The Old Bishop's Almanac
Prognostications for the future of vacuum coating - 2005.

Charles A. Bishop.
C.A.Bishop Consulting Ltd.

Almanac – an explanation

For those of you new to the Almanac I would stress that this is not meant to be a 'doom and gloom' view of the business. The aim of the almanac was to find a way of encouraging people to talk openly about topics that were of a concern to the industry. It is always hard to initiate these discussions and it was believed that having somebody prepared to raise the topics and, using published facts, to extrapolate the information to what might appear an extreme view in order to shock the audience into responding. The belief was that once the ice was broken and a discussion (or argument) was started that more delegates would participate. It became apparent in presenting these topics that most of the audience would listen and accept everything I said. They did not necessarily agree with what I was saying but did not disagree sufficiently to be prepared to argue with me in public. With this in mind I extrapolated information beyond what was likely to be able to make more outrageous statements that were more likely to provoke a reaction. Unfortunately what appears to stimulate most reaction is when the topics in some way threaten the industry.

The result of this has been to make this paper appear as if it contains only negative views and I only highlight problems. I personally believe that I have a positive outlook and by nature am a realist and so I view the Almanac simply as an entertaining method to get people talking. I personally believe the industry is buoyant and opportunities for business have rarely been better. That is not to say the industry does not have some problems or potential problems and so read on…….

Introduction.

Since I gave the first of these personal views of the vacuum industry (1) there have been some areas that have changed and others that have remained static and other topics have caught my attention.

As before the opinions expressed in this paper are mine & in no way represent the views of AIMCAL. I have tried to look at the broader picture and where possible I have included references to support my comments. Hopefully the topics I have chosen will be of some interest & will stimulate some discussions

Incidentally if any of you have a topic that you think merits some attention in next years Almanac please do not hesitate to contact me with your thoughts.

Review of topics dealt with in past Almanacs.

Holograms.

I commented that I thought that holograms were nowhere near as secure as everyone was led to believe. I think this is a view that has been confirmed by at least one multinational pharmaceutical company (2) who declared them to have no security benefit at all & would no longer use them on any product other than as decoration.

Needless to say this does not stop them still being marketed & sold as brand authentication security devices. In some cases other technologies have been added to the holograms to regain the security performance (3, 4)

Transparent barrier coatings.

Another couple of years have past & still the big breakthrough has not taken place. There is still a steady small growth in the use of transparent barrier coatings. On the physics of why barrier coatings are worse than they should be there has been steady progress (5).

One area that is moving more quickly is that of the super barriers. The development of these also is tending to drag along improvements into the more easily achieved packaging products.

On both of these both different market areas there is a continuing difficult future as both sell into markets that are noted for putting suppliers under pressure to keep reducing prices. The super barriers are early in their life cycle and currently there are few suppliers of material of good enough quality and so prices are not yet under pressure. However the display industry is not noted for their generosity & so as supplies become more available the prices will fall.

I have some specific comments on the super barrier coatings that I will address later.

Atmospheric plasmas.

Over the last couple of years this technology has made progress and the wider machines (>1m) are now producing coated material (6). They still do not appear to have got a working system for recovering the helium used in the process. As this represents a significant operating cost it will need an economic solution to be developed before it becomes widely used. There is no doubt that this technology represents a threat for some coating processes.

Solar cells

This is another market area that does not appear to have changed much. The organic solar cells have now been demonstrated as having close to 5% efficiency but this decays with time (7). However this is following the same progress pattern as the amorphous silicon solar cells. If this continues to follow the same pattern it will take another 5 – 10 years to achieve better than 10% efficiency and an acceptable lifetime.

Once this organic technology has been developed the cost would be expected to be lower than current cell costs particularly as all the processes are done at atmospheric pressure & by conventional printing techniques.

This will make the product less susceptible to the market variations caused by government subsidies.

Product differentiation & high-tech coatings

I suggested that it would be advantageous to try to use product differentiation to increase margins. To achieve this I suggested that additional processes would need to be integrated into vacuum systems. This would include patterning, polymer coatings, as well as other sources for multilayer deposition.

Since then there have been a number of papers that have taken up this theme of modular systems (8,9). There appears to be a trend of belief that in future production machines will be narrow width, not dissimilar to earlier research & development machines. The systems being talked about are modular and appear to have the expected flexibility.

However even though these machines look good they are, as yet, completely unproven. Nobody has yet run some, any or all of these processes together in a single process & so they are still very high-risk machines. A number of the processes are not yet production robust, they have been run in the laboratory for a few minutes or an hour or so but not for shift after shift. Thus this also increases the process risks.

Hence whilst I welcome the work towards offering the type of machine that looks to be more flexible & useful I would like to see some potential process mixtures demonstrated.

Review of new topics for 2005

Super barrier – the measurement con.

Since the excitement of the display industry happened with the discovery of the organic light emitting polymers there has been the expectation that roll-to-roll processing will be used for manufacturing. The vision was that the devices would be built based on indium tin oxide roll coated polymer webs. This vision was tempered by the reality that the light emitting polymers were very sensitive to contamination by moisture and so the requirement for a 'super-barrier' was born.

It was calculated that the need was for a barrier performance six orders of magnitude better than was required for standard packaging so the aim was for a performance of $<1 \times 10^{-6}$ g/sq m/day @ 40%RH & 25^{o}C.

This presented two problems, the first was to develop a structure with the desired performance & the second was to find a method of measuring the performance. The standard measuring techniques had a resolution that was orders of magnitude away from the target barrier performance.

Since then there has been good progress to producing the required barrier performance – or so we have been given to believe!

However this appears not to be true (10). What appear to be happening is that it takes time for the structure to absorb moisture, which, as the structure is designed as a barrier, is hardly surprising. During this absorption process the values for moisture passing through the structure are very low. However, once the structure is filled the values for moisture passing through increase dramatically.

As this process did not appear to be understood many of the early results published were of very low barrier values that reflect only they were still in this time lag region & if the monitoring had been continued the values would have eventually increased dramatically.

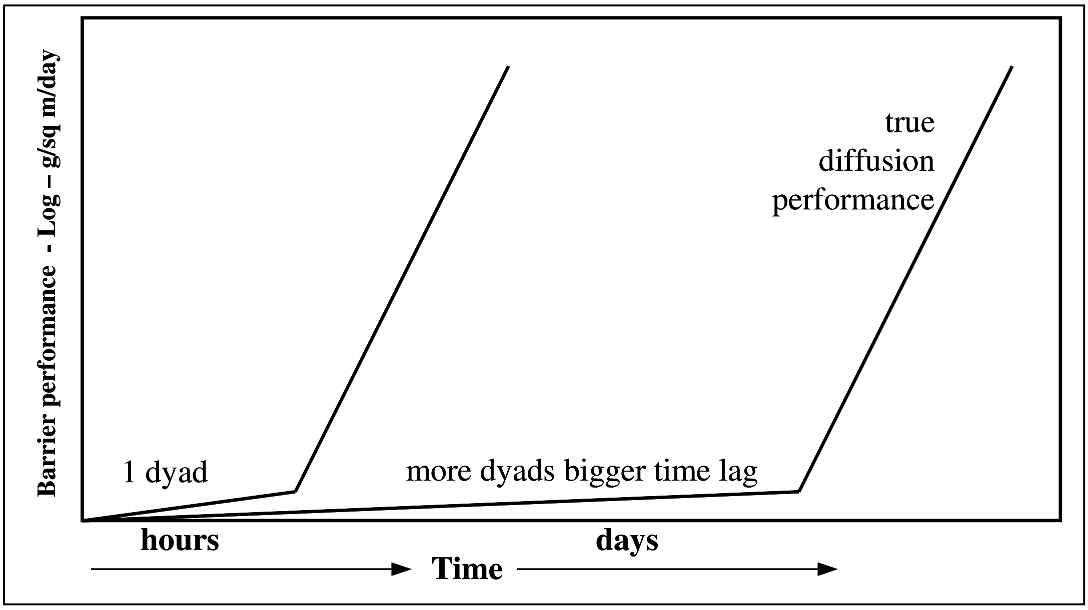

Figure 1 Schematic showing the time lag before the true diffusion rate appears

It might be worth drawing attention to the National Bureau of Standards and highlighting that the only reference standard available is at 5 x 10^{-4} g/sq m/day which is more than two & a half orders of magnitude higher than the levels that are needed to be tested. Thus it might be worth bearing in mind that if there is no reliable acceptable standard then there are two points to think about, the first is that there is no easy test method available & secondly that any value below this value ought to be viewed with some degree of scepticism.

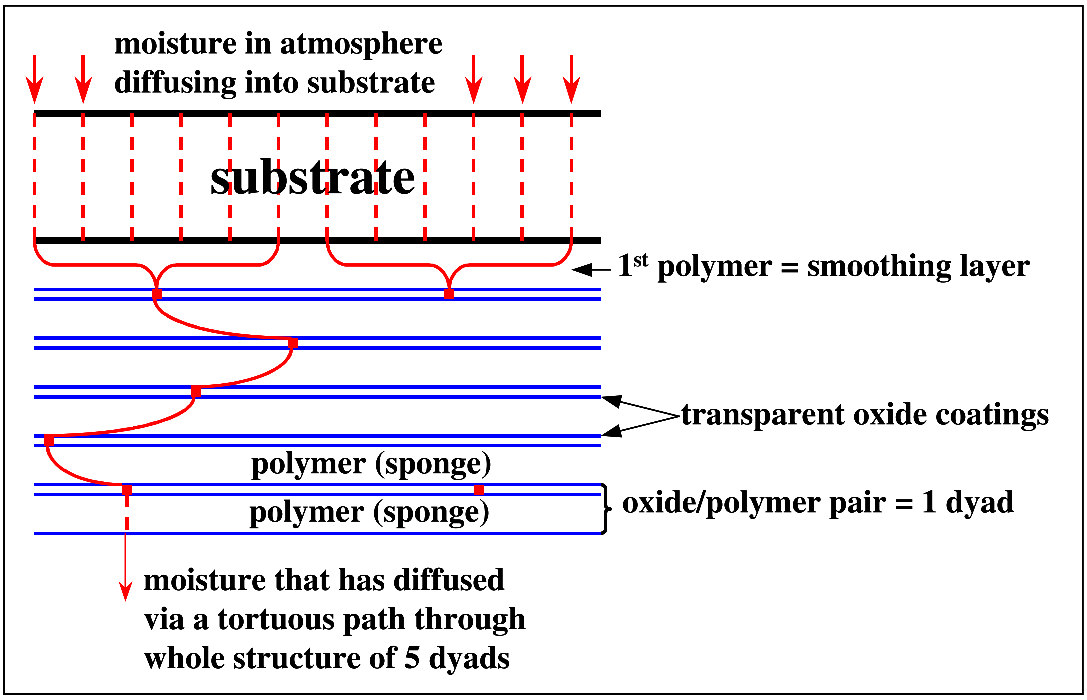

Figure 2 A schematic of moisture diffusion through super barrier structure. The moisture has to pass through defects in each oxide layer. The time lag is from the

moisture being absorbed into each polymer layer sequentially. The more layers the greater the time lag.

Concurrently with the development of the super barrier structures has been the development of different test methods. There have been various claims about the sensitivity & resolution of these different systems. From my perspective some look to be operator & material sensitive and whilst in theory may have the potential to measure such low barrier performance they do not look to be a very practical, user-friendly test.

Thus my advice from all of this is to be careful of all claims for structures to have met the requirements for super barrier performance. I have no doubt that they have achieved a huge improvement on the more basic packaging coatings and have increased the pace of work to help understand the mechanisms that make barrier structures work. I do, however, remain to be convinced of some of the values claimed.

The overseas threat or opportunity?

This topic is probably the one that provokes the most passion and some very extreme views. It is fraught with difficult issues including poverty, trade tariffs & subsidies, living standards, nationalism, job security, etc. I do not intend to pass comment on any of these topics here.

What I would like to do now is for those who feel threatened by China to double your worries, but for those who see China as an opportunity, to double your opportunity.

We have been hearing for a few years' now two messages firstly that China is a massive opportunity for trade because of the huge population and secondly that China is a massive threat to jobs because of the low wages & cheap copies of 'western' goods. What has not really been highlighted is that India represents a similar threat or opportunity.

The Indian economy is growing at 8% per annum compared to 9.5% per annum for the Chinese economy. The growth in the Chinese economy will slow and in 10 – 15yrs it is expected to be below 5% whereas the Indian economy is expected to have a higher growth than China in about 10yrs time.

The predictions are that China will have the 2nd largest economy in around 20yrs time. In the same timescale India will be expected to have the 3rd largest economy.

Where China is seen as problematic because of the rules about compulsory Chinese co-ownership of businesses and constraints on some of the inward investment India has more relaxed rules. This makes the opportunities in India significantly greater than for China. If you look at wages, currently the hourly rate is \$0.67 in China but is only \$0.58 in India. The other factor that makes India look to be a better opportunity is the political stability. This is viewed as being more stable in India than China.

Potentially this makes India a cheaper offshore manufacturing opportunity for China. Thus, potentially, this makes it a greater opportunity than China for investment, partnerships, manufacturing, company expansion, etc.

For those who can only see this as a threat I have no words of comfort. If you thought China was a big threat then it has just doubled & these are just the biggest of a whole range of countries that are all progressing from third world status and are aiming to compete in the ever shrinking global market.

Indium

To re-cap indium is not mined as the primary product by mainly as a by-product of zinc mining (11). The price of zinc is at an all time low & some mines have been taken out of production. Coupled to this one zinc mine was closed following flooding & more than 80 miners killed in the accident. In the near future Nippon Mining have announced that the Tohoya mine in Japan is exhausted & will be taken out of production in 2006 to balance this China & South Korea have plans to open mines that are predicted to deliver a similar amount to that being closed in Japan. Thus the amount of indium mined has fallen over recent years for a variety of reasons.

Compare this with the increase in the requirement for indium to make the transparent conduction indium oxide coatings for the display industry. This requirement is predicted to continue growing. A few years ago this use represented only 45% of the use of Indium but it now represents 70% of the indium use and is still growing. Other industries have sought alternative materials to avoid the prices swings and the uncertainty of supply.

My prediction was that the price of indium would continue to increase from the minimum of around $100/kg in 2002. This has proved to be true and it has been reported to be as high as $1100/kg in the early part of 2005.

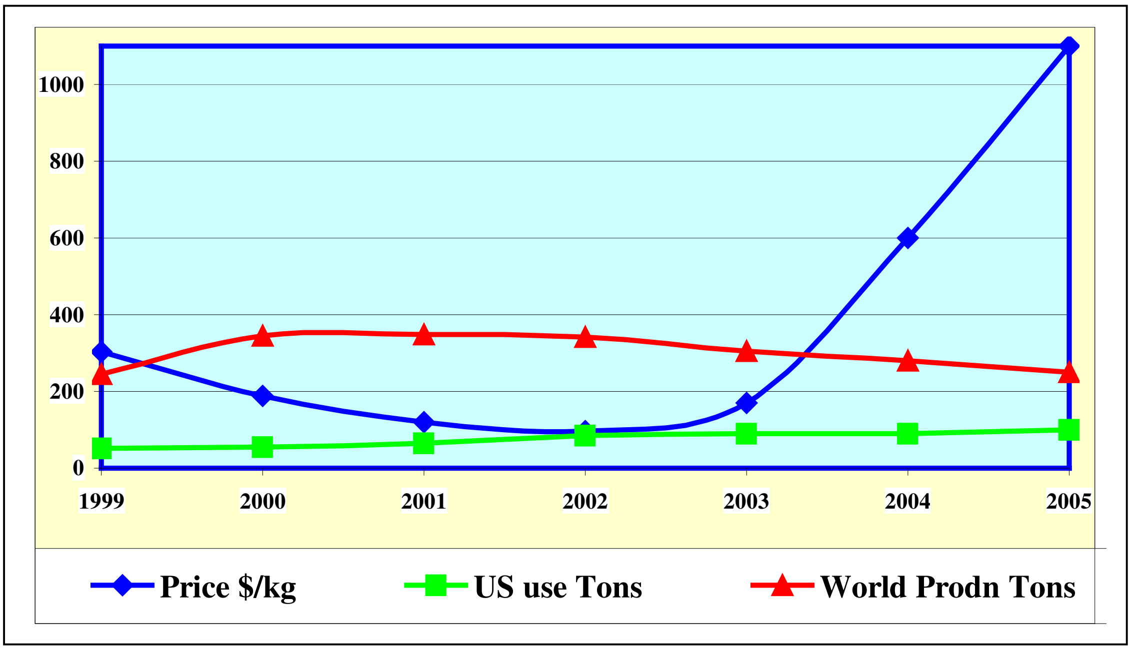

Figure 3 Indium. Trends on use, mining & price.

I see no reason why this price should not continue to rise. There does not appear to be any significant change on the horizon. The display industry is continuing to grow, there appears to be no change in the low price of zinc & no signs of the flooded mine being reopened in the near future.

It is predicted that the liquid crystal display industry will require 64 tons of indium by 2006. This does not sound too bad until you realise that the indium mined is unrefined & it takes around 8 to 8.5 tons of unrefined indium to make 1 ton of refined indium. Thus 64 tons multiplied by 8.25 becomes 528 tons of unrefined indium which compares badly to the currently less than 400 tons mined per year.

There is some current stability partly brought about by a big push in the recycling of indium largely based in Japan. In fact it has been claimed that 85% of the indium finds its way back into the supply by recycling. This to me looks like a quite high efficiency in recycling the material & so further gains in indium supply for this route are probably going to be small.

Looking to the future there would appear to be a widening gap between supply & demand which will push prices up further.

When an article was published in the Wall Street Journal in Aug 2004 commenting on the limited quantity of indium being mined this prompted some of the indium suppliers so publicise articles about the security of supply. These articles were very emphatic about there being sufficient indium for everybody but there was nothing included in the articles about the price being contained.

Thus my message has not really changed since I first highlighted this problem. Indium supply is short of the demand therefore prices will continue to rise. Thus it is worth working on alternative transparent conducting coatings in order to become less dependent upon indium. Aluminium doped zinc oxide looks attractive from the materials supply perspective as zinc prices are so low & aluminium is so abundant. However this needs to be balanced against electrical performance that is not as good.

My only other though is, why did I not take my own advice and invested in Indium, if I had I might have been rich by now?

Slitting

Believe it or not this is a topic I first raised around 15 years ago. At this time we were having problems of winding some rolls of film in vacuum. The product was particularly sensitive to surface defects and particularly to any damage to the freshly deposited coating. One of the winding problems that occurred all too frequently was that of the web edges being raised. This was purely due to the quality of the slitting. It is costly to change &/or sharpen the blades & so it is only done when deemed to be absolutely necessary. Now what is deemed absolutely necessary for a slitting machine operator differs from that deemed necessary to a vacuum coating machine operator. The slitting machine operator only see the web being wound at atmospheric pressure with the benefit of entrapped air keeping the polymer layers separate. Without the benefit of this air entrapment the polymer layers and hard wound against each other & any minute thickness variation can become a significant problem. Thus a blunt blade does not cleanly cut through the polymer but can generate heat and can smear the polymer & raise the edges. This can become a significant increase in thickness. I have seen edges raised so that when wound in vacuum the edges of the roll increased so rapidly that the polymer eventually folded over because the slope was so great.

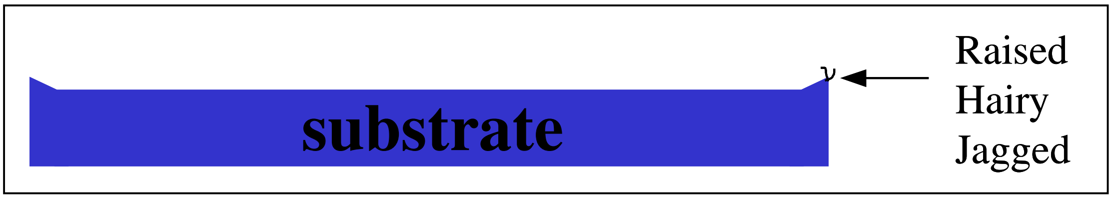

Figure 4 A schematic of the raised edge caused by slitting with blunt blades.

Whilst investigating what might be done to reduce the problem I happened to be also looking at techniques for information mining & when evaluation some mining software I used cutting techniques as the topic to search. The results were fascinating. The search looked across all industries & showed that there were some global trends of which different industries were at different stages along the trend but all followed the trend. The global trend was that all cutting processes would start with mechanical cutting tools such as scissors, razor blades, rotary blades, etc but would then progress through other technologies such as water jet cutting, plasma torches/jets through to laser cutting. It did not matter really matter about the material to be cut it could be hard materials such as steel or stone or flexible softer material such as fabrics all of the industries ended up with laser cutting.

The benefit of this type of information mining is that for those who chose to trust the information they can shortcut all the intermediate development steps and can jump straight to the final optimum solution.

Thus there appears to be the opportunity here to jump straight to the end result and use lasers to slit the polymer web.

I probably have heard most of the arguments against using lasers. They are expensive, dangerous, do not absorb enough, too bulky, unreliable, etc.
The translation of this is more likely to be, we do not want to change our existing technology as it works 'well enough' & we cannot charge our customers a premium for better quality slitting so why should we.

I would contend is, whoever becomes the first to adopt laser slitting will set the new minimum standard.

There will be quality improvements no only because of a cleaner slit edge but also a much more consistent slit edge because the laser does not wear & become blunt and hence the cut is identical day after day, roll after roll.

A second, not insignificant, benefit will also be a reduction in the dust/debris levels on the polymer webs. As the blades wear they produce a greater level of powder which is attracted to the polymer surface because of the electrostatic charge on the web. When debris levels were measured they doubled following slitting (12). The laser slitting does not produce this powder & so does not contaminate the film.

Thus a cleaner film with not raised edge would become the basic standard & any supplier not able to deliver this could expect to lose some business to those that could deliver the standard. Hence the first to adopt could expect some marketing benefits and over time all could be expected to transfer to laser slitting.

There are advantages for the manufacturers too, lasers do not need sharpening and changes to slitting widths can be altered rapidly using optics. Thus the costs of downtime associated with width changes & sharpening & replacing blades is eliminated. This offsets the higher initial cost of the laser. I believe that with the power & reliability of the modern day lasers this technology ought to be adopted & would prove to be cost effective.

I have heard polymer film suppliers tell customers that they are the only ones complaining even when most of the customers are complaining about the same problem. This is aimed at diffusing the problem so they do not have to take action.

Thus I would recommend everybody complains every time they get a poorly slit film & to continue to complain about dust/debris levels on substrates & not to suffer in silence. It is probably only by a concerted effort and high level of complaints by customers that will get the manufacturers to pay attention & consider upgrading their antiquated technology.

Cleanliness – Gap analysis

This topic follows on nicely from the last one. There are an increasing number of products that require cleaner substrates such as the organic displays as well as the larger volume barrier products. As the amount of dust/debris is directly related to the number of pinholes/pinwindows and the barrier performance falls with increasing numbers of defects (12).

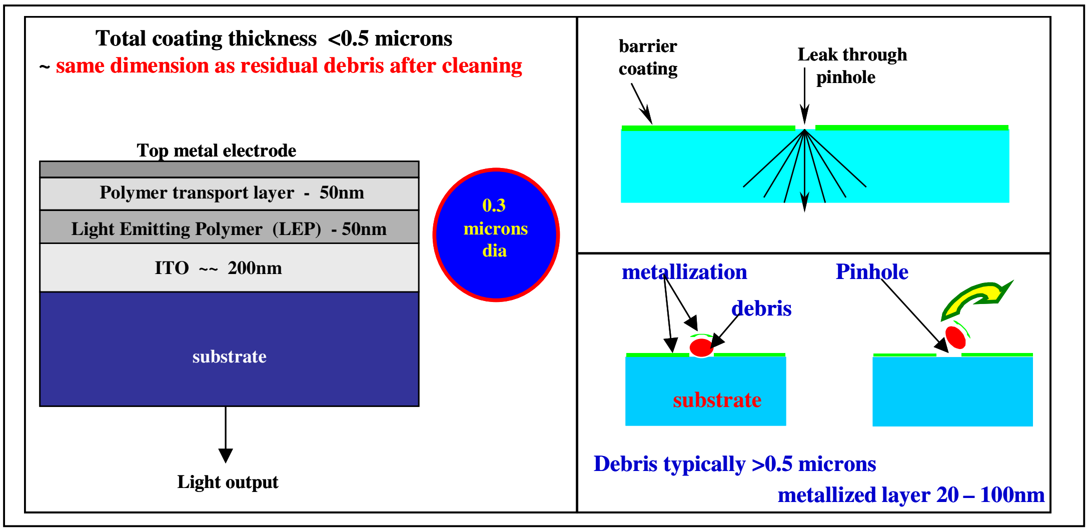

Figure 5 Schematics showing how debris can produce pinholes which can reduce the effectiveness of the barrier performance. Also the dimensions of the debris with respect to the total thickness of layers used in organic light emitting devices.

The cleanliness of the polymer webs starts with the film manufacturing process. The hot film can give off a vapour of unpolymerised monomer that can condense on cooler surfaces and this can fall back on the web as ‘snow’. As the web winds over rollers it builds up an electrostatic charge which can attract dust from the atmosphere. Added to which is the generation of large quantities of dust from the slitting process. All of this means that no polymer web is truly clean even at the point where it is first wound up. Any additional downstream processes just add more contamination to the surface.

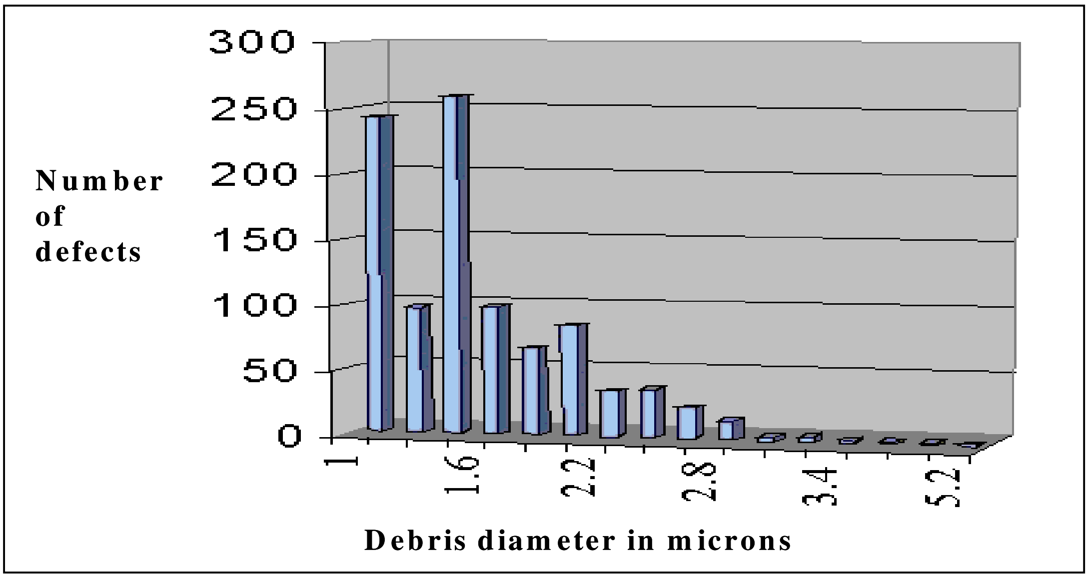

Figure 6 This histogram is from what was recommended as the cleanest available film at the time. You would think this should be cleaner now, but is it?

Thus if you look at the gap between desired & delivered surface quality the gap is getting wider. The newer applications need the surface to even cleaner that ever before and yet the cleanest the manufacturing plant will have ever been would have been on day one when the plant was brand new.

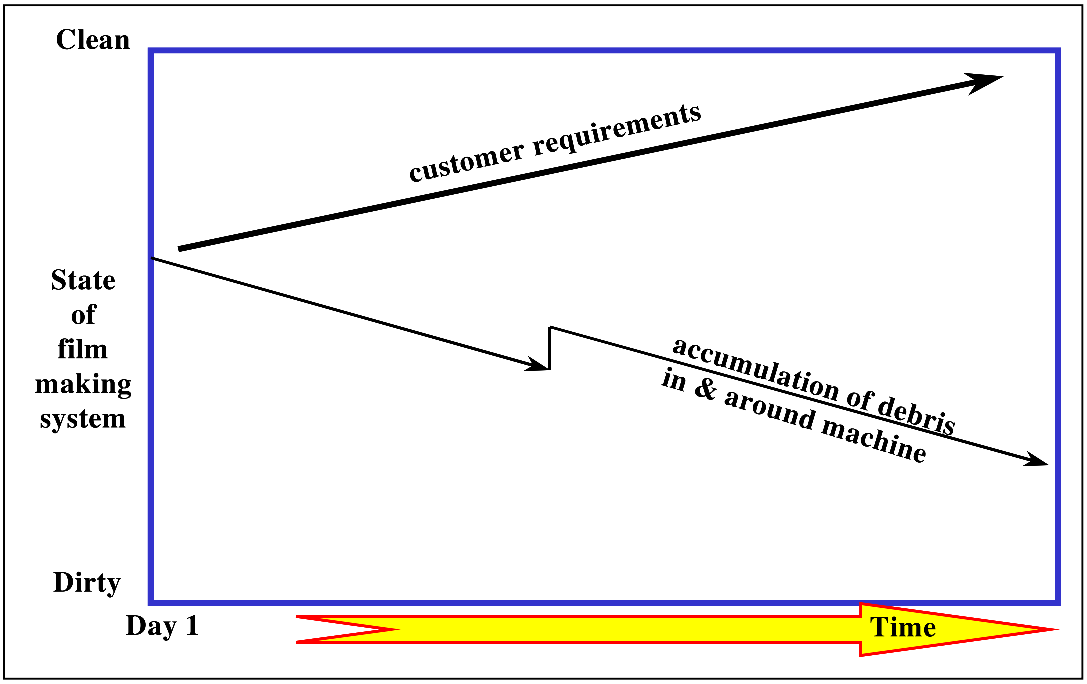

Figure 7 A schematic of the widening cleanliness gap.

Since then there will have been an accumulation of dust/debris from the process as well as the general debris accumulation that includes everything from human debris (skin & hair), pollen, smoke debris, chipped paint fragments, etc. Thus the quality of film cleanliness is slowly but surely falling.

Thus the cleanliness gap is widening and I see nothing to stop this continuing. It is not cost effective to put the whole film line inside a cleanroom. It is possible to use some strategically placed clean air hoods, anti-static devices, improvements such as lasers slitting, electrophoretic collectors and tack roll cleaning for where the other techniques have failed. However these will reduce the rate of decline & they do nothing for the increasing requirements.

Hence we need to think differently about substrates and clean surfaces. Possibly no longer aim to buy super clean film but to buy a cheap carrier substrate & cast on a fresh clean surface just before use. This is in effect what some of the polymer evaporation and cure in vacuum processes are doing but this still works from the starting point of using a high cost substrate. Instead of buying a high cost substrate that does not meet your requirements think of trading off some of the substrate cost into a higher cost thicker coating. It might even be possible to peel this coating away as a freestanding substrate after the all the coating processes have been completed & this would allow the original substrate to be re-used.

The main message was really meant to be do not expect more from your substrate supplier than they can deliver. Also do not expect them to change quickly or very much. On substrate cleanliness you are going to have to find your own solution.

Low-cost vacuum systems

There have been a number of papers suggesting that the next generation of vacuum coaters for some of the high-tech applications are likely to be narrow width modular roll-to-roll coaters. The expectation is that the volumes of product are much smaller in terms of numbers of square meters of material. The whole area of nanotechnology suggests that things will be smaller & hence the number of products per square meter could be huge & hence a small roll coater could service the whole demand with time to spare.

What becomes apparent when costing some of these narrow width machines is that the cost is very close to the cost of wide machines. Thus there has been some though about how some of the cost could be taken out of these smaller machines. One thought was to make a standard size machine so that they did not need to be designed from scratch every time. The modular design was also aimed at giving the flexibility to change sources to allow process changes more easily allowing different products to be produced without having to compromise on the process.

Even with using a standard design & components the cost of these machines remains high. This led to a suggestion that we are not looking at the problem freely enough we are looking with too much experience & too many preconceptions. As a result of somebody else's freethinking this idea was expressed. 'Why do we not make vacuum systems out of plastic?' The first reaction was to think of the thin walled fizzy drink bottles & laugh. However if one then thinks about thick walled drainpipe extruded tube of <1m diameter the laughter dies away & the question is left, why not?

Thus, as ever, I offer no solutions but only questions for you to mull over & possibly try out. We have a whole range of engineering plastics that we are happy to use in hostile environments such as automotive engines. We have sophisticated finite element analysis programmes to test things out. Thus if we think of using a thick walled pipe as out vacuum vessel with flexible links to a rigid free standing web winding system inside it looks as if this might be feasible.

If this main vessel pipe works then why not use polymer pipe for all the backing lines. Think how much time might be saved in manufacture & assembly & even in installation with such lightweight easily machined materials.

There are some areas that need particular attention such as where there is a high heat load & so suitable cooled shielding becomes more critical. However this is just engineering & can be managed.

What this idea does is test out some of the assumptions we usually make. Thus if we want low cost machines perhaps we need to do a more thorough review of everything including materials. Thus I throw out the challenge for machine makers to do some more radical thinking to help get the costs down and tell us can we use extruded polymer pipes to advantage?

Emerging technologies

It is worth trying to dispassionately look at any emerging technology & to try to place its position on a Gartner hype cycle of emerging technology graph (ref 13).

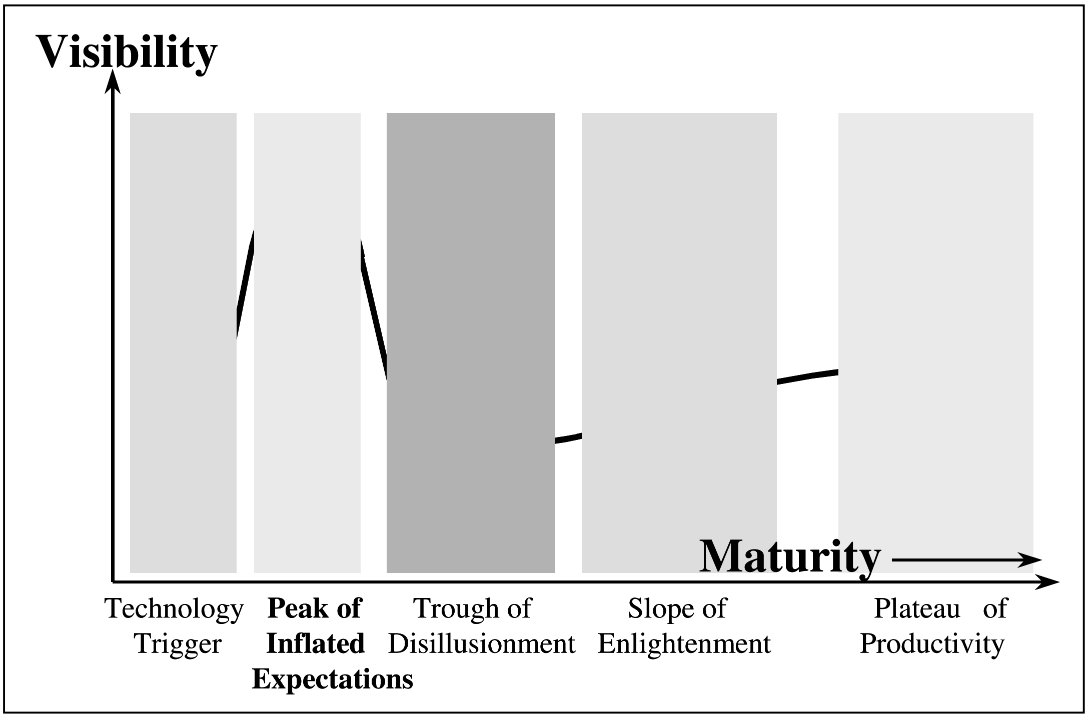

Figure 8. Gartner hype cycle of emerging technology graph

In doing this assessment it helps to prevent over expectations on what the opportunity really is. If we look at the OLED business we can see that it has had a tremendous amount of publicity for a number of years but so far the only products that have been delivered have been very small displays that are a direct replacement for LCDs. This trend is expected to continue and so the OLEDs will have to compete with LCDs on performance & price and for each larger size application when they beat the LCDs on both they will begin to replace the LCDs. This probably makes the OLEDs somewhere on the slope of enlightenment following all the big publicity followed by a lull before anything was delivered & now the steady production of devices with improvements in quality, larger sizes & reducing costs starting to show how the market penetration will work over the years to come.

Now, just for fun, try to place your latest favourite emerging technology on this graph. Does it still look as good as before you started?

Obsolescence.

Here is another topic that has no answer but is really just to highlight a growing trend. The semiconductor & electronics industry are now getting so good at developing new products or better versions of old products that there is a problem of obsolescence.

Obsolescence is where the replacement items do not function properly in the earlier circuits. Their interaction with other components is not quite as it was & so either the device does not work at all or if does not function properly.

Now many companies used to have vacuum systems that were quite old. Sometimes they have been refurbished, other times not. Thus it is common to see vacuum systems that are over 10 years old & I have operated systems that are well over 20 years old.

This might become much more difficult to achieve in the future. It could be that the system will have to be refurbished every 5 years in order to replace the electronics because the electrical components to repair the existing electronics no longer exist. This could make it uneconomic for some systems & buying a new one more cost effective, not only to gain up-to-date electronics but also the advantages of increased production speeds because of technology improvements.

Hence this is just a warning to be aware that when investing in a new vacuum system it may not be the long-term investment you were expecting.

Conclusions.

One conclusion is that not a lot has changed since last year. A number of the trends are continuing such as the indium supply problem & pricing. The overall ‘feel’ of the vacuum coating industry seems to be more positive than a year ago but I do not see much that has changed in the area of threats or opportunities. This good feeling might well be just reflecting a higher volume of sales.

I hope this Almanac has been of interest and provided you with a different perspective on the industry & some food for thought.

References.

1. The Olds Bishop's Almanac – Prognostications for the future of vacuum coating. Proceedings AIMCAL 2003 Fall Technical Conference & 17th International Vacuum Web Coating Conference.

2. Proceedings PISEC April 2005

3. Magnetic smart tags in brand protection & document tracking. D.Arnold Paper 44 Proceedings 2nd World Product & Image Security Convention 2000

4. Using vacuum roll coaters to produce anti-counterfeiting devices. R.W.Phillips & A. Argoitia Proceedings 48th SVC Annual Technical Conference 2005

5. Gas barrier properties of transparent metal oxide coatings on PET film. B. Henry Et Al. Proceedings 47th SVC Annual Technical Conference 2004 pp 609 - 614

6. Rapid deposition of functional coatings using an in-line atmospheric plasma source. D.P.Dowling et al
An atmospheric pressure plasma route to hydrophillic coatings. S.R.Leadley et al. both Proceedings 48th SVC Annual Technical Conference 2005

7. Large area plastic solar cell modules. F.C.Krebs. et al. www.risco.dk/solarcells Proceedings 48th SVC Annual Technical Conference 2005

8. MiniLab &/or OptiLab systems from General Vacuum www.bobstgroup.com

9. Smartweb system from Applied Films www.appliedfilms.com

10. Mechanisms of vapour permeation through multilayer barrier films: lag time versus equilibrium permeation. G.L.Graff et al
Journal of Applied Physics. Vol 96 No 4 Aug 2004 pp 1840 - 1849

11. http://www.minerals.usgs.gov/minerals

12. The quest for cleaner polymer web surfaces. C.A.Bishop
Proceedings AIMCAL 2002 Fall Technical Conference & 16th International Vacuum Web Coating Conference

13. http://www.gartner.com/pages/story.php.id.8795.s.8.jsp