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Analysis of the bonding process and materials optimization for mitigating the Yellow Border defect on optically bonded automotive display panels

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ABSTRACT

The Optical Bonding (OB) technology has become a critical aspect of the performance of displays, and an essential requisite of their supply chain. This paper presents the development and the implementation of a technological solution to the OB of automotive instrument panel displays. The goal is to select and develop the adequate materials and bonding techniques that can meet the rigorous performance, quality, cost and productivity of OB displays for the automotive industry. The implementation of a display wet-OB production line is firstly presented. The process is then optimised by selecting the adequate silicone based OB materials that can eliminate defects such as Yellow Border, YB (a type of MURA defect), meeting the application requirements at reduced cycle time.

1. Introduction

The information panels available to the driver and passengers in a car are increasingly equipping current vehicles. The digital displays (e.g., based on thin film transistor-liquid crystal displays (TFT-LCD)) are an interface for the exchange of information that presents a host of requirements and features to ensure a good performance. In the specific case of the automotive industry, a good readability is required under different environmental conditions, such as high brightness or direct sunlight. Display's readability is greatly improved by eliminating the air gap between the display and the cover glass surface (e.g., glass, touch screen), reducing the reflections at the various interfaces of the optical elements (Fig. 1). This can be achieved with the introduction of an optically clear material of matching refractive index, between the display and cover surface. The technology for this lamination process is called optical bonding (OB) technology. In recent years, OB technologies emerged with high importance for the production of high quality and performance displays. This technique attains a major importance on the performance and supply chain implantation of projective capacitive technology (PCAP) in 2007 [1]. It is now a fast-growing market in displays technology that is worth more than $ 2 billion USD [2].

By eliminating air gaps, the OB process greatly improves the display readability by reducing the reflections at the various interfaces of the optical elements of the display, and by decreasing the number of necessary anti-reflective (AR) treatments in the front cover glass (CG). The adoption of OB technology for displays shows a few advantages: (i) improvement of the display contrast, enhancing display outdoor visibility and readability under exposure to sunlight [3]; (ii) increased display robustness (resistance to impacts, vibrations, extreme temperature and moisture condensation on the display); (iii) avoiding of the inclusion of particles in the display; and (iv) increased display durability. The appropriate selection and implementation of the display OB technology and the proper material selection strongly prevents or eliminates process defects and determines the final display quality and production success.

This work investigates the wet-OB process for automotive displays, focusing on the effect of selecting the adequate material, the bonding technique, and then optimizing them in order to develop a robust solution that meets performance, costs, quality requirements and productivity goals. The implementation of a wet-OB production line for displays OB is presented along with the activities that led to a robust process implementation and a high quality display. This implementation starts with the initial definition of materials and processes, equipment procurement and deployment of wet-OB production line. After first production trials, the process is optimised in order to reduce cycle time, the

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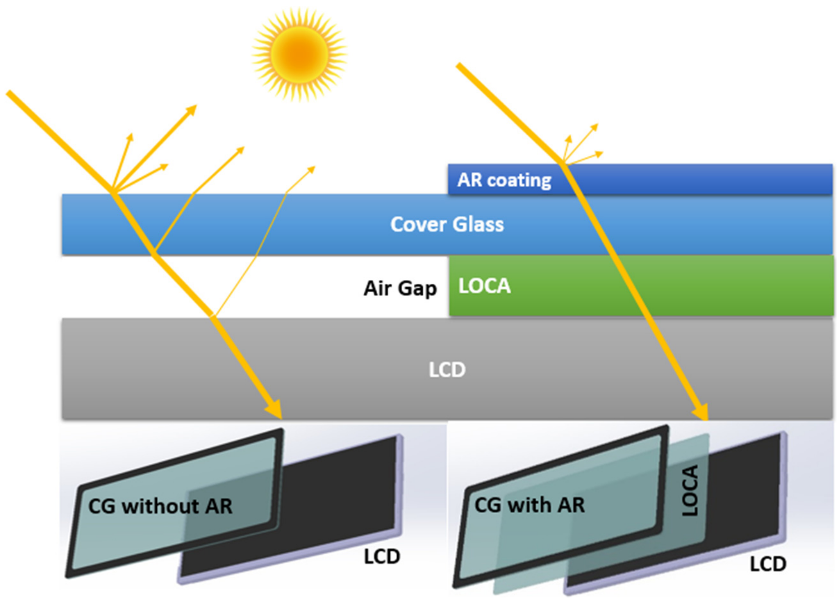

Fig. 1. Reduction of reflections in a display: before (left) and after (right) OB with an anti-reflective (AR) layer over a cover glass (CG).

number of non-conform products, defects such as Yellow Border, YB (a type of MURA defect) and air bubbles.

2. OB technologies

OB consists in the use of a material (usually an optically clear adhesive) between the protective glass and the display (Fig. 1) in order to improve the display optical performance in outdoor environments of high brightness or direct exposure to sunlight. The adhesive eliminates the air layer between the glass and the display, thereby reducing the specular reflectance and increasing the overall contrast of the display. The adhesive is called optically clear because it is transparent and it has a suitable refractive index (i.e., a refractive index coincident with the protective glass and display). On the other hand, the adhesive must be applied under suitable and controlled conditions, so that there are no significant differences in the optical properties at the interface and, equally important, providing adequate bond strength, reasonable pot life after preparation, and not showing any health or safety issues. Within the OB process, the main technologies are the wet bonding [4,5] and dry bonding [6]. The wet-bonding uses a liquid optically clear adhesive, LOCA, to fill the gap in between the substrates. The dry bonding uses thin-sheet materials, which are typically made of fully cross-linked pressure-sensitive optically clear adhesives or optically clear thermoplastics. Rockwell Collins were the first using optical bonding of LCDs in the latest 80s, using conventional wet-OB process [5,7]. The wet-OB technology has been studied by Mozdzyn and Rudolph [5], Bahadur et al. [7], and many commercial firms [4].

Wet-OB is a versatile process allowing the production of small and large displays and touch displays for various applications in several industrial sectors. However, the wet-OB process itself requires know-how and expertise in order to take the greatest advantage of the process and to be able to further optimize it. The implementation of wet-OB process involves three main aspects closely interlinked: (i) Selection of the proper materials; (ii) the process and appropriate equipment; and (iii) the correct operation of the production line.

What concerns the optical adhesives selection, it is important to select the material in order to ensure the overall quality of the optical connection process and its long-term performance. Among the wide variety of optical clear resins (OCR), not all of them are suitable for bonding substrates to a display. The most used materials are acrylic-based or silicone. Normally, materials based on epoxies are not used (due to their poor adherence and unwieldy process of production) neither materials based on urethanes (which tend to yellow over time) [8,9]. The silicone is the most commonly found adhesive in OB processes since the 1970s due to its core properties: low conductivity, chemical reactivity, thermal stability, the ability to repel water and form watertight seals, and in certain conditions, it is a soft material, so it is very feasible to rework for bonds that become damaged over time [10].

In addition to their adhesion and optical characteristics, OCR mechanical properties, such as elastic modulus, tensile strength and hardness are also important because they affect the display performance. The tensile strength and adhesion guarantee durability and the robustness of display. The modulus and hardness may affect the load transfer from the CG to the display and its shock resistance. This presents another major challenge when a substrate is optically bonded to them. The mechanical properties of the OCR can affect the displays and cause defects, such as, bright marks and wavy effects expressed by the discoloration of the picture when an external pressure induces changes of the LCD behaviour (e.g., at high temperature exposition, the LCD technology is sensitive to deformation). The proper selection and formulation of the adhesive may minimize or eliminate these and other defects, e.g., yellow mark and MURA (SEMI Document #3324, “New Standard: Definition of Measurement Index (SEMU) for Luminance Mura in FPD.”) on the display. These defects are characterized by a local uneven brightness on the display surface, typically larger than single pixels. MURA may be caused by a variety of physical factors such as, touch induced, an unevenness of the coated layer thickness, local pressure, local surface roughness, or local non-uniformities. The viscosity of the adhesive is also important because it will determine the process parameters, such as, wetting and the adhesive distribution and degassing. These parameters affects the total assembly time and the final display quality [11].

3. Materials and processes for wet-OB

3.1. The OB-display

The wet-OB process was selected for display OB. This includes the dispensing of a barrier and filling materials. The former mate-