On-Die Diffractive Alignment Structures for Packaging of Microlens Arrays with 2-D Optoelectronic Device Arrays

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***Abstract*—A novel technique for aligning a microlens array to an electrically packaged optoelectronic device array is presented: reflective Fresnel zone plates (FZP's) are fabricated on the device die to provide registration spots during alignment. A proof-of-concept experiment in which an MSM array was aligned to a microlens array with an accuracy of better than 9 microns is described.**

I. Introduction

Free-space optical interconnects based on microlens technology promise to alleviate data throughput bottlenecks in future electronic computing systems [1], [2]. However, a major problem in the construction of optical interconnects is the alignment of optoelectronic device arrays to microlenses. Current techniques addressing similar alignment problems include imaging fiducial alignment marks on the component substrate. However, to avoid lateral alignment errors incurred when imaging marks on different xy planes, additional components must be added [3], [4]. Other techniques in which microlenses are attached or defined during device fabrication also exist [5], [6].

This letter presents a new technique for aligning a microlens array to an optoelectronic device array: reflective diffractive structures fabricated on the device die provide registration spots during alignment. This technique can produce prealigned device/microlens packages which loosen alignment tolerance requirements for free-space optical interconnects.

II. Description of Technique

The objective is to align an array of microlenses of focal length f with respect to a packaged array of optoelectronic devices a distance d away from the microlenses, as Fig. 1 shows. The technique can yield precise alignment in x, y, and θ_z, and to some extent alignment in the other three degrees of freedom. There are three steps.

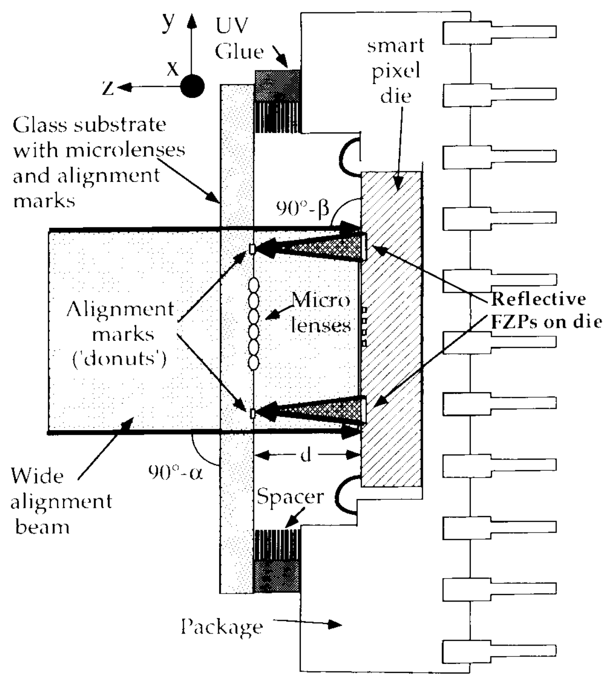

Fig. 1. Schematic of technique: reflective FZP's on device die focus light back onto alignment marks located on the microlens array.

The first step consists of laying out reflective FZP's of focal length $f_{fzp} = d$ on the edge of the device array, and laying out alignment marks at corresponding positions on the edge of the microlens array. In this experiment, FZP's are defined beside an array of metal semiconductor-metal (MSM) detectors, and corresponding marks ("donuts") are on the microlens substrate as Fig. 2(a) and (b), respectively, show.

In the second step, a wide, planar alignment beam with uniform irradiance distribution is generated as shown in Fig. 1 (the wide beam covers all FZP's). The microlens substrate is brought into the beam path, with the substrate perpendicular to the beam, and secured in place.

In the third step, UV glue is deposited on top of the package and the package is placed directly behind and moved into contact with the substrate. The alignment beam is then

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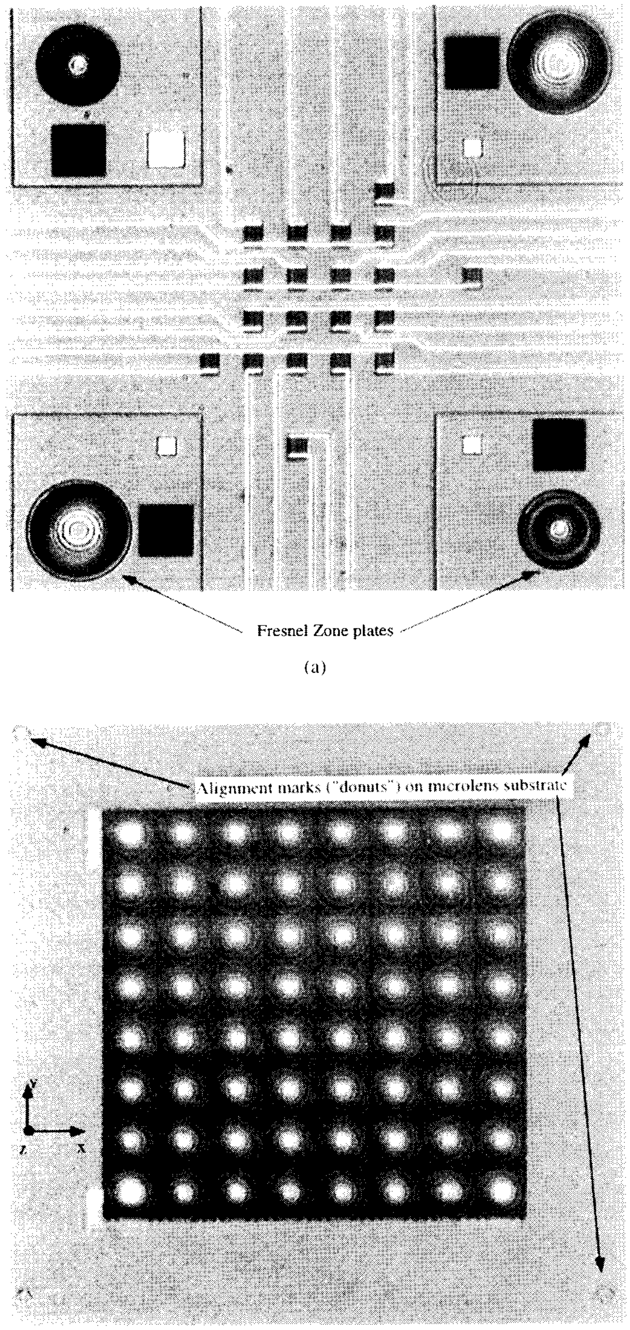


Fig. 2. (a) Reflective Fresnel zone plates on four corners of MSM die. (b) Alignment marks ("donuts") on microlens array substrate.

reflected off the FZP's and forms spots a distance $f_{\rm FZP}$ in front of the die. The package is then moved until the reflected spots from the FZP's coincide with the alignment marks on the microlens substrate, at which point the glue is UV cured. A spacer may be required between the package and the substrate.

III. Alignment Accuracy

Four main sources of errors affect this technique's lateral (xy) alignment accuracy: misalignment of FZP's relative to the optoelectronic device array during fabrication, misalignment of the alignment marks to the microlens array during fabrication, the effect of an angular tilt ($\alpha, \beta \neq 0$ in Fig. 1) in the alignment beam on the position of the spots generated by the FZP's, and error in judging when the FZP spot is aligned to the alignment mark.

For operations in which the FZP's and the device array are defined in the same step, the error will be minimal and defined by the accuracy of the mask fabrication process. In most other processes, for example, when devices are flip-chipped onto metal pads on a die, the error can also be under one micron [5]. During microlens fabrication, the accuracy of the alignment mark position relative to the microlens array is determined by the mask aligner; conventional mask aligners routinely align to within 0.5–1 μm [7].

In Fig. 1, the angle between the die and the alignment beam is $90 - \alpha$. Since the interference pattern between the part of the alignment beam reflected from the substrate and that reflected from the die is used to determine the perpendicularity of the alignment beam to the die, a deviation from the normal of β between the alignment beam and the die will cause the spot generated by the reflective FZP's to be misaligned with respect to the die by approximately $\Delta = f_{fzp} \tan[2(\alpha^2 + \beta^2)^{0.5}]$. For $f_{fzp} = 1$ mm, $\Delta < 1\,\mu$m if $2(\alpha^2 + \beta^2)^{0.5} < 0.057°$.

Thus, in principle, a lateral alignment error of $\varepsilon < 2\,\mu$m is achievable.

Two FZP's can yield rotational (θ_z) alignment information. For FZP's on diagonally opposite corners and a distance $\tau/2$ away from the array center, the θ_z error is under arctan (ε/τ). If this technique is also used for z alignment, the error is determined mainly by the depth of focus of the FZP's which is $\delta = \lambda/2(NA^2)$ [8], where NA is the FZP numerical aperture.

Other minor diffractive effects have been neglected in this analysis; these had negligible impact on the results below.

IV. Experimental Setup

The central 4 × 4 array of an 8 × 8 diffractive microlens array was aligned to a 4 × 4 MSM array using the above technique (MSM's were 50 μm × 50 μm with Ni–Pt–Au metallization on InP). These are shown in Fig. 2(a) and (b). The array pitch was 125 μm. The microlens glass substrate had nominal dimensions of 15 × 15 × 1 mm. Two binary amplitude FZP's ($D_{FZP} = 295\ \mu$m) a distance $\tau = 1909$ μm apart on diagonally opposite corners of the MSM array were defined; alignment donuts with an inner diameter of 25 μm were fabricated at corresponding places on the microlens substrate. Both the microlenses and the FZP's had a focal length of 1000 μm at $\lambda = 850$ nm. The MSM die was glued and wire bonded into a side brazed 22 pin dual in-line package. The average distance from the top of the die to the top of the package was ~451 μm (standard deviation = 20 μm), making a ~550-μm-thick spacer necessary. Fig. 3 shows the optical train which generated a flat beam with uniform irradiance. Only the central 1% of the light emerging from the fiber was captured by the ×40 microscope objective, ensuring a uniform irradiance distribution. A very flat beam was obtained by longitudinally moving the ×40 microscope objective until

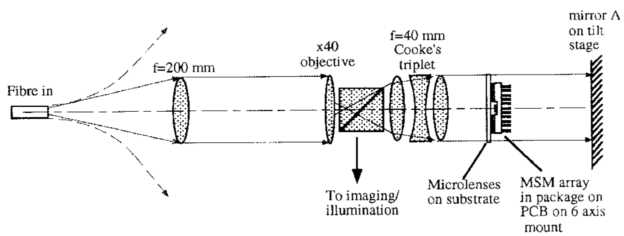
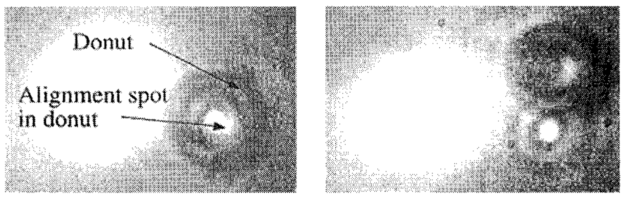


Fig. 3. Optical train for producing normally incident, flat, uniform irradiance beam.



(a) (b)

Fig. 4. (a) Spot generated by FZP in upper right alignment mark ("donut"). (b) Microlens array deliberately misaligned by $\sim$40 μm to show spot and donut separately.

the back focal plane of the $\times$40 objective coincided with the front focal plane of the triplet. The beam flatness was measured with a shear plate interferometer and found to be better than $\lambda/10$ over the regions of the beam hitting the FZP's. Mirror A was then adjusted to reflect the incident beam back into the fiber. Standard interferometric techniques were used to ensure that the substrate was normal to the light beam. Afterwards the package was brought in as described in step 3 above.

V. Results

Interferometric measurements indicated that the angular errors were $\alpha = 0.09°$, $\beta = 0.09°$. Fig. 4 shows images of the FZP-generated spots in the donuts on the microlens substrate. Fig. 4(a) shows the spot in the donut on the upper right hand corner of the microlens substrate; a similar picture was obtained for the lower left spot. Fig. 4(b) shows the spot deliberately misaligned by $\sim$40 μm and thus falling outside the donut. The large bright smear is due to the light from the illumination LED (λ = 880 nm) which was also focused by the reflective FZP. The LED was misaligned in order not to have the bright smear drown out the donut and alignment spot.

The measured diameter of the spot inside the donut was 12.5 μm ($\pm$3 μm) and the spot was measured to be $\sim$4 μm off center (this 4 μm error was due to the low resolution of the manual xyz stage used). Given the angular misalignments α and β, a further error of $\Delta = 4$ μm could have been introduced. Assuming a total error of 1 μm in mask alignment during various device fabrications, the total xy misalignment error was thus $\sim$9 microns for this proof-of-concept experiment. This was verified by imaging the spots on the MSM's through a hybrid microlens-bulk lens relay. Additionally, first order calculations reveal that the 12.5-μm spot diameter corresponded to a 42-μm error in z alignment [8].

The alignment errors in future systems will be reduced by improving the orthogonality of the incoming beam and using more precise positioning equipment.

VI. Conclusion

By using on-die reflective diffractive structures, a smart pixel array was aligned to a microlens array in x, y, and θ_z. Further projects will involve on-die astigmatic FZP's for precise information on z misalignment, as in CD players [9]. These packaged devices will be used in experiments involving the analysis of optical crosstalk for detecting misalignment in larger systems [10].

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