Optical design aspects of VCSEL-Solder-Joints

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We consider a multichip module (MCM) based on a planar optical system. To reduce fabrication steps the emitters (VCSEL diodes) are bonded directly onto the substrate, and the micro-optical components are placed only onto the bottom of the substrate. The optical interconnect may be realized as a micro-channel system with deflection angles in the order of $\alpha = 20^\circ$ [1], fig. 1(a).

Fig. 1: (a) Path of the folded beam in the substrate (b) Calculated spacing $z_0$ and interconnection distance $s$ limited by the beam divergence for different beam waists $w_0$ and with $k = 1.6$, $a = 4/3$, $\lambda = 850\,\text{nm}$, $n = 1.5$, $p = 100\,\mu\text{m}$ and $h = 21.5\,\mu\text{m}$ ($\alpha = 20^\circ$). The substrate thickness $H$ is derived for a spot radius $w' = p/(2k)$ at the bottom of the substrate. The dashed line indicates the maximum interconnection distance by the Rayleigh condition, equ. (2).

The mentioned integration technique limits the optical interconnection length $s$: The optical spacing $z_0$, which is equal to the thickness of the solder joints, has typical values for a diode pitch $p = 100\,\mu\text{m}$ of $z_0 < 40\,\mu\text{m}$. Assuming a Gaussian beam model the beam has diverged at position $z'$ in the substrate with refractive index $n$ to a Gaussian radius $w'(z')$

$$w'(z') = w'_0 \left[ 1 + \left( \frac{z'}{z_{R,n}} \right)^2 \right] < kp \quad \text{with} \quad z' \approx nz_0 + H - h/2$$

(Here $z_{R,n}$ denotes the Rayleigh range in the medium, $H$ the substrate’s thickness and $h$ the thickness of the deflecting prism). The beam in the medium corresponds to a virtual beam waist $w'_0$, which can be calculated with the help of Snell’s law and the divergence angle $\theta' = \arctan(\partial w'/\partial z')$, for example. At the bottom of the substrate the emitted light extends to a maximum beam spot, which must not exceed a fraction of $k = 1.6$ of the diodes pitch $p$ to avoid diffraction at the edges of the micro-optics and power losses. After deflection from the lens, the collimated beam shows the waist $w''_0$. The optimum beam waist $w'_0$ of the folded beam is $w'_0 = w'/(\sqrt{2}\cos(\alpha))$, compare [2]. Thus the maximum interconnection length $s_{\text{max}}$ is constant:

$$s_{\text{max}} = 2w''_0^2 \pi n \sin(\alpha)/\lambda.$$

(2)

For small laser diameters, i.e. $w_0 \ll p/(2k)$, the total interconnection length is limited by the beam divergence. For the considered Gaussian radii $w_0$ and the corresponding beam divergence the substrate thickness varies between $H = 310\,\mu\text{m}$ for a diameter of $2w_0 = 4\,\mu\text{m}$ and up to $H = 2643\,\mu\text{m}$ for $2w_0 = 40\,\mu\text{m}$. The plot in fig. 1(b) shows, that for the considered dimensions the Rayleigh length of the deflected beam is not the limiting factor but the beam divergence along the vertical axis.
