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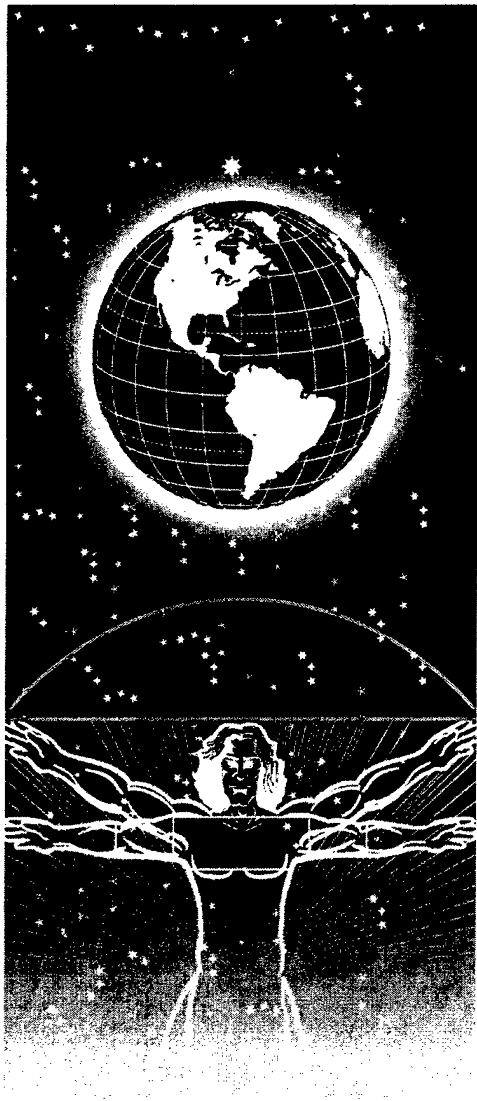

UNITED STATES AIR FORCE RESEARCH LABORATORY

HIGH BRIGHTNESS EMISSIVE MINIATURE DISPLAY DEVELOPMENT

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FOR THE COMMANDER

Brian P Donnelly

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The program thrust was material/device development, to improve the thermal characteristics of OLED materials so that they can withstand more heating without deterioration, and to improve the efficiency of the devices so that less heat is generated. Additionally, the program was to engineer a better thermal management strategy, to remove generated heat quickly and effectively, thus limiting the temperature rise in the OLED device.

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High Brightness Emissive Miniature Display Development

Introduction

This development program was created in response to an RFP from the Dual Use Science and Technology Program of DoD. Organic light emitting diode (OLED) displays had been demonstrated to have many of the characteristics which are desirable in helmet mounted displays. They are light, efficient, capable of good contrast at high resolution, and have Lambertian emission characteristics, an important feature for use with magnifying optics. OLEDs were also known to be capable of very high brightnesses (> 30,000 cd/m^2) in pulsed operation, even though they would tend to overheat and suffer irreversible deterioration when operated at such brightnesses for extended periods. For certain helmet applications, namely projection of information by reflection from a clear plastic visor, such high brightnesses are required on a sustained basis, so this became a requirement to extend OLED technology to allow it to fulfill this type of application.

eMagin Corporation, together with Eastman Kodak Company and Honeywell Corporation, proposed to achieve the required technology extension by a dual-pronged approach. One thrust of the program was material/device development, to improve the thermal characteristics of OLED materials so that they can withstand more heating without deterioration, and to improve the efficiency of the devices so that less heat is generated. The second thrust of the program was to engineer a better thermal management strategy, to remove generated heat quickly and effectively, thus limiting the temperature rise in the OLED device. Significant progress toward these goals has been achieved, as has been reported in the series of milestone reports over the course of the program.

New materials were developed to replace the conventional hole transport materials, which were subject to deterioration at any temperature over 100° C. New device structures, based upon a better management of internal barriers, allowed a demonstration of improved efficiency, even for the most well known emitter material, Alq_3. Also, simulation analysis of the thermal dissipation in proposed device packages, by eMagin, coupled with an analysis by Honeywell of a system for dissipating heat in a helmet, led to the conclusion that the heat load expected in high brightness operation could in fact be managed without reaching excessive temperatures at the OLED display.

In other words, all of the ingredients for meeting the needs of a high brightness projection microdisplay for helmets have been demonstrated, short of building an actual packaged high brightness display, which would have required a new chip that is not yet available.

Materials Development

Hole Transport Materials – When this work was undertaken, the most widely used hole transport materials for making OLED devices were CuPc (Copper Phthalochanine) and NPB (naptha phenyl benzidene), used in a layered combination. Devices made in this way were unstable at temperatures greater than 100° C, due to crystallization of the NPB. The tendency of an amorphous material to crystallize is best quantified by the glass transition temperature, T_g, which in the case of NPB is about 95° C.

We set as a goal the development of suitable hole transporters capable of use at temperatures up to 130° C. Of course, there are requirements other than T_g which a hole transport layer (HTL) material must meet. The material must have a HOMO (highest occupied molecular orbital) energy that is in a suitable range between about 5.0 eV for a material used close to the anode and 5.5 eV for a material used adjacent to an emitter such as Alq_3. Also, the LUMO (lowest unoccupied molecular orbital) energy of the HTL material must be less than about 2.7 eV, to stop electrons at the HTL/emitting layer (EML) interface. A final requirement relates to evaporability. Typically, higher T_gs can be achieved with larger molecules, but larger molecules generally require higher evaporation temperatures. If the evaporation temperature becomes too high, decomposition may occur, resulting in a layer with uncertain composition and stability.

In the course of this work, many new materials were synthesized and evaluated, and these have been reported in detail in the earlier reports. Most interesting of these were HT-306, an attractive hole injector layer (HIL) material, and HT-308, an excellent replacement for NPB. HT-308 was shown in experiments at Kodak to be more stable than NPB, even at moderate temperatures of operation. Its HOMO and LUMO energies are similar to those of NPB, which is not surprising, since it can be viewed as a composite of NPB structural elements.

Since we were focused on achieving better performance from OLEDs at higher temperatures, we also evaluated new materials from commercial OLED material suppliers. Some of these turned out to be very good, and they have the advantage of easy availability, whereas we do not have production capability for materials developed by us. Among these materials are a spiro-triaryl diamine (S-TAD) from Covion, which is well suited as an HIL material, as well as IDE-406 and IDE-320, from Idemitsu Kosan Co., which are excellent HTL materials. IDE-320, like our HT-308, is a high T_g (>130° C) material with electronic properties very close to those of NPB. This material was developed partly at our request.

Emitter Materials - On the emitter side, Kodak tried various approaches to achieving a green efficiency superior to that of Alq_3, the standard. Some carbazole compounds were thought to be attractive until they were found to be lacking in stability under operation. Kodak also explored the phosphorescent dopant approach introduced by the Princeton/USC collaboration. As detailed in our earlier reports, this system turns out to have superior efficiency at low luminances, but at the very high luminances required in this program it is not as efficient as a conventional fluorescent dopant system, namely coumarin in Alq_3. For this reason, we ended up concluding that for a very high brightness green OLED display, Alq_3 doped with coumarin or with dimethylquinacridone (DMQA) is the best choice today.

<u>OLED Devices</u> – Using combinations of these selected materials, we were able to achieve quantum efficiencies of nearly 15 cd/A even at the highest luminances required. In an up-emitting configuration, this should translate to a power efficiency of about 1.8 lumens/Watt, even at 30,000 cd/m^2 (Efficiencies, of course, are much higher at low luminances). For an SXGA microdisplay with 5% of the pixels lit (a Honeywell estimate for typical helmet use), this would translate into a power level of only 0.5 W.

Thermal Management

As detailed in Milestones 19B and 20, experimental and theoretical analysis of the thermal characteristics of a packaged OLED-on-silicon microdisplay revealed that, with a suitable heat sink and chip bonding process, the temperature rise in the OLED relative to the temperature of the heat sink could be maintained at a very acceptable level. Specifically, the temperature rise of the OLED was found to be less than 0.5° C per Watt dissipated in the OLED. Even for a worst case scenario, where the display had all pixels lit, the power would reach about 10W, causing a temperature rise of only 5° C.

The problem in the worst case scenario would be getting the heat out of the helmet; 10W is probably unmanageable. However, for any reasonable fraction of lit pixels the problem is manageable. For example, a 20% fill factor (4 times Honeywell's estimated fill factor) would result in a power level of about 2W, and a Honeywell design for a feasible heat sink system would result in a temperature rise for the heat sink relative to ambient air of about 20° C in the moving air assumed in a cockpit environment. This would be added to the 1° C rise in the package for a 2W load, totaling 21° C . Given the improvements in the thermal characteristics of the materials described earlier, this would not present a serious problem. For the more realistic estimate of 5% pixel usage factor, the total temperature rise over ambient is only about 5° C.

Summary

We have successfully established in this program that even the exceptional demands of a visor-projection type helmet mounted microdisplay can be met with OLED technology, using the proper combination of OLED materials, device structure, device packaging, and helmet heat sink design. In this way, the other benefits of the OLED approach can be gained: simplicity, light weight, resolution, contrast, large exit pupil, etc.