Practice of multi-step hybridization: Case study based on OLED display manufacturing problems described in US 20130071775

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Summary

This article describes practice of multi-step hybridization for resolution of complex inventive problems. Applying inventive principle "Combining" for increasing of ideality of engineering systems was proposed and carefully described by Genrich Altshuller. Later, algorithm of Feature Transfer was proposed by Vladimir Gerasimov and Simon Litvin. Feature Transfer is an analytical tool for improvement of base engineering system by transferring relevant features from the alternative system. In case of very complex problem, it is very difficult to resolve contradictions by single-step combining or feature transfer. That is why multi-step approach for consecutive hybridization was developed. Authors discuss details of application of this approach for development of high resolution mask resulted in concepts proposed in USA patent application US 20130071775 A1.

Keywords: feature transfer, algorithm of hybridization of alternative systems, multi-step hybridization, OLED

1. INTRODUCTION

Applying inventive principle "Combining" for increasing of ideality of engineering systems was proposed and carefully described by Genrich Altshuller in 1969 [1] as inventive principle, suggesting combine or merge identical or related objects, operations or functions. Later, he described mono-bi-poly trend, according to which at some point, technical systems evolve via combining with another into bi-systems, then tri-systems and next – poly-systems [2]. In classical TRIZ this line is known for combining of similar engineering systems and different engineering systems. Opportunity to combine systems for obtaining more efficient concepts attracted a lot of attention of TRIZ-developers in 1980s. Thus, Boris Zlotin and Alla Zusman proposed their recommendations for combining "bi-systems with biased characteristics" [3]. Later, Vladimir Gerasimov and Simon Litvin were first to propose remarkably efficient algorithm of Feature Transfer [4]. Feature Transfer is an analytical tool for improvement of base engineering system by transferring relevant features from the alternative system. It was designed only for combining of very narrow category of engineering systems – systems with same main functions and opposite advantages and disadvantages.

2. FEATURE TRANSFER ALGORITHM

Vladimir Gerasimov and Simon Litvin have defined their algorithm of feature transfer as set of following steps:

1. Identify main function of the system/component
2. Formulate key advantages and disadvantages in form of a contradiction
3. Identify competing systems
4. Select alternative engineering system
5. Select base engineering system
6. Formulate feature transfer problem

Feature was described as characteristic of an alternative engineering system to be transferred to the base engineering system to eliminate disadvantage of the base system. During feature transfer process one of the alternative systems was selected as basic system. Usually, it was recommended to select system which is simpler and less expensive as basic one. Goal of this algorithm is to obtain solutions, where the advantages of two alternative systems are integrated, and disadvantages are eliminated. But in reality, it is not so easy to eliminate disadvantages, and also, new unexpected disadvantages can appear as result of feature transfer. Thus there was a need in recommendations and algorithms for combining of non-alternative systems.

3. ALGORITHM OF CONSECUTIVE HYBRIDIZATION OF MULTIPLE SYSTEMS

The algorithm of consecutive hybridization enabled crossing of as many systems as required [5]. Also, the algorithm helps in combining different engineering systems, both alternative and non-alternative. Here is brief description of the algorithm steps:

1. Identify initial engineering system (describe as a set of simple ideas with list of advantages and disadvantages)
2. Describe candidate for crossing (describe as a set of simple ideas with list of advantages and disadvantages)
3. Describe hybridization contradiction
4. Select dominant engineering system
5. Reveal resources for hybridization
6. Describe portrait of hybrid
7. Formulate ideal vision of hybridization problem
8. Reveal resources of dominant engineering system
9. Describe intermediate hybrid
10. Reveal drawbacks, not addressed by intermediate hybrid
11. Select next engineering system for hybridization
12. Repeat hybridization problem

Consecutive hybridization process will be briefly explained below based on concepts described in US 20130071775 A1.

Currently, most OLED display products use shadow mask for color patterning [6]. Simply speaking, that means that organic material is heated and evaporated from crucible (Figure 1), then molecules of evaporated materials fly through the openings (apertures) of the mask and reside on the glass (substrate).

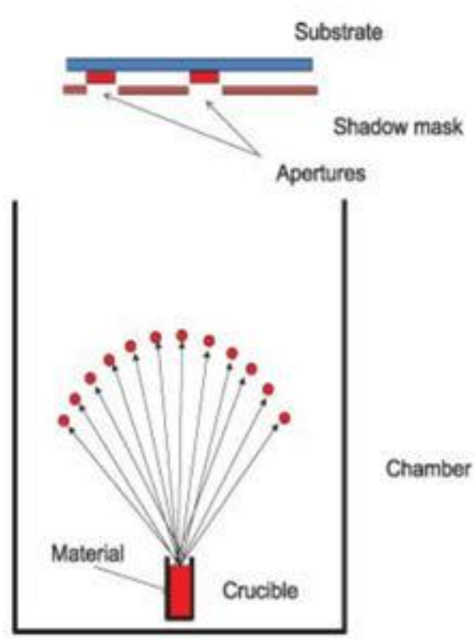

Figure 1. [Source: OLED Display Fundamentals and Applications. Takatoshi Tsujimura. Wiley; 1st edition, ISBN-10: 1118140516, 256 pages]

Criteria for optimal patterning include

1. High dimensional accuracy
2. High aperture accuracy
3. Low thermal expansion
4. Minimal shadowing effect (unintended excessive shadowing due to high-incident-angle incident molecules relative to the normal angle, which are prevented from reaching the substrate).

To reduce the shadowing effect, use of a thin shadow mask with tapered shape in its aperture provides an effective method [6].

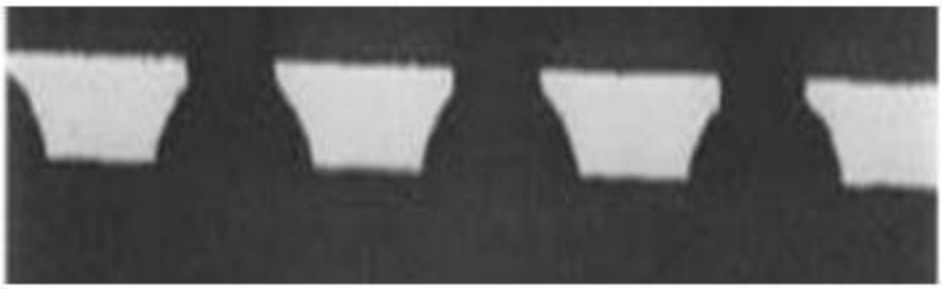

Figure 2. Cross-sectional view of a shadow mask. [Source: OLED Display Fundamentals and Applications. Takatoshi Tsujimura. Wiley; 1st edition, ISBN-10: 1118140516, 256 pages]

Recently, in order to meet the technical requirements for a high-density semiconductor device or a high-resolution flat panel display, a deposition mask or a photomask capable of depositing or transferring high-resolution patterns onto the substrate has been required [7]. That means that size of the mask rib is continuously decreased every year due to the resolution growth. If more pixels have to be placed on square inch, cross section of the masks' rib has to be reduced. At some point, the mask's rib became so small, that it loses its strength. In this case, the ribs are "twisting", i.e. distance between the ribs became non-uniform. In some places of the mask ribs are too close to each other, in some places they are located too far. In such cases, after evaporation of organic material and its deposition on glass, it results in too big or too small pixels and too big shadows, when materials from neighboring pixels are mixed. So, initial contradiction is: rib of the mask has to be small to define small pixels, and rib of the mask has to be big, in order to remain "straight" and prevent twisting. Initial concept was generated very straightforward, as ribs with small and big cross-sections one after another, providing strong ribs (fig. 3). But, drawback is non-uniform edges of the pixels, that is why this concept cannot be accepted.

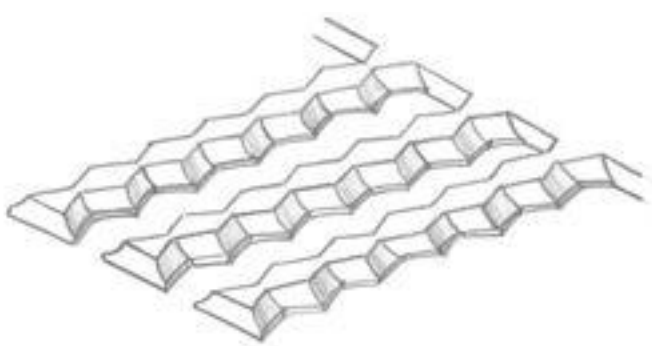

Figure 3. First Iteration

Second Iteration

Due to drawbacks of the initial concept, additional resources have to be revealed for second iteration of hybridization. It was revealed, that after evaporation, evaporated organic material in the central part of the mask is flying through the mask nearly without any inclination angle. On the edges of the mask (right and left sides), inclination angle value far from optimal straight angle. This can be used as resource, so in case of using asymmetric ribs on right and left edges of the mask, ribs cross-section can be asymmetrically increased (Figure 4). But drawback is increased complexity of the mask manufacturing.

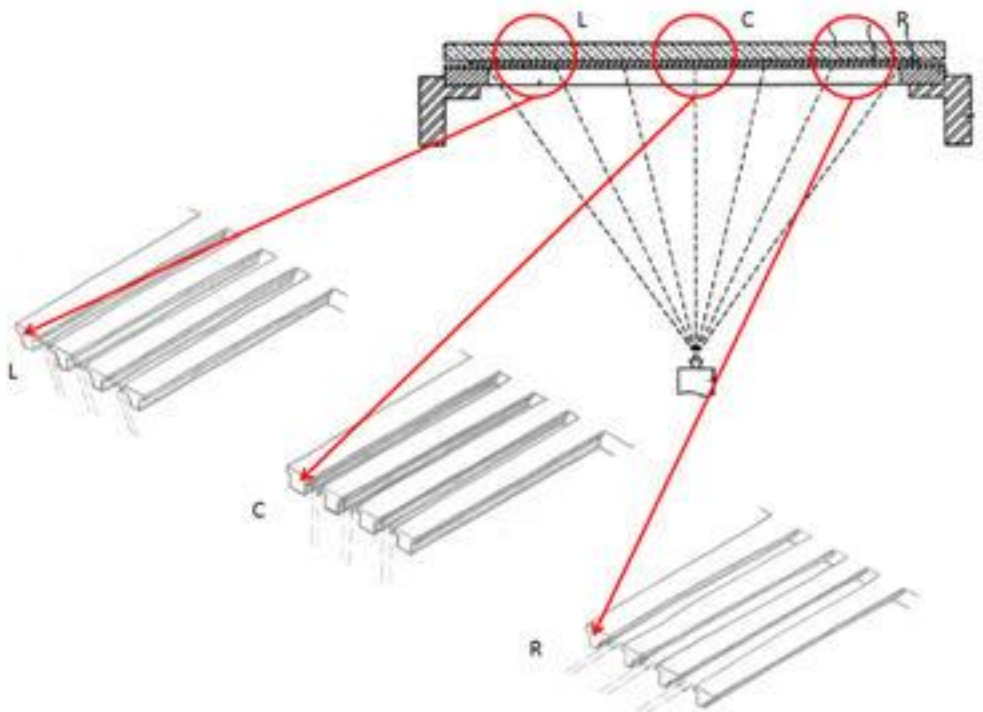

Figure 4. Second Iteration

Third Iteration

Current mask manufacturing process was studied as next candidate for hybridization. Most popular mask manufacturing process can be schematically illustrated by following steps (Figure 5):

1. Patterning mask substrate (usually metal sheet) by forming first photoresist pattern on a top surface of the mask substrate
2. Forming a second photoresist pattern on a bottom surface of the mask
3. Etching mask to form first recess
4. Forming a third photoresist pattern to cover the first photoresist pattern and the first recess
5. Etching the mask substrate using the second photoresist pattern to form a sidewalls of the ribs.
6. Stripping of photoresist and obtaining mask.

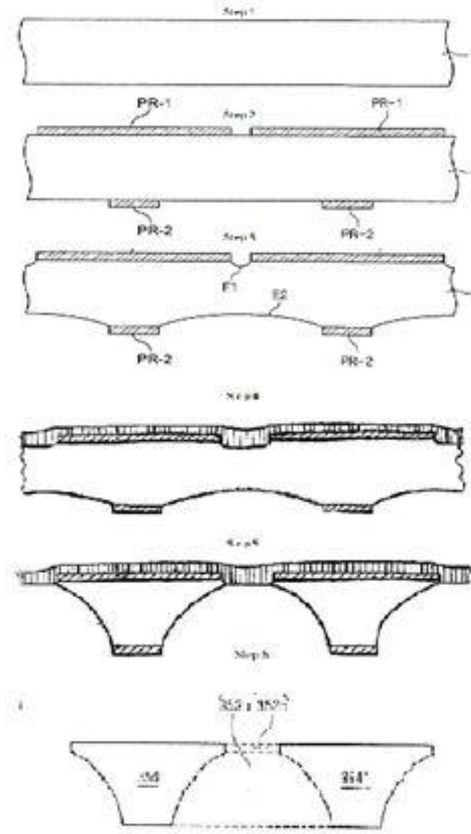

Figure 5. Third Iteration

Advantage of this mainstream manufacturing process is reliability, but at if this approach will be applied for manufacturing the mask with fine high-resolution pattern, the upper edge portion of the rib will be too small. For example, linear sidewalls 354c and 354’c may disappear during etching, and final ribs may have a reduced rigidity, and may be deformed or distorted (Figure 6). This may result in a pattern failure of the mask.

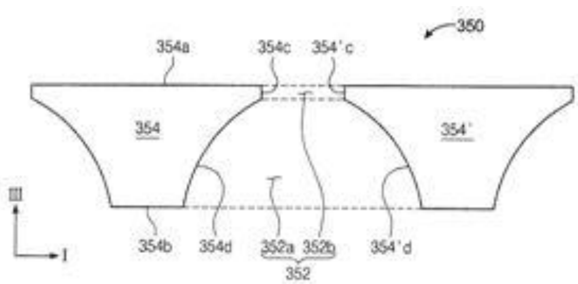

Figure 6. High resolution pattern problem

Fourth Iteration

For follow-up step of hybridization, it was decided to cross concept of initial small-and-big ribs with advantages of the current manufacturing technology. For this, it was proposed to produce mask with “oversized” wide ribs, and then apply additional patterning to remove excessive material and make ribs smaller. Final concept of proposed technology will have following steps (Figure 7):

1. Patterning mask substrate (usually metal sheet) by forming first photoresist pattern on a top surface of the mask substrate, where first photoresist pattern having a top width greater that those of the final ribs

2. Forming a second photoresist pattern on a bottom surface of the mask

3. Etching mask to form first recess

4. Forming a third photoresist pattern to cover the first photoresist pattern and the first recess

5. Etching the mask substrate using the second photoresist pattern to form sidewalls of the ribs

6. Forming photoresist pattern having width substantially equivalent to the top widths of the final ribs and facing the bottom photoresist pattern

7. Etching the upper edge portions of the initial ribs using the upper and bottom photoresist patterns as etching masks

8. Stripping of photoresist and obtaining mask.

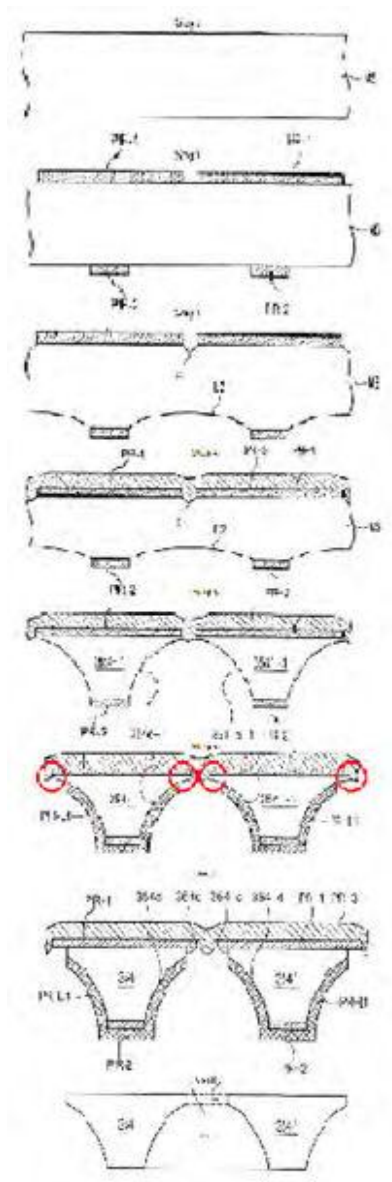

Figure 7. Fourth Iteration

4. CONCLUSION AND FUTURE TRENDS

As has been discussed, the mask manufacturing process was improved significantly through systematic innovations by applying consecutive hybridization using advantages of different engineering systems and technologies. New competitive advantage was achieved by selecting suitable candidates for hybridization process.

Consecutive hybridization can play key role in modern innovation processes. It should be noted that currently lifetime of the electronic consumer products is continuously reduced, so that number of the candidates available for hybridization is dramatically increased. Eventually, this will enable development of more detail approaches and recommendations for multistep hybridization, providing solutions for new disruptive technologies and products, because this thinking approach can drive companies for better and more systematic innovations, defining advantages that important for consumers.

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