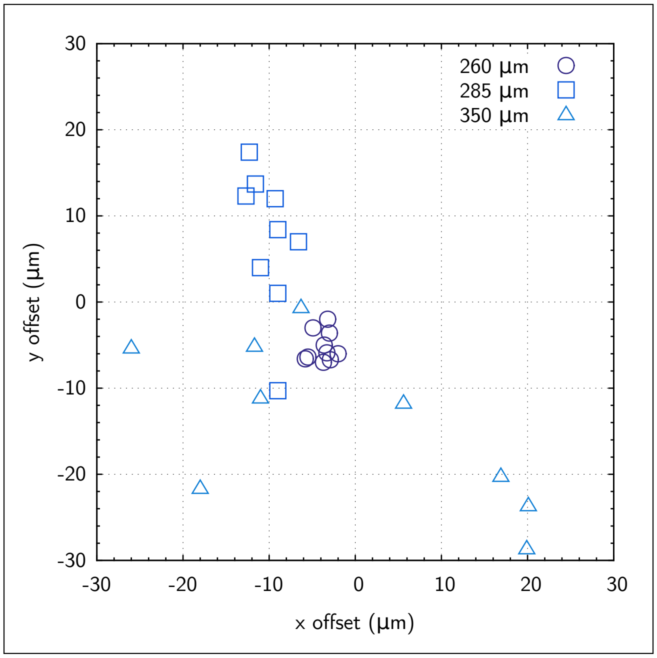

Fig. 10. Offset of the centre of a laser die with respect to the centre of the trap for different sizes of the trap. This laser was face up and showed a smooth movement.

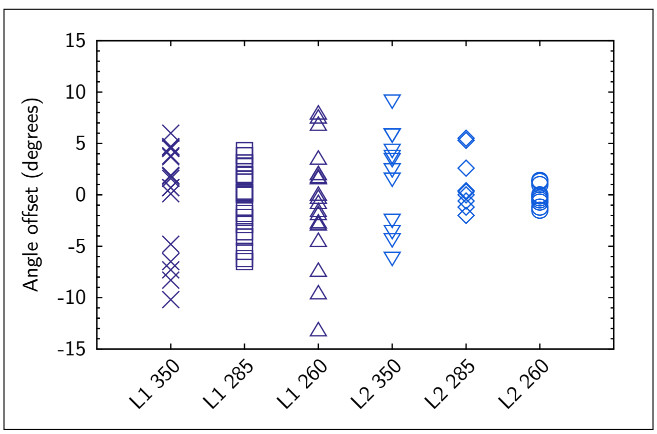

Fig. 11. Offset in the angular orientation of two laser die with respect to the trap, for different sizes of the trap. The labels L1 and L2 correspond to the die of Figs. 9 and 10, respectively. The numbers 350, 285 and 260 correspond to the size of the trap in µm.

difference of 1.4° between maximum and minimum values. As already stated, the error in the individual measurements is 1.4 µm for the distances and 0.4° for the angles.

In a previous work [16] we explored the accuracy of optoelectronic tweezers when performing small displacements in a given direction and small rotations with the same InP microlasers used in the present work. The results indicated accuracies better than 2 µm and 2°, with an error of ±1 µm for the measurement of the absolute travelled distance and ±0.5 ° for the absolute rotation.

The positional accuracy is at the limit of what would be useful in terms of the associated

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coupling losses, and the angular accuracy would be good enough for components that are not far from each other [5, 17].

Future work involves the design of a strategy to electrically contact the microlasers. An interesting possibility is to realise the contact within the optoelectronic tweezers device itself through positioning of solder beads at the edges of the microlaser and further heating. The dielectrophoretic trap could be kept on during the process to ensure the lasers do not change their position. Another possibility is to use mechanical stops such as mesas on the substrate or to bring the die into a recess on the silicon substrate. Finally, pre-deposited metal layers could also be used after moving the die on top of them. While the movement of the laser is limited to the surface of the silicon, it is possible to move them onto thin metal layers (of the order of a few hundred nanometres thick). A problem that will have to be solved is what to do with the roughly 50% of microlasers that land upside down, that is with their bottom contact face up. One possibility is to discard those and put them back into the pool for later reuse.

5. Conclusion

We have reported the accuracy of the positioning of standard Fabry-Pérot InP semiconductor laser die with optoelectronic tweezers. The results indicate that, after movement of the dielectrophoretic trap, the microlasers can be centred within the trap with a positional and angular accuracy of 2.5 ± 1.4 μm and 1.4 ± 0.4 °, respectively. This positional accuracy is at the limit of what would be acceptable for positioning in a photonic platform, but the angular accuracy would be good enough for components that are not far from each other.

The dependence of the accuracy with the size of the trap can be explained with the help of the simulations. Furthermore, comparison of the simulations using two different formalisms with the experimental observations leads us to conclude that the effective dipole moment approximation is not valid for the InP semiconductor lasers, and the Maxwell stress tensor formalism should be used instead.

The results of the accuracy reported in this work are in good agreement and complement previous results that explored the accuracy in the absolute travelled distance for small displacements and rotations. While those previous results give an idea of how accurately the position of a microlaser can be corrected when it is close to the final intended position, the results presented here give a more general estimate of how accurately the microlasers can be brought from their original position to an arbitrary final location in the device.

We believe there is room for improvement of the accuracy and the systematic misalignment with respect to the nominal centre of the trap by carefully setting up the optical path of the projected dielectrophoretic trap and by seeking ways to reduce the friction between the laser die and the a-Si:H surface.

Our results and previously published works indicate that optoelectronic tweezers are a promising technique for the micromanipulation and alignment of light sources and other optoelectronic components of a wide range of sizes (from hundreds of nanometres to hundreds of micrometres) for integration on a photonic platform in applications from communications to sensing. Indeed, previous work with smaller microdisk lasers and nanowieres, as well as current work with solder beads indicates that smaller components are easier to manipulate, possibly due to a smaller influence of the mass and much smaller contact surface and therefore reduced friction.

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