Enhancement of the Optical Quality of Microtraps for Single Atoms with HASO4 First

Olga Nabirotchkine
Imagine Optic, 18 rue Charles de Gaulle, 91400 Orsay, France
contact@imagine-optic.com

APPLICATION NOTE

Introduction

Over the past years, an interest in advanced optical trapping of atoms has arisen. From simple initial configurations such as crossed optical dipole traps, researchers' needs have evolved towards more complex light fields such as two-dimensional arrays of microtraps. These configurations open appealing applications in quantum-information processing and quantum simulation for instance. In this report, we present the results of an experiment performed at Institut d'Optique Graduate School (CNRS, France), demonstrating the successful trapping of cold ^{87}Rb atoms in reconfigurable 2D arrays of microtraps obtained with a spatial light modulator (SLM). The use of a HASO4 First, the wavefront sensor from Imagine Optic, proved to be essential to achieve high-quality optical microtraps.

Experimental Setup

Figure 1 shows the experimental setup used to generate an array of microtraps for single-atom trapping. To do so, a collimated trapping beam at 850 nm is sent on a SLM, which imprints a phase onto it. Then, this beam is focused in the focal plane of a high-numerical-aperture aspheric lens. A cloud of cold atoms is produced at 50 µK with a magneto-optical trap (MOT) to load the microtraps. The atoms are detected thanks to the measurement of their fluorescence at 780 nm. The trapping beam is transmitted via a second aspheric lens to a diagnostic CCD camera to image the trap array, or to the HASO4 First.

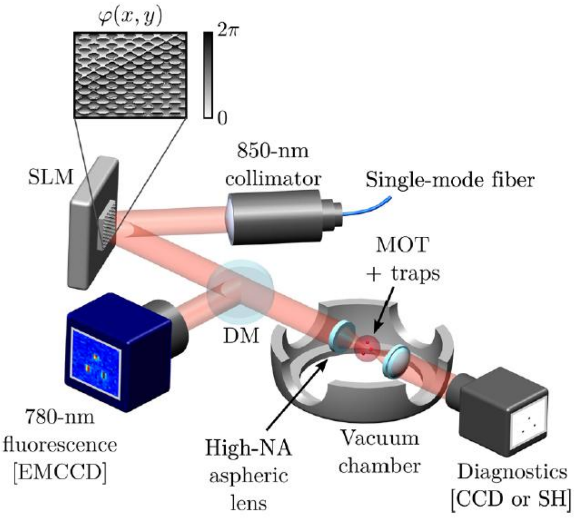


FIG.1: Experimental setup to generate an array of microtraps for single-atom trapping.

The 2D trap arrays can have various geometries. Thanks to the SLM, one can create large lattices with up to 100 sites, with a spacing of 4-5 µm between each other. Figure 2 shows a few examples of geometries that have been created with this setup.

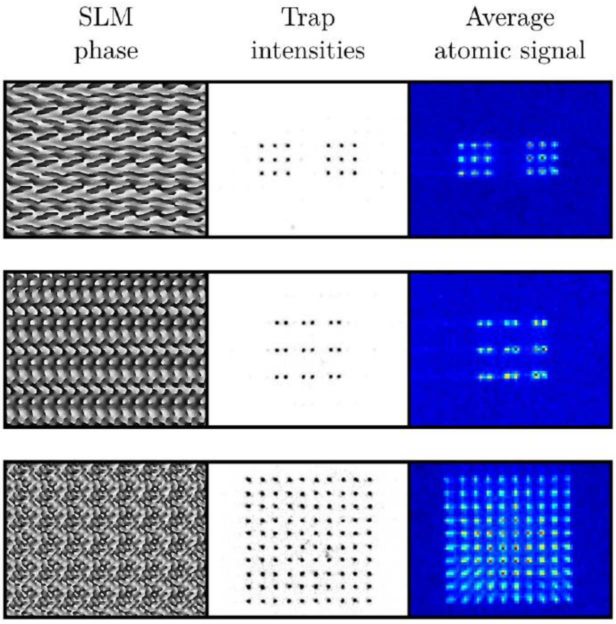


FIG.2: For each trap array, the calculated SLM phase (left), the trap array imaged after the vacuum chamber by a CCD camera (middle) and the average of 1000 images of the fluorescence at 780 nm of trapped single atoms (right) are shown.

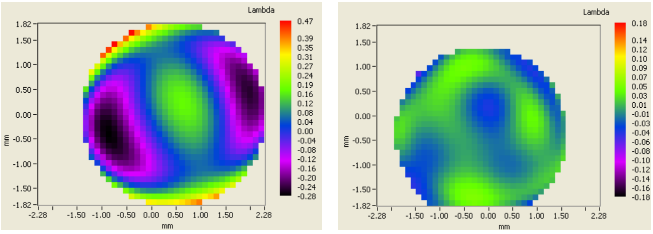
However, the optical quality of the microtraps is not optimal due to optical aberrations present in the setup. For instance, one can see on Fig 5 (a) that for a 4x4 square array, the individual spots have a low Strehl ratio, below 0.5. This impedes efficient trapping of single atoms.

To overcome this issue, one can use HASO4 First for trap array diagnostics. Indeed, HASO4 First provides a direct measurement of the wavefront distorted by the optical setup. Thanks to this measurement, one can apply a phase correction on the SLM, in order to increase the optical quality of the microtraps.

Improvement of the trap arrays thanks to HASO4 First

The HASO4 First is a wavefront sensor based on patented Shack-Hartmann technology, which performs absolute achromatic measurement of both phase and intensity independently, simultaneously and in real-time. The accuracy of the measurement is λ/150.

Figure 3 (a) shows the wavefront measured after the vacuum chamber, for a flat phase applied to the SLM. One sees that the wavefront aberrations are 0.155 λ RMS. The SLM present in the setup can be used, in addition to the phase imprinting for the generation of trap arrays, to compensate for the aberrations measured with the HASO4 First. Figure 3 (b) shows the residual wavefront aberrations after correction, giving 0.019 λ RMS.



(a) (b)

FIG.3: (a) The wavefront is distorted after the vacuum chamber. (b) The wavefront obtained after the vacuum chamber with a correction applied to the SLM.

Moreover, a comparison of the PSF before and after the correction demonstrates a dramatic increase of the Strehl ratio, from 0.43 to 0.98, as one can see in figure 4. Figure 5 illustrates the results of the experiment.

(a) (b)

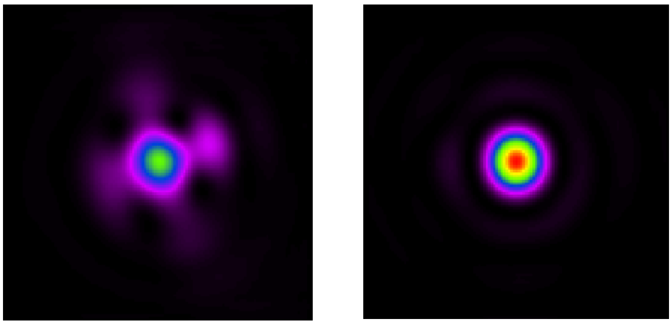


FIG.4: (a) The PSF of the optical setup before the correction. (b) The PSF of the optical setup with a correction applied to the SLM. Both are obtained with HASO4 First.

This improvement can also be observed for arrays of several traps, as can be seen on Figure 5 (b) and (c) obtained by imaging the trap plane onto a diagnostic CCD camera:

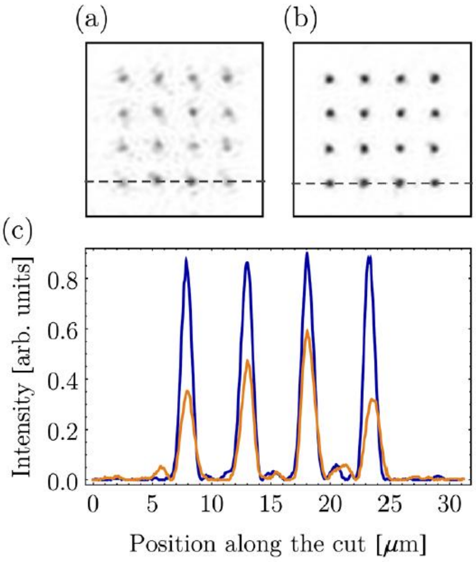


FIG.5: A CCD image of 4x4 microtraps with (b) or without (a) the correction from the HASO4 First. (c): Intensity profiles along the dashed lines in (a) (orange curve) and (b) (blue curve).

These improvements need to be confirmed at the level of the atoms by measuring the essential characteristics of the trap, i.e. its depth and its frequency. Figure 6 shows the results of such a measurement, giving an improvement of 50 % in the trap depth and 30% for the trapping frequency.

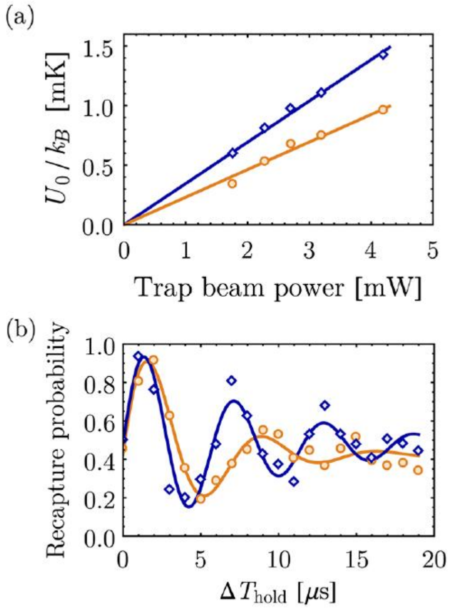


FIG.6: Measurement of the trap characteristics using single atoms. (a) Trap depth versus trap power, with (blue curve) and without (orange curve) the HASO. (b) Recapture probability of an atom versus the hold time ΔT_{hold} with (blue curve) and without (orange curve) the HASO4 First.

Conclusion

HASO4 First is an off-the-shelf wavefront sensor able to provide a simple, direct measurement of the wavefront quality, enabling researchers to greatly improve the quality of the intensity distribution of the light used for atom trapping experiments.

Acknowledgements

We would like to thank Thierry Lahaye and Henning Labuhn from the Laboratoire Charles Fabry of the Institut d'Optique Graduate School (Palaiseau, France) for allowing us to present the results of their experiments.

Literature

F. Nogrette, H. Labuhn, S. Ravets, D. Barredo, L. Béguin, A. Vernier, T. Lahaye and A. Browaeys, Single-Atom Trapping in Holographic 2D Arrays of Microtraps with Arbitrary Geometries, *Physical Review X* **4**, 021034 (2014).

(The full text is freely available online, at http://journals.aps.org/prx/abstract/10.1103/PhysRevX.4.021034)