Digest of Tech. Papers *The 11th Conf. (1979 International) on Solid State Devices, Tokyo*

B—2—4 A New Type GaAlAs Monolithic Lensed LED

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Introduction A new type GaAlAs monolithic lens coupled LED, different from the hemispherical LED's previously reported,[1-3] has been proposed and developed to achieve the highly efficient performance for fiber-optical communications. A GaAlAs lens monolithically formed on the LED surface and the spherical-ended fiber are effectively coupled under the optimized design. By this new coupling technique, the highest coupled power ever reported can be obtained for very low current level.

Principle and Design Figure 1 shows the new coupling technique compared with the flat LED.[4,5] For both coupling methods, the optimized coupling can be obtained by the same condition of $d_o=d_c$, where d_o is the diameter of virtual image of emitting area and d_c is the critical diameter defined by the critical angle of the fiber.[6] The angle φ_m is the maximum value accepted by the fiber. For lensed LED, the virtual image is magnified by the factor β and the angle φ' is $\beta\varphi_m/n_o$ by the lens effect of the refractive index n_o. Therefore, $\varphi'=\beta\varphi$ is derived because $\varphi=\varphi_m/n_o$ and φ_m has the same value as that for flat LED. According to the analysis of geometric optics, the improved ratio χ of the efficiency for lensed LED to flat LED is approximately β^2 under the simplified model. Table I shows the dominant factors on which the coupled powers P_f for flat LED and P for lensed LED depend. In the case of the flat LED ($\beta=1$), the coupling efficiency η_c is proportional to r^{-2} for $d_o \leqq d_c$ and to d^{-2} for $d_o > d_c$,[4] where d is the emitting area diameter. Under the constant current density, the operating current I is porportional to d^2. In the simple estimation, therefore, the optimized coupled power P_l determined by the condition of $d_o=(\beta d=)d_c$ slightly increases against d in the region of $d_o \leqq d_c$, and P_l is proportional to d^{-2} for $d_o > d_c$, where χ_{opt} is the optimized value of χ. The detailed calculations for P_f, P_l, I and χ_{opt} vs d are shown in the solid lines of Fig.2. As seen in this figure, P_f becomes smaller as d becomes smaller because I is smaller, but P_l can be improved because of χ_{opt}, over one order of magnitude better than that of the flat LED. Plots show the experimental data. The dotted line of χ_{opt} is derived from the ratio P_l/P_f of the experimental plots. As seen from the figure, good agreement between theoretical and experimental results can be obtained. If I=10 mA is defined by the drive circuit, d=10 µm is determined and P_l>100 µW can be obtained.

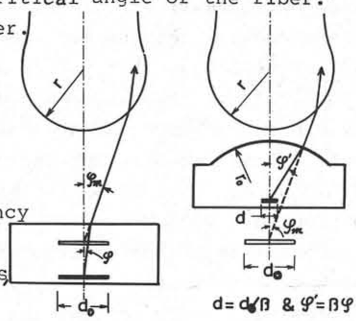

Fig.1 New Coupling Technique.

Table I Dominant Factors.

	Flat LED (β=1)			Lensed LED (β>1)	
	η_c	P_c	$P_f=\eta_c P_c$	$P=\chi P_f$	P_l
$d_o \leqq d_c$	r^{-2} (const)	d^2	d^2	$(\beta d)^2$	d_c^2 (const)
$d_o > d_c$	d^{-2}	d^2	const	β^2	d^{-2}
remark	$d_f/2f' \ll 1$ $d_c=2f'\tan\varphi_c$	J:const $I \propto d^2$	fiber:fixed	$\chi=\beta^2$	opt. cond. $\beta d=d_c$ $\chi_{opt}=(d_c/d)^2$

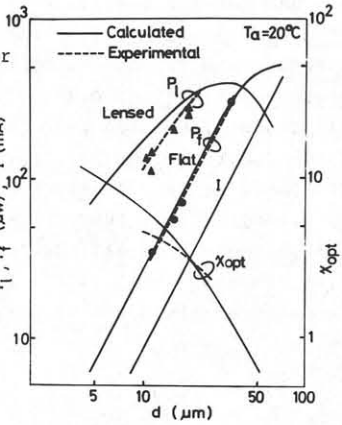

Fig.2 P_l, P_f, I and χ_{opt} vs d.

Fabrication The structure of GaAlAs lensed LED is shown in Fig.3. At first the GaAs substrate was etched through oxide mask to give the spherical recesses with radius r_o. Then $Ga_{1-x}Al_xAs$ DH structure with a thick window layer is successively grown by LPE.[7] By employing a preferential etch which attacks GaAs but not $Ga_{0.6}Al_{0.4}As$, the lens structure could be formed without damage. Figure 4 shows the scanning electron micrograph of the lensed window. The magnification β of lensed window can be designed by controlling L/r_o, and $1/\beta$ vs L/r_o is shown in Fig.5. As an example, when l= 50 μm, β=2 can be obtained by designing r_o=80 μm and L=56 μm. In this case, X_{opt}=4 can be achieved. The diameters of P electrode are chosen to be 10 μm and 20 μm, respectively. The radius r of spherical-ended fiber is 75 μm.

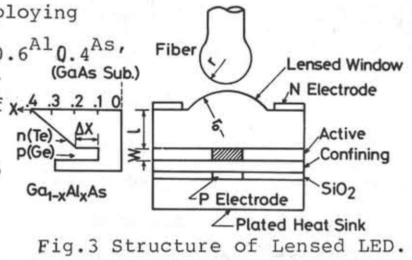

Fig.3 Structure of Lensed LED.

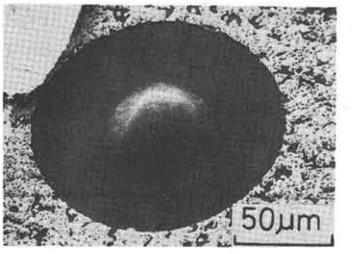

Fig.4 SEM of Lensed Window.

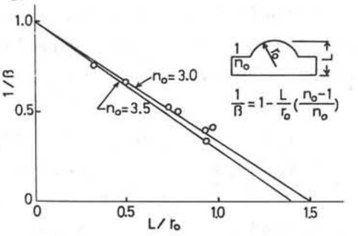

Fig.5 $1/\beta$ vs L/r_o.

<u>Characteristics</u> The comparison of the coupled power was made between the lensed LED and the flat LED, both of which were fabricated from the same wafer. The powers P_l and P_f coupled into 0.16 N.A., 85 μm core step index fiber, vs the forward current I_f are shown in Fig.6. For lensed LED designed by β=2, P_l of 280 μW at I_f of 30 mA and 420 μW at 50 mA, almost without cladding mode, were obtained, and the efficiency was improved about four times better than that of the flat LED. For lensed LED of d=20 μm, P_l of 570 μW at I_f of 50 mA and about 1 mW at 100 mA were coupled into 0.28 N.A., 100 μm core step index fiber. These are the highest values ever reported for such a low current level.

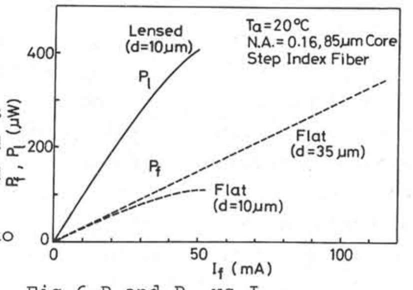

Fig.6 P_l and P_f vs I_f.

<u>Conclusions</u> To achieve the highly efficient performance, a new type GaAlAs monolithic lensed LED has been developed. For the new coupling technique presented here, designed values were compared with the experiment and good agreement was obtained. By the optimized design for power coupled into fiber, the efficiency was greatly improved and the highest coupled power ever reported could be obtained. This high efficiency LED can be applied to the direct drive by IC because of operating under very low current level.

<u>Acknowledgment</u> The authors wish to thank M. Fujimoto of NTT, H. Takanashi, T. Kotani and T. Yamaoka of Fujitsu Labs. for continuous encouragement.

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