually rejected because of the formation of aluminium carbide. This has been found as a contaminant in the crucible but it is not clear that it has been found as a contaminant in the coating. Certainly carbon crucibles have been successfully used in induction-heated sources for deposition aluminium in Japan [8]. These crucibles were carbon with the internal surface impregnated with alumina. The impregnation of alumina means that the contact of the molten aluminium to the carbon is limited overcoming the interaction problem. The alumina also fills the pores limiting the porosity. Limiting the porosity prevents the surface cracking and also limits the moisture absorption. Both of these advantages help extend the crucible lifetime. These impregnated and heat-treated crucibles have a lifetime extended from 4 – 5 to 20 – 30 deposition cycles. These crucibles provide a similar molten pool area to the resistance-heated crucibles. They have not been made into linear slot sources.

There is a significant cost of the carbon crucibles with the impregnation and heat treatment. Another approach is to aim to reduce the cost of crucibles. One option put forward to produce an inexpensive crucible is to use a thin walled metal crucible simply folded or pressed. This crucible is then coated with a boron nitride/titanium diboride coating. The aim being that the fabrication would be simple and cheap enabling the boats to be thought of as disposable items used once or twice (or more if possible).

The crucibles need only have a very limited mechanical performance. All they have to do is retain a limited quantity of molten aluminium for half an hour per cycle at high temperature in vacuum. The crucible itself is

46th Annual Technical Conference Proceedings (2003) ISSN 0737-5921

supported by the retort. As the crucible is only to be used once or twice any thermal distortions are of limited consequence. The size of crucible, up to several metres long, means that it is probable that vacuum coating the boron nitride in vacuum is probably impractical and it was proposed that the same boron nitride paint, that is used to limit the metal adhesion on shielding, is used to coat the metal crucible.

The other option is to use a solid ceramic crucible. In the case of radiant heated sources the choice of ceramic is wider than for the resistance heated boats because there is no requirement for the crucibles to be electrically conducting. The thermal conductivity is of more interest that electrical conductivity. However solid ceramic crucibles tend to be more expensive and so need to be used many times for the economics to be advantageous. This may be difficult to achieve.

On the positive side, it has been suggested that if there is no wire feed into the boat the erosion from where the wire meets the boat will be reduced and hence it could be expected that the boat life would be extended. However, this is at present conjecture and needs to be proven.

On the negative side, many ceramics are pressed powder compacts and have a granular porous surface. The molten aluminium wets the ceramic surface and may even penetrate the pores. It is this metal penetration that is the cause of the crucible problems. If the crucible is cooled whilst the ceramic surface still contains metal the differential thermal expansion can cause premature failure of the crucible.

The strategy to minimise this is to evaporate all the metal from the crucible before cooling the source down.

Source replenishment

There is a choice between feeding new material into the source or to use a fixed charge of material and evaporate to extinction.

Feeding a molten evaporation source is one of the big problems facing source designers. Feeding is possible but tends to make the design complex and expensive. In general simplicity of design is to be preferred because it tends to be more robust particularly in a relatively dirty production environment.

Traditional boats have a wire feed to the boats and a thin molten pool of aluminium the size of which is controlled by the heating current and the wire feed rate. These boats are in the open and feeding them is easy. In an enclosed source feeding is more problematic. Where the wire or rod feeds into the source it is also possible for the vapour to leak out and to condense on any cold surface thus blocking up the feed orifice. If the orifice is made large enough to prevent the vapour from blocking it up the loss of material through the orifice will be significant leading to lower material efficiency and a greater cleaning requirement. If the orifice is kept hot to prevent any condensation occurring the vapour will leak out and also there may be a tendency for the feed material to distort from the heated surfaces causing snagging and feed variations.

In electron beam systems they also use a rod feed from beneath the crucible with the rod feeding directly into the molten pool of metal. Again the rod feed is balanced against the rate of evaporation to keep the pool height constant. Here there is still the problem of the vapour leaking through the feed orifice of the source enclosure. There is also the problem of the cooling of the source. The aluminium rod has to pass through the crucible and as the metal solidifies and cools the differential thermal contraction will cause cracking of the crucible and leaking of molten metal during the next heating cycle. Where this system has worked well is where the diameter of the feed rod has been equal to the molten pool diameter.

The alternative strategy is not to feed the source at all but to fill the crucible with sufficient aluminium to complete the deposition run onto a standard roll of material. In this case the evaporation continues to completely empty the crucible minimising the problems of differential thermal contraction. As there are likely to be several crucibles around the deposition drum the mass is divided between them and this still allows for a fast heating cycle.

This strategy has risks. If there is any other problem during the process there is little tolerance to be able to run the process for longer, or, if the process is curtailed by a system fault, the sources will have to be cooled with a partial charge of aluminium contained in the crucible which may then be prone to the thermal stress cracking. If there are many such failures then the material efficiency can drop dramatically. However any process that is so unreliable has more serious cost implications from loss of production and this would just be reflected in the lower material efficiency.

This process of heating the complete inventory also means that a quick and simple method of exchanging the empty crucibles for recharged, full crucibles is required as part of the design to enable a fast turn around of the process. The retorts need to be sealed to prevent vapour leaks and capable of thermal cycling whilst maintaining the integrity of the seal. Once down in temperature the seals need to be easily released to enable quick and easy access to make the crucible change. This may not be as easy as it sounds and it may be preferred to have a complete exchange source to enable the crucible changes to be made on one source whilst the other is being used for deposition.

Uniformity

To get uniformity across the full width of the substrate roll evaporation should be from a molten pool that extends across the full width. By altering the slot width at the ends to suit the deposition thickness fall-off, at the end of each source, can be compensated for.

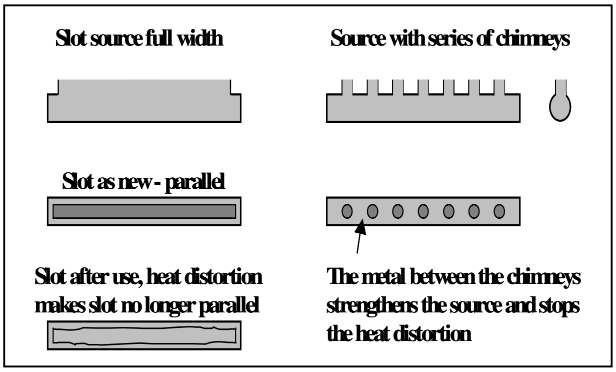

Figure 4. A schematic of two slot sources one with a full width slot and the other with chimneys

Another of the choices to be made is which type of slot is to be used. A single slot the full width of the source or a series of chimneys.

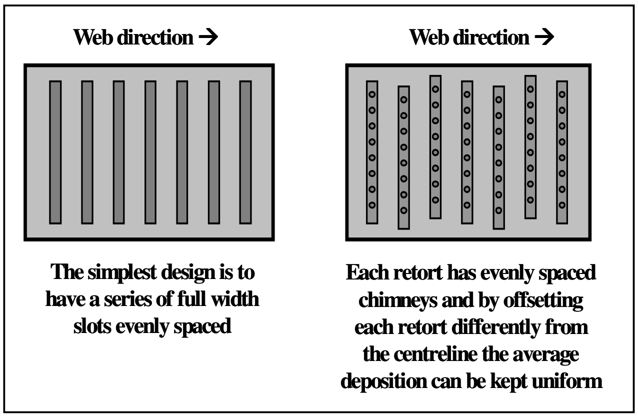

Figure 5. A comparison of full width slots and a series of retorts with offset chimneys.

The source shown in figure 6 was based upon the use of six retorts each of which had 8 chimneys to give a distributed heat load. It was used at a deposition rate equivalent to depositing an aluminium coating of optical density 2.25 at a winding speed of 2000m/min with a uniformity of better than +/- 5% [9].

Figure 6 shows two sources for double side deposition. The top surface of the source has the insulation material removed to make the retorts and chimneys more visible. The front surface insulation was an alumina blanket coated with boron nitride paint to limit the adhesion of any backscattered aluminium.

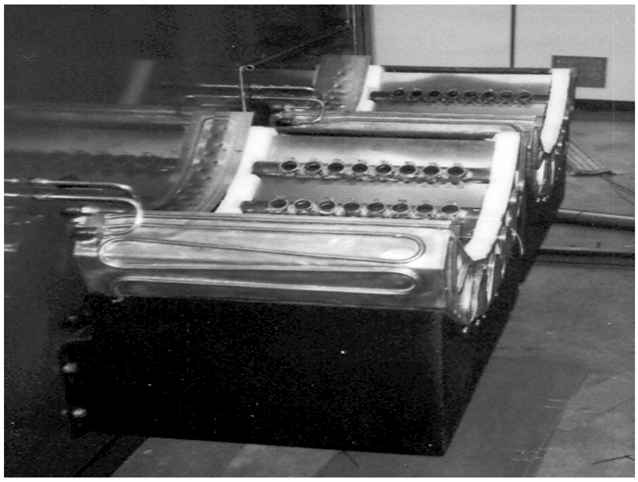

Figure 6. An example of a two sources for a double side coating application.

Shutters

To get the best possible efficiency the source to substrate distance should be quite close. As the source to substrate gap is reduced it makes it more difficult to use a shutter over the source. The combination of multiple slots, wide rolls and narrow gap means that it is simpler to dispense with a shutter. The source temperature can be raise to just below the deposition temperature with the substrate inching round the deposition drum and then as the temperature is brought to the operating temperature the winding speed can be raised using the deposition monitors to control the thickness.

If a gas is used for cooling it may also be possible to use the gas to change the pressure to slow down the deposition speed until the operating temperature is achieved.

46th Annual Technical Conference Proceedings (2003) ISSN 0737-5921

RISKS

Resistance heated source evaporation of aluminium has been carried out for many decades and the process is well defined. It is a risk to discard all that knowledge and move to a new and relatively untried source.

However slot sources have been used for many years to deposit zinc with a material deposition efficiency in excess of 90% for capacitor materials [10]. Although the capacitor metallizer machines tend to be narrow in width typically around 1m wide. Also they tend to have only a single slot source.

The machine built to deposit pyrotechnic material was designed to deposit thick coatings and so did have a source designed with six retorts to each source as shown in figure 6. This source also made use of the forced gas quenching. This system too was only of limited width being approximately 0.4m wide.

Crucible materials for use with a fixed charge of aluminium have been used for many years and so the more expensive option crucible material represents a low risk. The use of pressed metal with a painted boron nitride layer represents a potentially cheaper crucible cost but has a higher risk having not been yet evaluated in a large-scale system.

Thus there is a risk associated with scaling the process up from less than one metre width to several metres in width.

This has to be traded off against the opportunity to make a step change in the process. The process change would more than double the deposition speed, more than double the material efficiency, and significantly reduce the cleaning time and costs along with an opportunity to reduce the overall power consumption.

CONCLUSION

The resistance heated source technology could be used to make ever-wider metallizers however there are significant advantages in moving to slot sources.

The distributed heat load would allow much faster deposition rates to be used and the multiple source approach would easily provide the additional deposition rate.

The other largest factor that looks to have several cost benefits is the massive improvement in efficiency of material use.

The other added benefits of improved deposition uniformity and reduced operating power all add to the argument that this process change should be adopted sooner rather than later.

REFERENCES

1. S.van Slyke et al 'Linear source deposition of organic layers for full colour OLED' SID 02 Digest paper 27.2 p886

2. E.Hartwig et al. 'New developments & future trends in vacuum web coating.' Proceedings of 31st Annual SVC Technical Conference p75 1988

3. A.Pasqui et al. 'High rate deposition on new high speed aluminium roll coaters'. Proceedings of 36th Annual SVC Technical Conference p185 1993

4. European Patent EP 0652302 Vacuum Web Coating 1995

5. European Patent EP 0652303 Evaporation source for vacuum web coating 1995

6. M.J.McCann et al. 'Process modeling of a novel double-sided vacuum web coating system'. Proceedings 40th Annual SVC Technical Conference p338 1997

7. Eds. L.I.Maissel & R.Glang 'Handbook of thin film technology' ISBN 0-07-039742-2 p 1-48 1983

8. I.Tada et al. 'Comparison of evaporation sources for vacuum web coaters' Proceedings 32nd Annual SVC Technical Conference p131 1989

9. J.J.Fonseca et al. 'A novel roll coater for double sided heavy deposition of Magnesium onto PTFE films'. Proceedings 38th Annual SVC Technical Conference p64 1995

10. E.Hartwig, et al. 'New developments & future trends in vacuum web coating' Proceedings 31st Annual SVC Technical Conference p75 1988