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Thermal Behavior of LED Arrays

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Abstract

This document deals about the ability to construct high power-small size optical sources using hybrid circuit technology with ceramic substrates. The size of the optical source must be kept small enough to reduce optical source-lens coupled losses in quasi-difussed optical channels

Introduction

In point to point channels, distance of 70 meters have been covered at 10 Mb/s using commercially available infrared LEDs as the L3989 of Hamamatsu [1], and passive optical systems. The distance to be spanned is primarily dependent on the optical aids used. Suitable reflector, lenses or lens combinations in the beam path of the source and the detector cause a considerable increase in the radiant power falling on the photodetector. In diffused channels, due the high optical power levels required, an array of LEDs has to be used as optical source. In Full-Diffused channels, where the goal is to produce a relatively homogeneous diffuse radiation field over the whole room area, the array may be constructed with packed LEDs. However, in Quasi-Diffused channels, where the optical radiation is collected with a lens or concentrator, the size of the array must be kept small enough to reduce the array-lens coupled losses. Therefore, the array must be constructed with LEDs in chip form. Due to the higher integration density, more power is dissipated in smaller volumes giving rise to higher peak temperatures. This problem has been solved using hybrid circuit technology with ceramic substrates [2]. The high thermal conductivity of ceramic substrates ($k_{alumina\text{-}96}$ = 20 W/°C m^2, $k_{aluminum\ nitride}$ = 170 W/°C m^2) is a very attractive solution in power electronics as contrasted with printed circuit boards where expensive cooling fans are needed for the heat removal [3]. The relation between the size of the area for the array and the number of LEDs depends upon the thermal characteristics of the single LED , the ceramic substrate, and the environment conditions.

Mathematical model for thermal simulation

Several mathematical models for thermal simulation of hybrid circuits have been reported in the literature. They are based upon the three mechanisms by which heat may be transferred: conduction, convection and radiation [4]. The general heat conduction equation can be developed by writing an energy balance for a differential element of a conducting body. However, to obtain useful solutions, certain simplifying assumptions must be made: material homogeneous, isotropic and steady-state conditions. With these assumptions, the differential equation ruling the thermal behavior reads:

$$\left[\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right] - \frac{T}{L^2} = - \frac{P}{k\,e} \qquad (1)$$

where

k: substrate conduction coefficient
e: substrate thickness
$L=(ke/2h)^{1/2}$: characteristic length
h: convection coefficient (included convection and radiation effects)

This is a Poisson equation with Neumann boundary conditions, no heat flow out of the borders of the substrate is assumed. As the thickness of commercial available substrates ($\approx$ 0.4 mm for aluminum nitride) is much smaller than the others two dimensions, it is reasonable to assume that the temperature gradient between the faces can be neglected resulting in a two dimensional model [5].

L can be interpreted as a length constant. Around each LED one can say that approximately a zone with radius L will be warmed up. If the distance between two LEDs is smaller than L, their temperature fields will interfere with each other. The numerical solution of (1) can be obtained by a finite difference scheme. Physically, this method is equivalent to the solution of a network with thermal resistances.

Results and discussion

Figure 1 shows an array of 25 (5 x 5) MFOEC1200 diodes (commercially available in chip form) distributed on a 5 x 5 mm^2 area, placed on the center of an aluminum nitride substrate. The substrate dimensions are 60x60x0.5 mm^3.

If the power dissipation of each LED is 200 mW, the theoretical temperature distribution on the substrate under natural convection can be shown in Figure 2. As it can

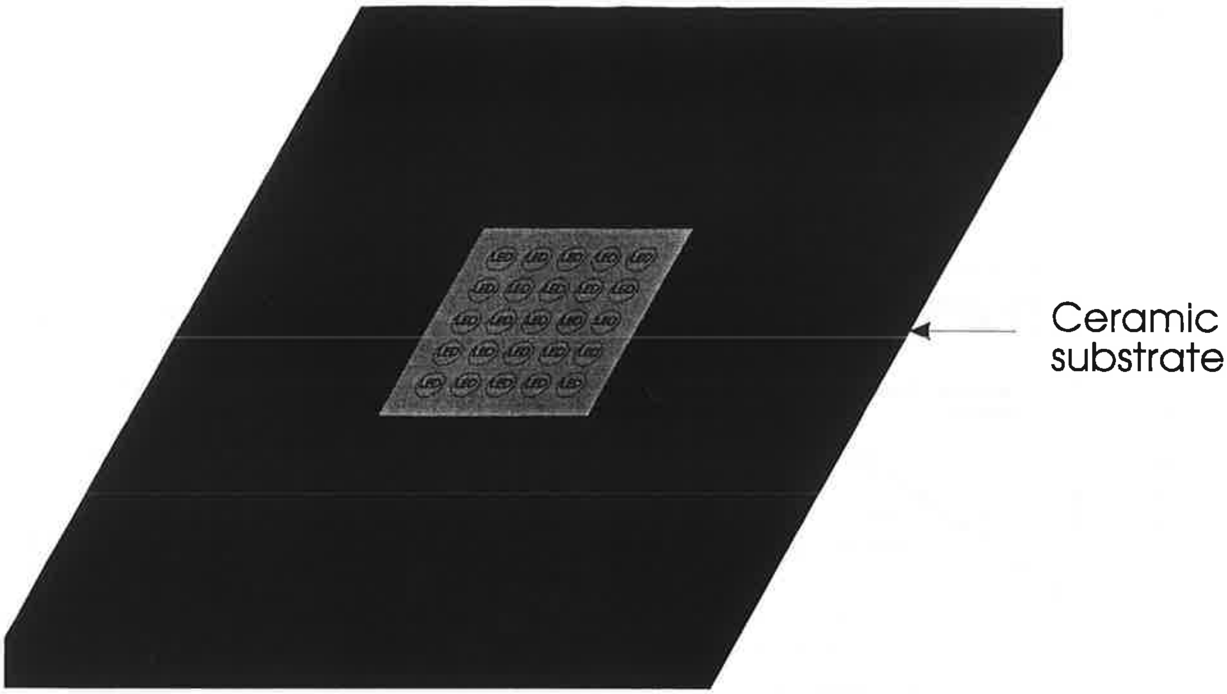

Figure 1. Array placement on a ceramic substrate

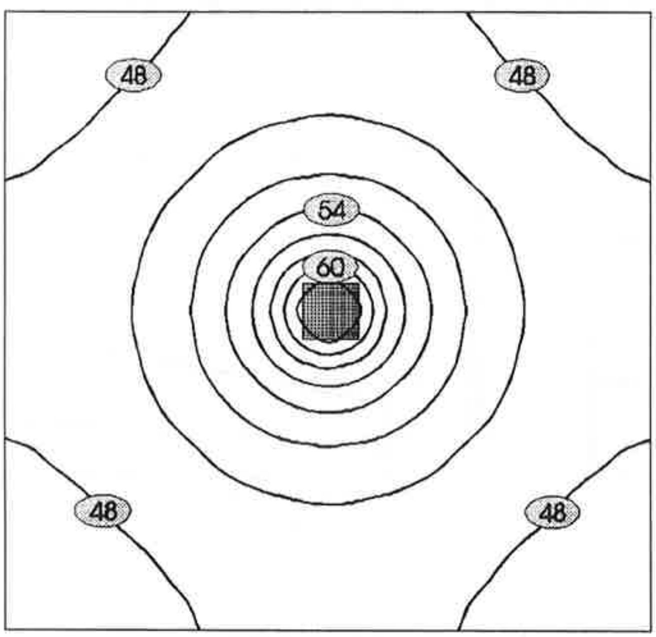

Figure 2. Temperature distribution on the array

be seen, peak temperature is 62°C, and practically is the same for overall array.

Optical power emitted and power dissipated are related with forward current. Unfortunately, both of them are direct function of the forward current; therefore, an increment in the current to obtain an increment in the optical power emitted leads an increment in the power dissipated. Without a correct thermal design, this increment in the power dissipated will reduce the optical power emitted at about a rate of 0.012 dB/°C.

Figure 3 (a) shows the optical power emitted from the array of LEDs in function of the number of LEDs when the array in mounted on a AlN (aluminum nitride) substrate. In this representation it has been considered that the optical power emitted from each LED individually is 2 mW. Ideally, the optical power emitted from an array of 10 LEDs will be 20 mW, and from an array of 25 LEDs will be 50 mW. However, the power dissipated for 25 LEDs is greater than the dissipated for 10 LEDs, and therefore, the real behavior gives a deviation due the thermal penalization. This phenomenon is more evident (figure 3 (b)) when the array is mounted on a SiC substrate (poorer thermal features).

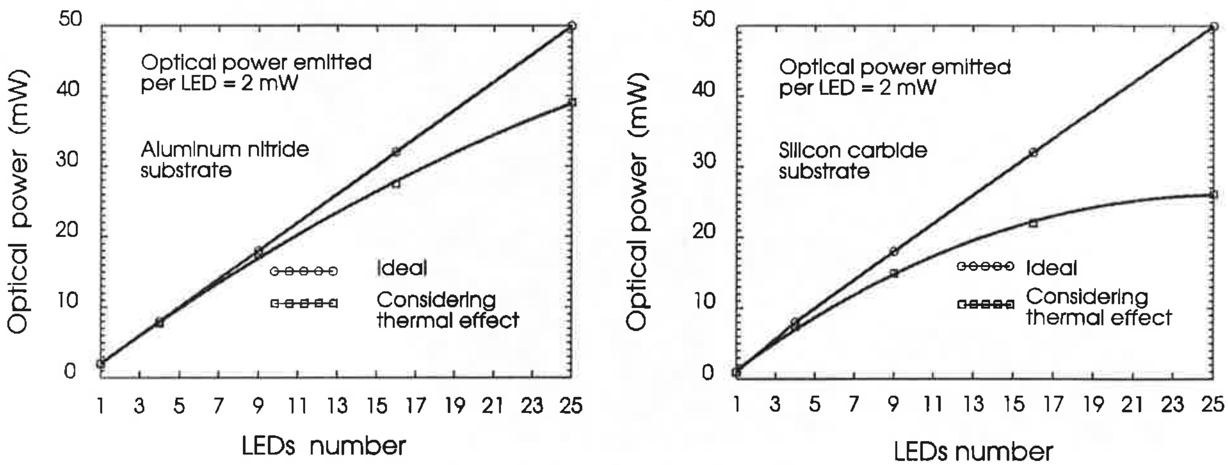

Figure 3. Variation of the optical power emitted with the number of LEDs on the array.

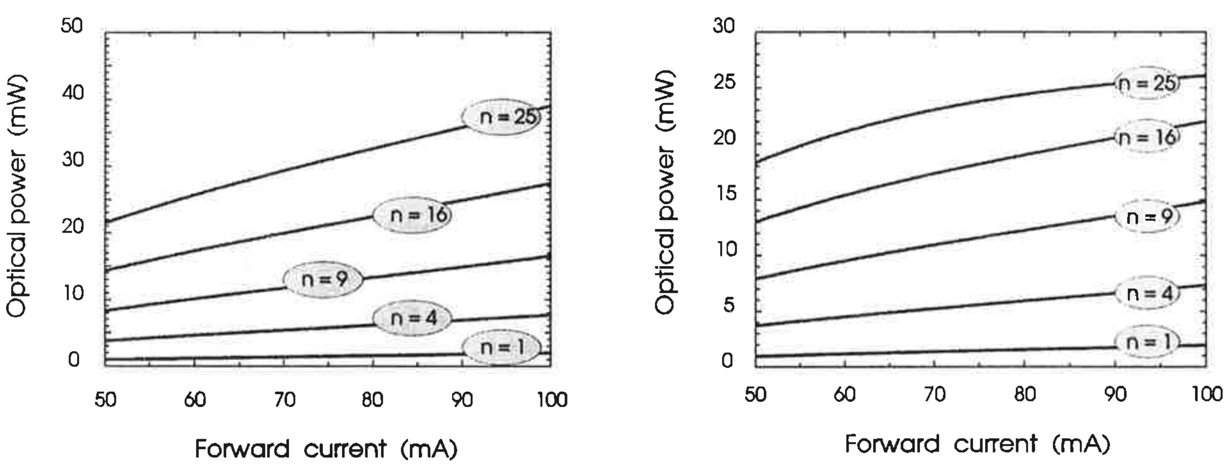

Figure 4. Variation of the optical power with the current and LED number.
Left: Al N, Rigt: Si C

Similar results will be obtained if the optical power is not considered as a fixed value. As shown in figure 4 (a), for low values of forward current (low optical power) or small quantities of LEDs, the optical power raises linearly with forward current. For high values of forward current or a great quantity of LEDs in the array, thermal penalization tends to make flat the curve P_0-I_F. As it has been mentioned above, this phenomenon is more evident when the array is mounted on a SiC substrate (figure 4 (b)).

Conclusions

* Quasi-diffused infrared channels require high speed-high optical power devices.
* Commercial available devices offer one of these two features, but not both simultaneously.
* With high speed commercial available LEDs in chip form, is possible to construct high speed-high optical power devices using hybrid circuit technology.
* To reduce thermal effects associated with the proximity among the chips, the array must be mounted on a ceramic substrate.

REFERENCES

[1] HAMAMATSU Technical Data, *High-Speed Infrared LEDs*, Japan, 1990.

[2] Antonetti, V.W., Simons, R.E., *Bibliography of Heat Transfer in Electronic Equipment*, IEEE Transactions on Components, Hybrids, and Manufacturing Technology, Vol. 8, No. 2, 1985, pp. 289-295.

[3] McPhillips, R.B., *Advanced Ceramic Materials for High Thermal Conductivity Substrate Applications*, Hybrid Circuit Technology, August 1988, pp. 21-23.

[4] Dean, D.J., *Thermal Design of Electronic Circuit Boards and Packages*, Electrochemical Publications, Scotland, 1985.

[5] Wehrhahn, E., *Temperature Distribution on Substrates of Hybrid Circuits*, 5th European Hybrid Microelectronics Conference, Stresa, Italy, 1985, pp. 288-295.