

# LED-BASED MICRO DISPLAY FOR AN INTRAOCULAR VISION AID (IOVA)

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**Abstract**-In this Paper a micro display for an intraocular vision aid (IOVA) projecting an image of the environment onto the retina is presented. The display comprises an image of an array made out of single LED pixels. It is connected to a CMOS driver circuit using flip-chip technique. Since micro lenses have to be integrated into the substrate material for proper image projection onto the retina the generated light has to pass the substrate. Thus, only semiconductors with adequate large band gap energies are suitable. This paper discusses the principle of GaAsP material systems for an LED-based micro display applied to an implantable vision aid.

**Keywords** – intraocular vision aid, IOVA, GaAsP, LED array, micro display

## I. INTRODUCTION

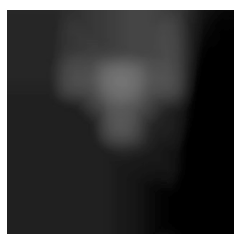
The objective of IOVA is providing artificial vision to people suffering from blindness due to opaque cornea [1], [2]. By applying IOVA to blind people it is supposed to restore some primitive kind of vision, e.g. giving them back again their orientation in an unknown environment. An example of the expected deterioration in vision is shown in fig. 1.

## II. METHODOLOGY

In order to bridge the opaque cornea the following concept has been developed. A high dynamic range CMOS camera placed outside of the eye generates a digital black and white image which is converted by a digital signal processing unit (DSP) into a serial bit-stream with a data rate of approximately 1 Mbits per second [3]. This bit-stream in conjunction with the energy is transmitted wirelessly to an implantable micro display encapsulated in an intraocular lens [4], [5]. It consists of a receiver for power supply, data and clock recovery and a miniature LED array flip-chip bonded to a silicon CMOS driver circuit. Fig. 2 shows a sketch of the system concept described above. Details of the signal



Sight of people having unlimited vision.



Sight of blind people having a blurred cornea.

Fig. 1. Comparison between normal and harmed vision.

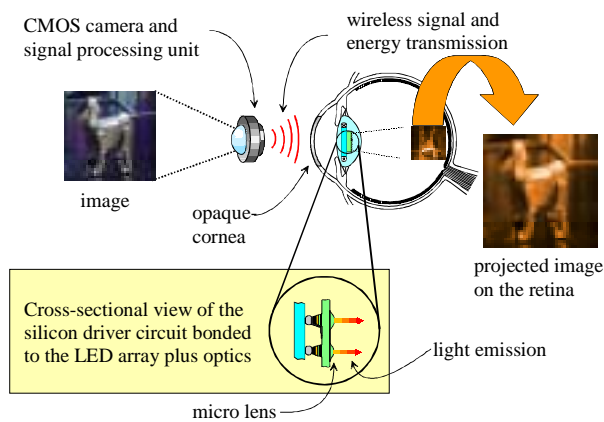


Fig. 2. System concept of the intraocular vision aid.

transmission technique can be found in [4].

### A. LED array

For the selection of the wavelength emitted by the LED array the standard observer function  $V(\lambda)$  defined by the Commission Internationale d' Eclairage (CIE) has been taken into consideration, confirm fig. 3. The semiconductor materials suitable for the LED array have to meet the following requirements:

- Due to the maximum value of  $V(\lambda)$  the emitted wavelength  $\lambda$  has to be in wavelength region between 500 nm and 600 nm.
- For this wavelength region the substrate of the required material system has to be transparent.

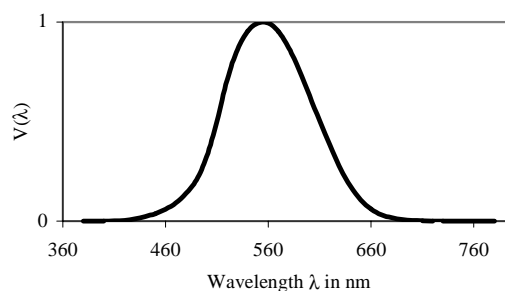


Fig. 3. The photopic standard observer function  $V(\lambda)$  defined by the CIE.

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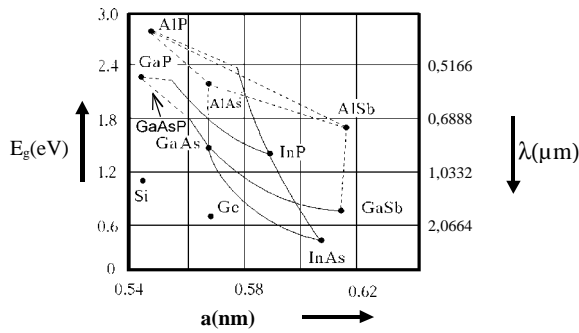


Fig. 4. Lattice constant  $a$  versus bandgap energy  $E_g$  and wavelength  $\lambda$ .

Considering the restriction mentioned above the material system GaAsP based on GaP substrate as a material with a sufficiently high energy gap was chosen. In this context fig. 4 shows the bandgap energy versus lattice constant for various semiconductors as an additional important technological property. To avoid critical tensions of the crystal several layers of n-doped GaAsP with increasing arsine concentration were epitaxially grown on n-doped GaP substrate. In the active zone nitrogen was included to improve the efficiency [6], [7]. The layer system of the LED closes up with p-doped GaAsP. One design of the above described LED structure is shown in fig. 5.

### B. Bonding process

The LED array is connected to the silicon driver circuit by means of flip-chip technology. Gold bumps are bonded onto the Si-driver circuit using a ball-wedge-bonder. Applying heat and pressure both devices are connected together. This thermocompression technique is sketched in fig. 6.

## III. RESULTS

In a first step the n-doped substrate has to be polished to get a smooth surface with an excellent optical quality. In order to get an array of LED pixels the p-doped epitaxial layer has to be etched down to the pn-junction. The necessary depth is approximately  $9\ \mu\text{m}$  for the GaAsP system. During the last processing step ohmic contacts are applied to the semiconductor using metal evaporation.

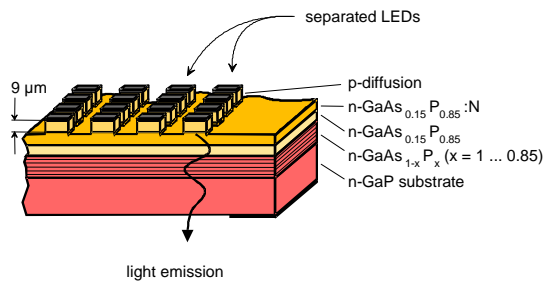


Fig. 5. GaAsP/GaP LED structure.

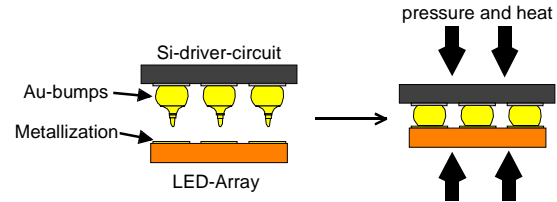


Fig. 6. Flip-chip-bonding based on thermocompression technique.

### A. Etching

To realize single LEDs the wet chemical etchant for p-doped GaAsP has to comply with the following properties:

- No narrowing and broadening of the LED edges.
- High etching rate concerning a depth of  $9\ \mu\text{m}$ .
- No deterioration of the optical and electrical properties.

Standard etching substances for GaAs-systems are  $\text{H}_2\text{SO}_4$  and  $\text{H}_2\text{O}_2$ . Due to the experience in etching GaAsP systems the first step was using an acid containing this starting matter [8]. Assuming the mentioned condition the averaged etching rate of  $\text{H}_2\text{SO}_4:\text{H}_2\text{O}_2:\text{H}_2\text{O}=1:1:1$  at room temperature is  $50\ \text{nm}$  per minute. For increasing the etching rate  $\text{HNO}_3:\text{HCL}:\text{H}_2\text{O} = 3:1:1$  at room temperature is used leading to an averaged rate of  $300\ \text{nm}$  per minute. In order to get the required depth of  $9\ \mu\text{m}$  the contact pads are covered with  $2\ \mu\text{m}$  positive photo resist. The samples are etched for 30 seconds. To avoid critical undercut the spin-coating and lithography procedure is repeated until the demanded depth is reached. Fig. 7 shows a section of a pixel array with isolated LEDs on the p-doped GaAsP wafer with  $9\ \mu\text{m}$  deep etched pads having a center distance of  $200\ \mu\text{m}$ .

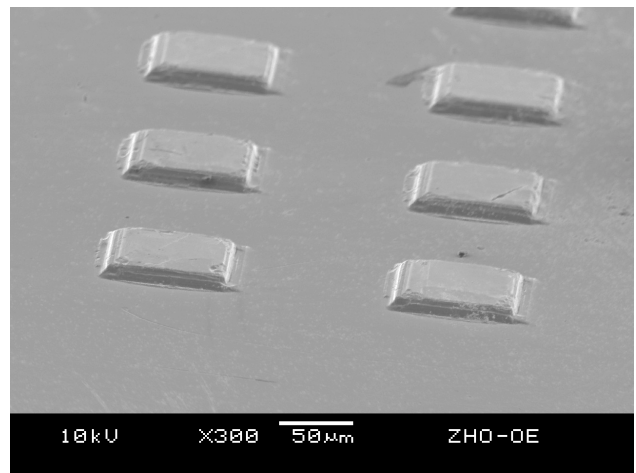


Fig. 7. SEM image of an LED array with  $90\ \mu\text{m} \times 90\ \mu\text{m}$ , each  $9\ \mu\text{m}$  in high and  $200\ \mu\text{m}$  in distance.

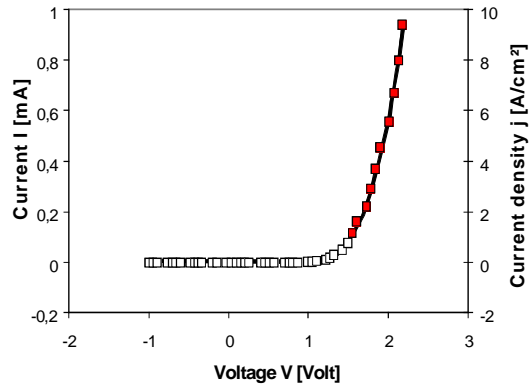


Fig. 8. I-V curve of a single LED pixel.

### B. Metallization

For the p-doped site the following layers are used: Pd(45nm)/Ge(90nm)/Ti(30nm)/Pt(50nm)/Au(100nm). The n-doped substrate site is evaporated with Ge(30nm)/Pt(10nm)/Au(100nm). Finally the contacts are alloyed at a temperature of 450°C for 60 seconds. As a result fig. 8 shows the I-V curve for one pixel of the array with the start of light emission at approx. 100  $\mu$ A.

### C. Device integration

Fig. 9 shows gold-bumps bonded to the Si-driver circuit using a standard ball-wedge bonder. The size of the contact pads is 100  $\mu$ m x 100  $\mu$ m with a 200  $\mu$ m pitch. The LED array is connected to the Si-driver circuit by using flip-chip-bonding techniques. Some important parameters among others are:

- Pressure: 20 cN
- Temperature: 320°C for the LED chip, 340°C for the Si-driver circuit.

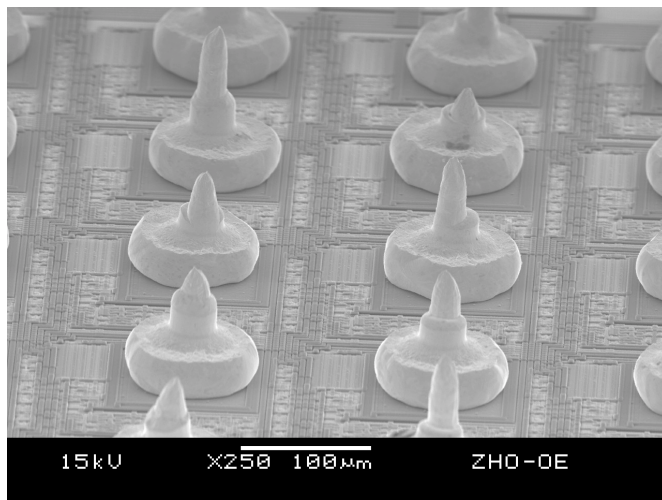


Fig. 9. Gold bumps bonded on a Si-driver-circuit.

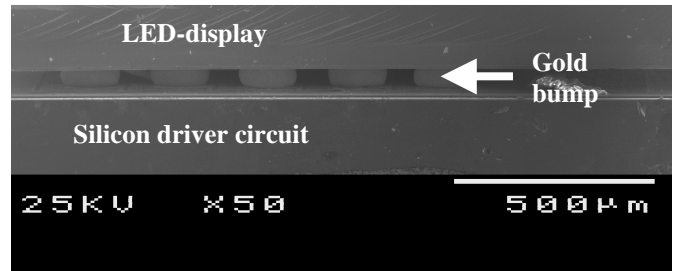


Fig. 10. SEM image of a Flip-chip-bonded LED array on a Si-driver-circuit.

The result of such a bonding process is shown in fig. 10. In fig. 11 the realized prototype of a 8x8 micro display with a total area of only 3.2 mm<sup>2</sup> bonded into a DIL casing is depicted.

## IV. CONCLUSION

In this paper a prototype of a miniaturised LED display applied to an implantable intraocular microsystem is presented. The connection to a silicon driver circuit is demonstrated using flip-chip technology. The LED display can be considered as the first step on the way to a LED array with much higher resolution. Therefore other bumping processes like electroplating or anisotropic conductive adhesives or films will be used for future flip-chip procedures.

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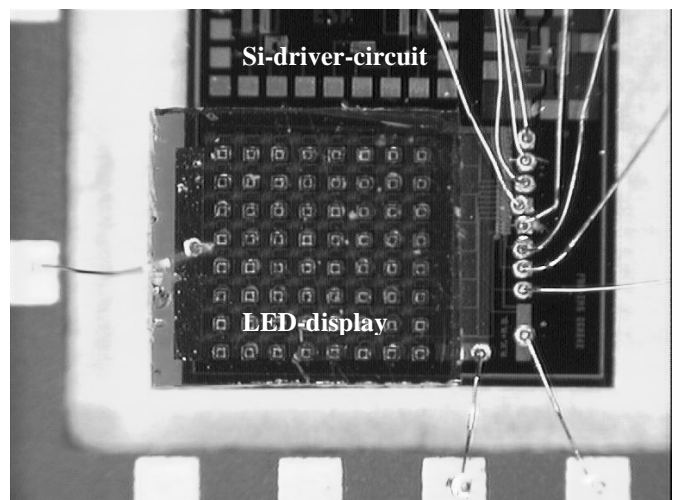


Fig. 11. Flip-chip-bonded device in a DIL casing.

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