Vertical In-Line Machine Concept for OLED Manufacturing

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Abstract

A profitable mass production of Organic Light Emitting Diode (OLED) displays needs a new type of manufacturing equipment. We have developed a vertical In-Line machine (VES400) equipped with linear etch sources (e.g. to activate an ITO layer), standard magnetron sputter sources for ITO and metal and linear evaporation sources for the organic and metal materials. We present new results concerning the linear evaporation sources for organic materials. We have optimized the vertical thickness non uniformity for the evaporation of different organic materials and achieved deviations of less than ± 5 % for the vertical thickness over a substrate height of 400 mm. We will further report first results about the long term stability of the deposition rate for different organic materials using rate control..

1. Introduction

The development of Organic light emitting diodes (OLED) solved a lot of breakthroughs in the last years. Various companies have already shown off the most recent OLED developments – mostly for portable devices, where the new displays really shine. Meanwhile various products with a OLED display are available: digital camera and cellular phones MP3 player, car audio components . At the larger end of the technology Samsung SDI, Sony, Kodak, Philips, Seiko Epson and others have presented large prototypes up to 40"(for an overview see [1]).

For a profitable mass-production of OLED displays new manufacturing systems are needed, and existing system platforms and processes need to be adapted.

The deposition of the organic layers itself is critical, because of the sensitivity of the material (e.g., high temperature, incorporation of dust and impurities). The high price of the coating materials also makes high material utilization a priority.

2. The vertical evaporation system

We have developed a new vertical In-Line machine (VES400) equipped with linear etch sources (e.g. to activate an ITO layer) and equipped with linear evaporation sources for the organic materials and sources for the metals. A schematically drawing of such a machine is shown in figure 1. The VES400 is designed for substrates of 400 x 470 mm^2 or even larger.

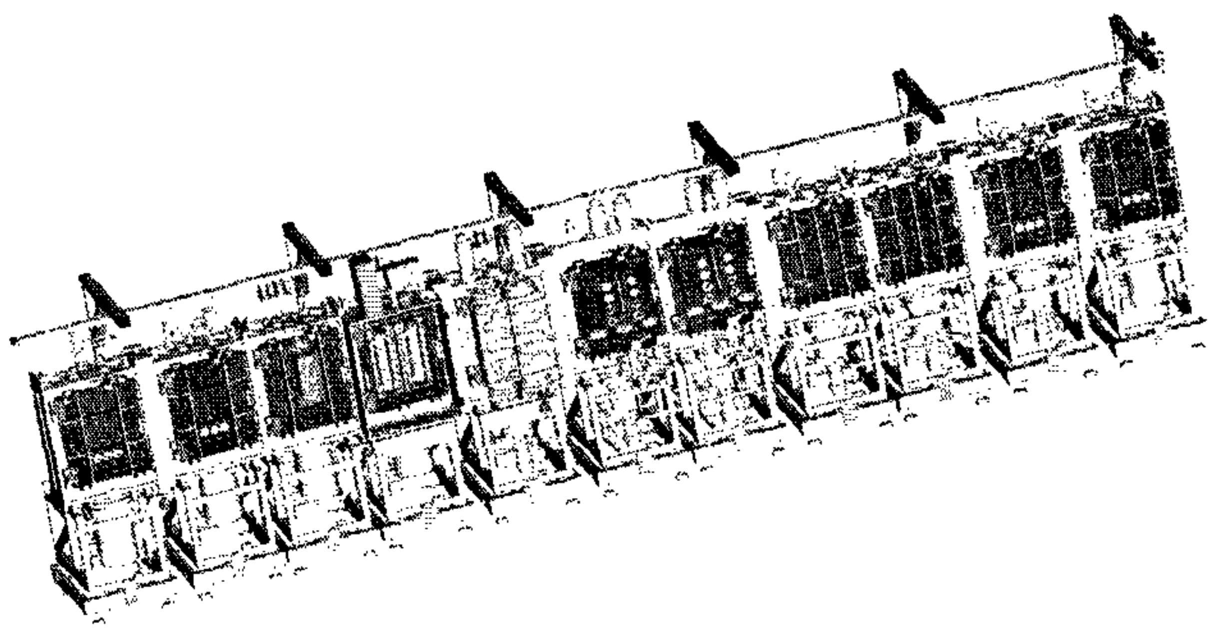

Figure 1 Schematically drawing of a vertical In-Line OLED machine: VES400

To realize the vertical machine concept new linear evaporation sources for the organic materials and a new source for the metals were developed. The principle of the linear source consist of one central crucible and a tube system to guide the organic vapor. The crucible as well as the tubes have to be heated up to a well defined and controlled temperature. The crucible, to control the evaporation rate and the tubes to prevent condensation. Crucible as well as tubes are made of a chemical inert material, to prevent reactions between the source and the organic material and to prevent contamination of the high purity OLED materials.

The central tube, consisting of a chemical inert material, is surrounded by a heating element and a shielding to guarantee a homogenous heat distribution.

Figure 2 shows schematic drawing of one chamber for organic evaporation an figure 3 shows one door equipped with two evaporation sources.

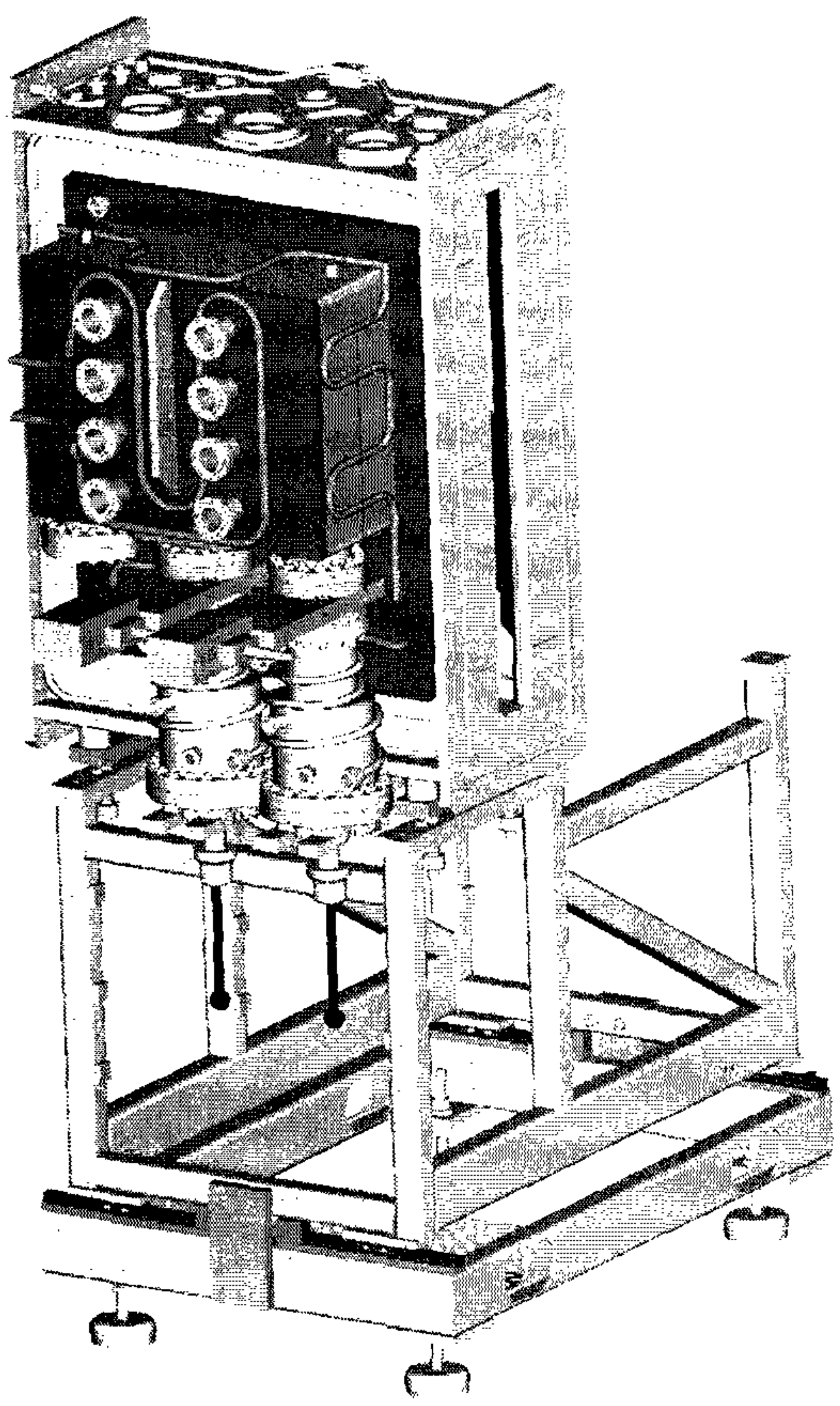

Figure 2 Drawing of one organic chamber equipped with two organic sources.

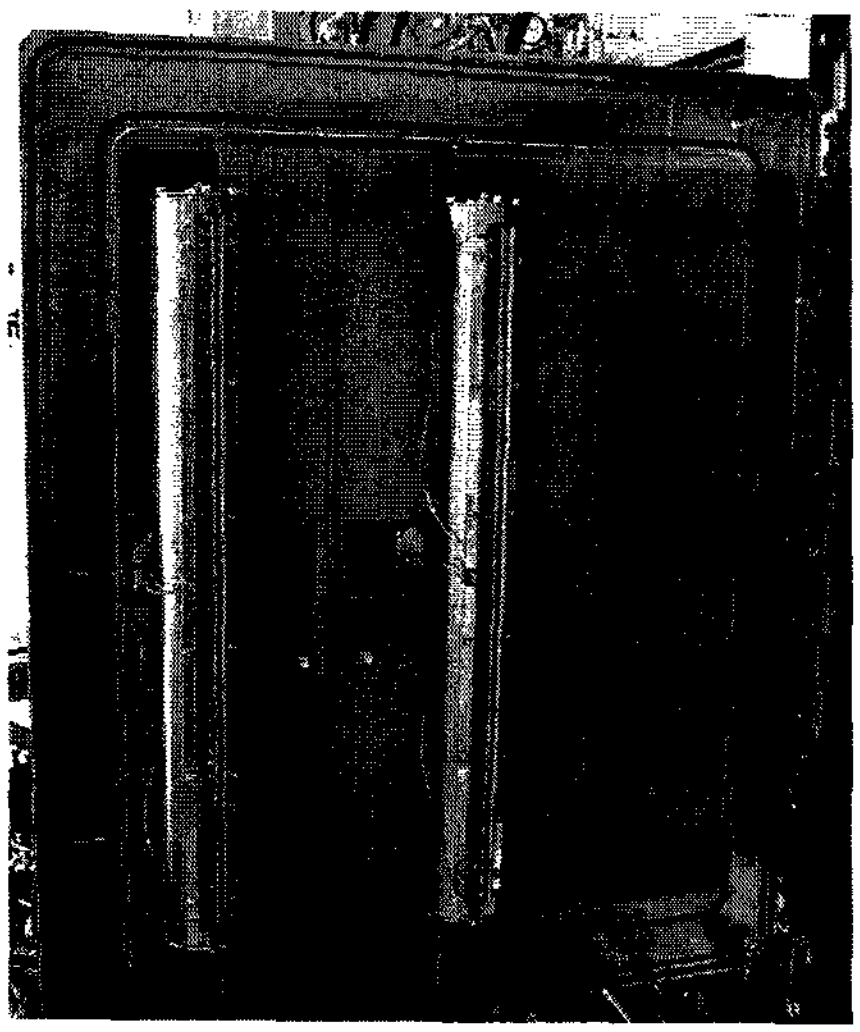

Figure 3 One door equipped with two sources

The first VES 400 was installed at the Fraunhofer-Institute for Photonic Microsystems (IPMS) Dresden, Germany, in autumn 2002. Equipped with four sources for organic evaporation in the beginning, 4,4',4''-tris[N-(1-naphthyl)-N-phenylamino]-triphenylamine (2-TNATA) was chosen as hole transport layer, N,N'-di(naphthalene-1-yl)-N,N'-diphenyl-benzidine (NPB) as electron blocking layer, tris(8-hydroxy-quinoline) aluminium (Alq3) as emitting- and electron transport layer and N,N'-diphenyl-quinacridone (QAD) as dopant. Results using this machine and materials were presented elsewhere [2].

Meanwhile the VES is equipped with 12 independent organic evaporation sources, so all three colors as well as doped transport layers [3] will be possible at that machine soon.

Like in all our vertical In-Line machines with linear sources a carrier with the substrate passes the source at a constant speed, so the horizontal deposition homogeneity is simply given by the accuracy of the drive. The vertical deposition homogeneity is controlled by the source design. The vertical thickness non uniformity for the evaporation of different organic materials is less than ± 5 %. As an example figure 4 shows the vertical thickness distribution of an TNATA coated glass substrate.

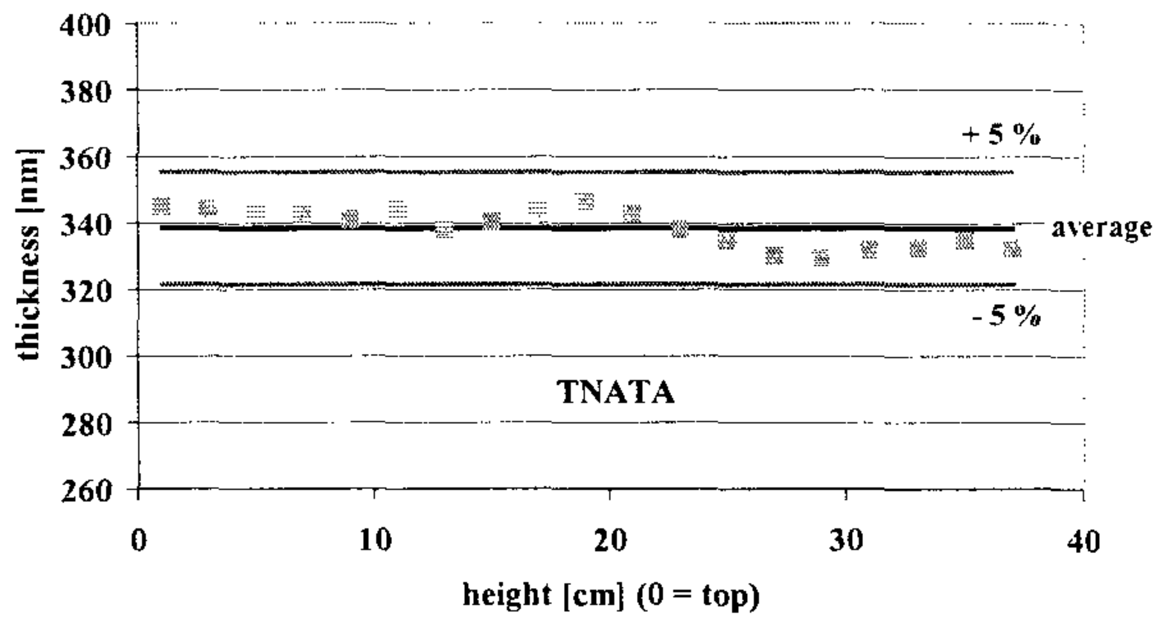

Figure 4 Vertical thickness distribution of TNATA.

The linear source design together with the continuous substrate flow (csf) concept of our production machines promises a high material utilization. Due to the linear source design most of the evaporated material reaches the substrate and due to the csf there is always a carrier with a substrate in front of the source.

To keep the chamber under vacuum if one crucible has to be changed, the crucible can be separated from the tubes under vacuum and can be vented separately. After that the crucible can be replaced by a filled one with the same or another material. Then the crucible can be pumped separately again and can be connected to the tubes under vacuum.

This change without venting the whole organic deposition chamber improves the base pressure in the chamber to the 10-5Pa range or even lower. The influence of the base pressure on the OLED efficiency and life time was reported in [4].

It is also possible to do some preconditioning of the material in the crucible away from the machine, e.g. some cleaning or heating.

3. Results and discussion

To check the rate stabilety of the vertical evaporation ssource we have selected two OLED materials with different evaporation behavior: namely Alq3, which sublimates and TNATA, which evaporates out off the liquefied phase.

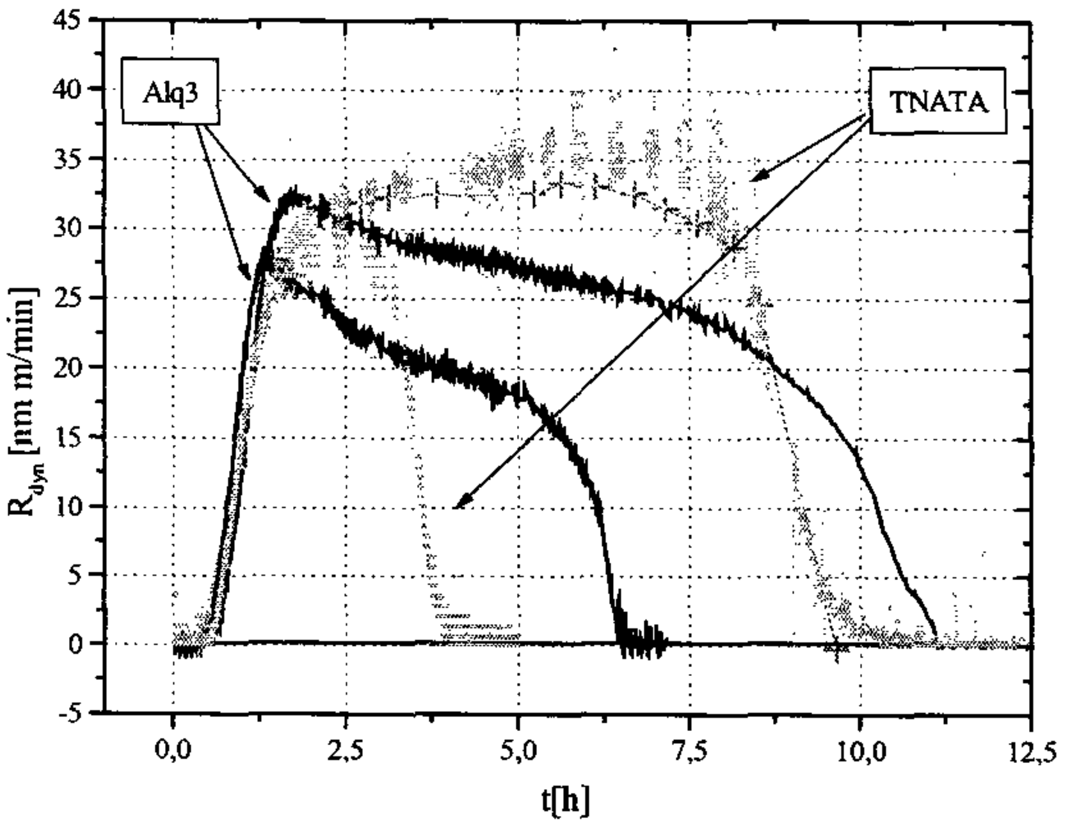

Figure 5 Deposition rates of Alq3 and TNATA for different evaporation experiments.

In Figure 5 the deposition rates for Alq3 and TNATA are plotted for different continuous (over several hours) evaporation experiments. In these Experiments the crucible temperature was kept constant until the whole charge was evaporated. The deposition rates were measured with a quartz crystal monitor. Parallel the thickness off different films deposited during the experiments were measured by means of single wavelength ellipsometry (the symbols in the TNATA graph correspond to dynamic rates, which were determinated by elipsometric data).

Both materials show again a different behavior-TNATA evaporates over relative long time for a given temperature with a constant rate, whereas the Alq3 exhibits a continuous decrease of the rate over the deposition time with an exposed high deposition rate in the initial phase. The strong dependency of the deposition rate over the deposition time for a given temperature illustrates again that for long up time of the sources a rate controlling system is needed. Such a rate controlling system has been installed at Applied Films and shows some promising results using AlQ3 as sublimation material.

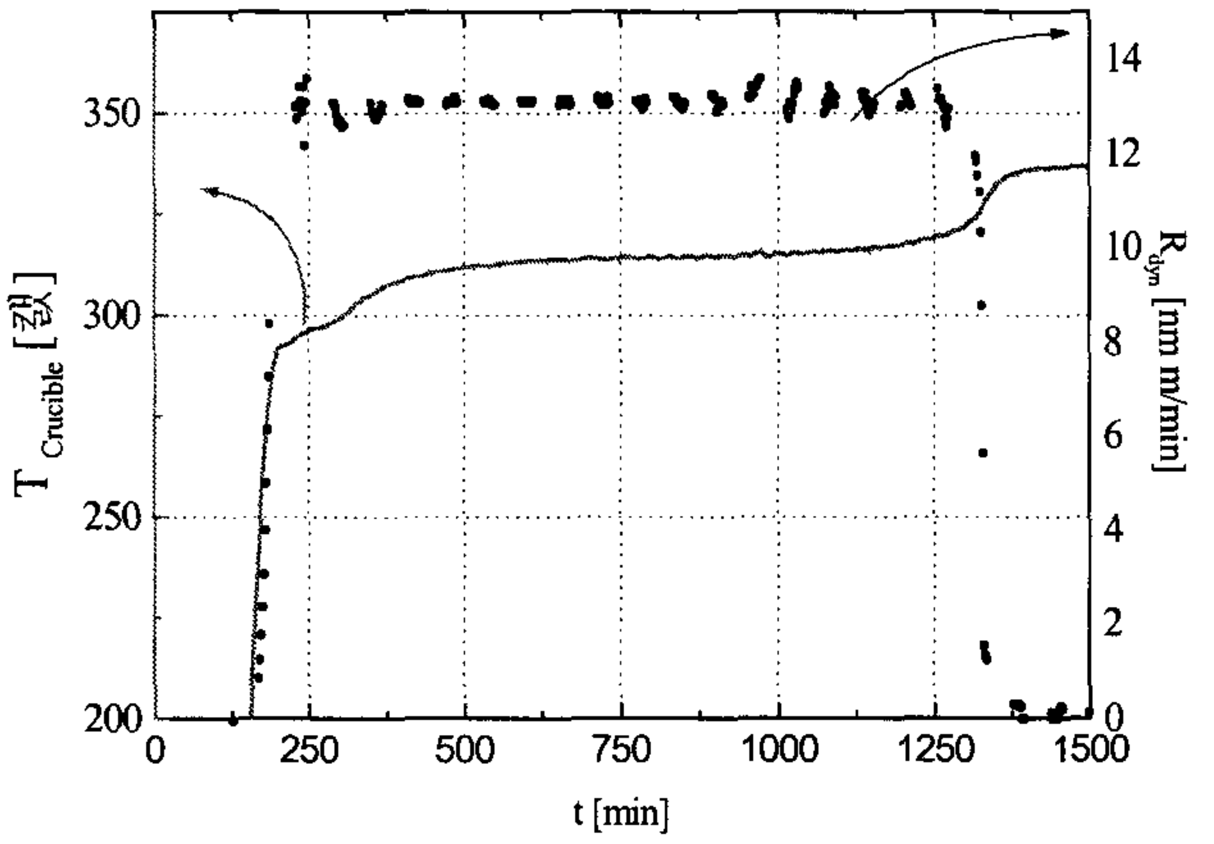

Figure 6 First result of automatic rate control for AlQ3.

The deposition rate was kept constant over nearly 20 hours, until the crucible is empty. This experiment was done using only 10 g AlQ3 although the crucible can handle 50 g and more, so stable deposition over more than three days should be possible.

In figure 7 we have plotted the material yield of various long term deposition experiments with Alq3 with different crucible temperatures and loads (typical loads were between 5 and 20 g Alq3, typical deposition times were between 10 and 70 hours). In these experiments the crucible was kept on a constant temperature until the complete material was consumed.

The material utilization is calculated over the integration of the area of below the plot of the dynamic deposition rate over the deposition time (see for example fig. 5). We assume a continuous flow off a glass band in front off the vertical evaporation source (no carrier). Taking into account the measured film thickness, the density of Alq3 and the substrate velocity it is possible to calculate for a given crucible load the amount of material, which has been effectively deposited on the virtual glass band.

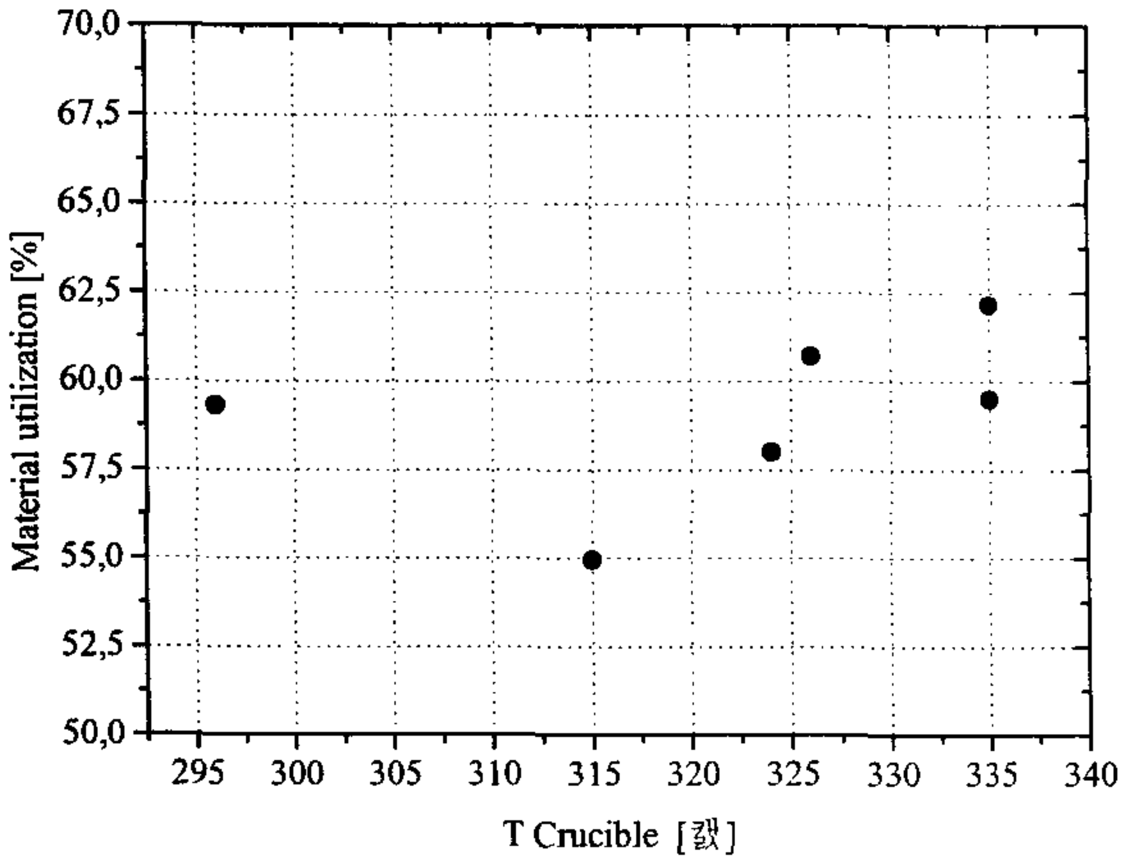

Figure 7 Material utilization at different crucible temperatures.

The results with material utilizations nearby 60 % look very promising compared to the efficiency of standard point sources. The calculated material utilization will be reduced in a real production system in two ways: first there will be a up- and down ramping of the deposition process, in which the evaporated material will not be used. The need of carriers will further reduce the material utilization, because the material which is deposited on the carrier is lost. Both lost mechanisms can be reduced by optimizing the carrier design and optimizing the up and down ramping in the production process. Estimating a reduction of 10% of the material utilization for these lost mechanisms leads to values of ca. 50% , which are still more than ten times superior to the results achieved by conventional point sources.

4. Conclusion

We have developed and realized a new machine concept to manufacture OLEDs, combining the well established vertical In Line concept of our mass production machines with the special requirements of the OLEDs. New developed vertical linear evaporation sources for organic material show thickness non-uniformity of less than +/- 5 and material utilizations about 60%.

Acknowledgments

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