BNS Spatial light Modulator: XY Phase Series, P256 – λ (1064nm)

Application Note

Generating light patterns for dynamic manipulation of ultracold atoms

G Smirne, GD Bruce, L Torralbo-Campo, D Cassettari

Scottish Universities Physics Alliance, School of Physics and Astronomy
University of St Andrews
North Haugh, St Andrews, Fife, Scotland (UK)
Email: gs71@st-andrews.ac.uk

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Introduction

Our research focuses on optical trapping of ultra cold atoms. We aim to trap laser cooled neutral atoms in dynamically controlled optical potentials. This can be achieved using different techniques, such as acousto-optic deflectors (AODs)[i] or spatial light modulators (SLMs)[ii]. The main advantage of the latter is fast re-configurability, allowing dynamic variation of non-periodical light patterns in real time.

For using these light patterns to trap and manipulate ultra cold atoms, it is essential that the variation of the pattern must be fast compared to the lifetime of the ultra cold atom cloud; this variation must also be sufficiently smooth so that any intensity flicker between frames does not appreciably heat the atoms.

The Boulder Nonlinear Systems (BNS) XY Phase Series P256 is a phase modulator based on liquid crystal technology, which works as a phase diffraction grating and is used in reflection. The SLM is an array of 256x256 liquid crystal pixels, each of which can shift the phase of incident light by an arbitrary value between 0 and 2π in discrete steps of $2\pi/256$. By imprinting a pattern of phase modulation on the beam using the SLM, a light intensity distribution corresponding to the Fourier transform of this pattern is generated in the focal plane of the optical system.

We have tested this phase modulator by generating a number of different patterns that may be of interest to our research plans and by measuring the dynamic performance of our light patterns in terms of intensity stability, inter-frame flicker, and ease of generation of our light pattern sequences.

Apparatus

Our light source is a free-running laser diode emitting at λ=1.06μm. The beam is first expanded to cover the full array of the SLM (6.14x6.14mm) and directed onto the SLM with a narrow incidence angle (~6.5 degrees). The reflected beam is then focussed using a 200mm focal length lens. On the focal plane, the zero order of the diffraction pattern is blocked and the first diffracted order is magnified by a factor of four and imaged onto a CCD camera (Thorlabs DCU224M).

Since the intensity recorded on the camera is integrated over the exposure time of each frame, we can alternatively send the beam onto a fast photodiode which gives us the intensity variation on much faster time scales.

Static Pattern Generation

We have identified a number of intensity distributions as interesting for cold atom experiments, such as a single focussed beam or a variable number of light spots distributed around a circumference, i.e. a ring optical lattice or continuous ring. The introduction of disorder to a periodic potential is also interesting for this field.

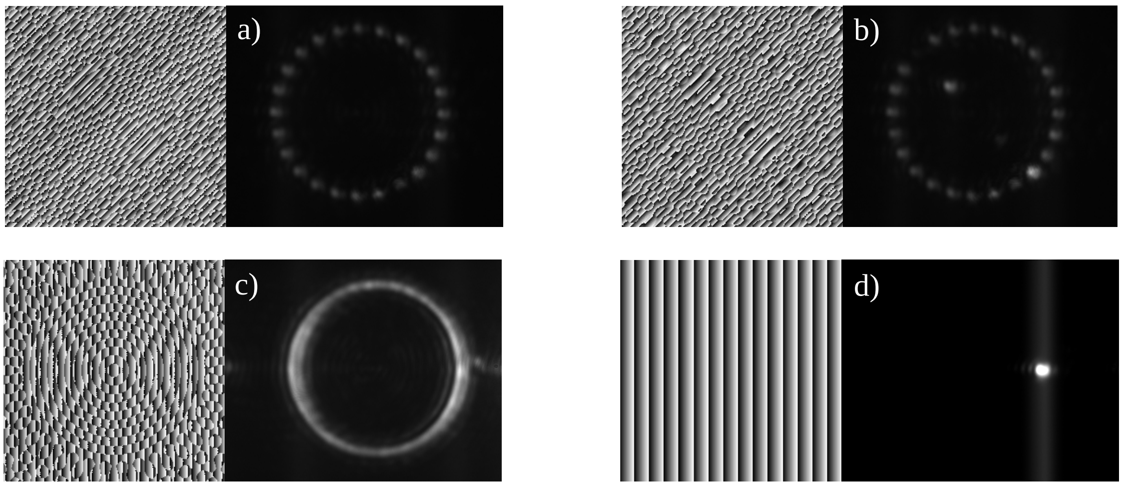

Figure 1 *– Example filters and light intensity distributions: a) uniform 24-site ring lattice. b) disordered 24-site ring lattice. c) time-averaged continuous ring trap generated by 1 kHz rotation of a 36-site ring lattice. d) single diffracted spot, used for the investigations described in the text.*

To generate the phase patterns, or “filters”, we use home-made software that produces 256x256x256 bitmap images of the desired phase patterns. These can be directly loaded onto the SLM using the software and controller provided by BNS. Figure 1 shows examples of filters that we upload onto the SLM and the corresponding light patterns as recorded by our CCD camera.

In order to test the suitability of these traps for ultra cold atoms experiments, we measure the fluctuations in the power and position of a stationary single spot. This is the first diffracted order generated by the phase grating and has a $1/e^2$ waist of w = 45 μm (180 μm on the CCD plane due to the factor of four magnification). As shown in Figure 2, the position is stable within $\pm$ 2 CCD pixels (1 pixel = 4.65 μm). We find a frame-to-frame intensity fluctuation of $\pm$ 0.5% by integrating on a $2w$ x $2w$ square centred at the spot position.

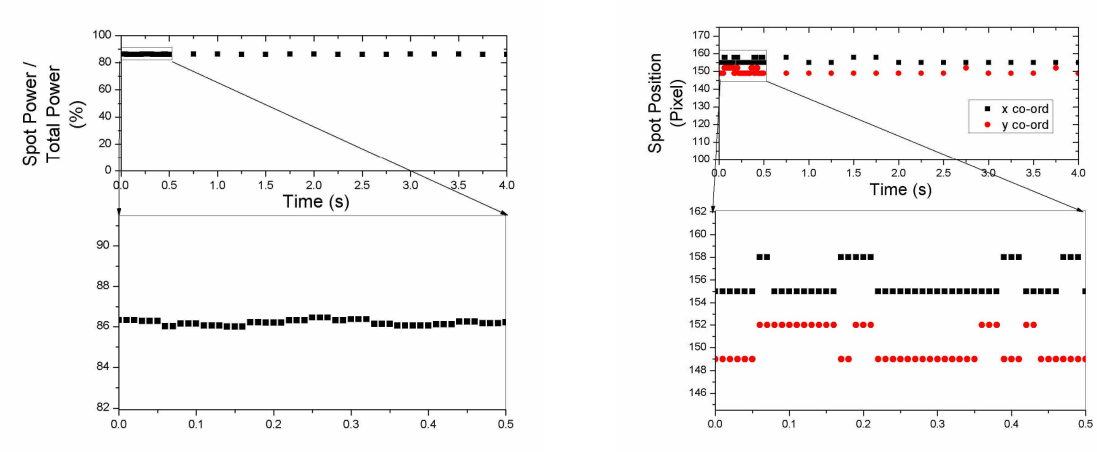

Figure 2 *– Time dependence of power and position for a stationary spot.*

The intensity stability of the input beam was measured to be better than 0.6%. The trapping frequency ω of an atom in an optical trap is related to the optical power P by $\omega \propto \sqrt{P}$, thus we have a trapping frequency fluctuation of $\pm$ 0.5% which we believe is acceptable.

Dynamic Optical Landscapes

In order to test the dynamic performance of the SLM we have used the single spot above. We then generated a sequence of filters with varying spacing between the lines on the grating, producing a uniform motion of the light spot in the x-direction. The sequence we used moves the spot about $20w$ in one hundred equal steps. We again measured both the position of the centre of the spot (to check the pointing stability) and the intensity of the spot as a function of time (see Figure 3)

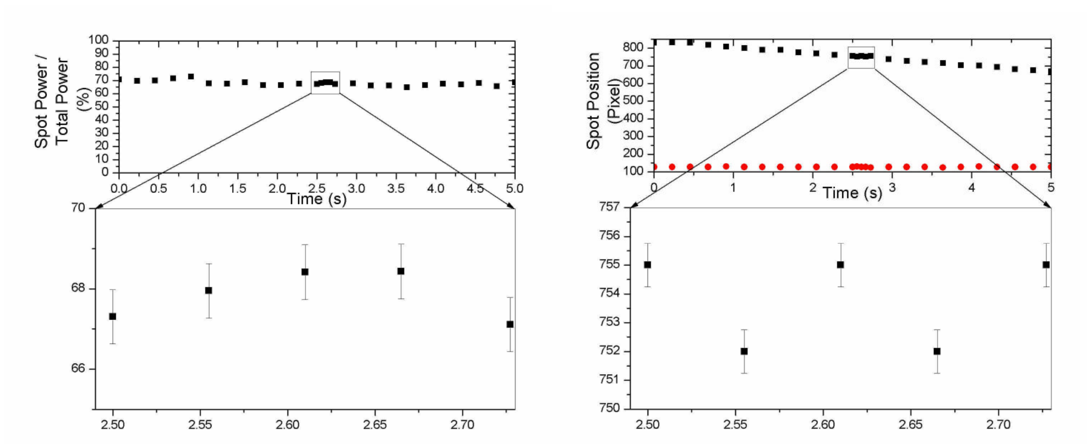

Figure 3 *- Time dependence of power and position for a moving spot. Each data point in the lower plots represents a new filter in the sequence.*

We also repeated this last measurement using the fast photodiode. Due to the small surface of the photodiode and the magnification, we could only afford movements of about 2*w* and therefore used three different sequences in which the spot was either jumping between the extremes of this interval, moving in ten steps of 0.2*w* or in 100 steps of 0.02*w*. For a given frame rate we monitored on the oscilloscope the signal as a function of time. For the 2*w* jump (cycled at 1 Hz) we measured a glitch in the signal at the time of going from one position to another of about 17.5% of the total DC value. When using the other sequences no appreciable glitch was detected. Therefore dynamic traps for ultracold atoms are possible, provided that the pattern evolves smoothly.

Conclusions

From our measurements we believe that static light patterns generated by this BNS SLM are suitable traps for ultra cold atoms. Generating the required filters for the SLM is straightforward, and the dynamic control of the corresponding light patterns is possible by applying an appropriate sequence of filters to the SLM. These light patterns remain suitable for manipulation of trapped atoms if the applied step size is small. Thus the SLM gives excellent flexibility in generating new, non-trivial and/or dynamical optical potentials for experiments with ultra cold atoms.

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[i] K. Henderson, *et al*, New J. Phys. **11** 043030 (2009)

[ii] V. Boyer, *et al*, Phys. Rev. A **73**, 031402(R) (2006)