**Responses to reviewer’s comments**

Jove manuscript: JoVE59158

Title: Shaping the amplitude and phase of laser beams by using a phase-only spatial light modulator.

**Comments of reviewer #1:**

*Manuscript Summary:*

*The manuscript presents a method to control the spatial amplitude and phase of a laser beam using a phase-only spatial light modulator. The method for generating such pattern relies on common-path interference resulting from a single phase pattern and the manuscript describes the technique clearly and concisely.*

*Major Concerns:*

*I have no major concerns, the work is technically correct and well presented.*

*Minor Concerns:*

*The main concern that I would like to see addressed is how this technique compares to the alternatives. In particular it has been typical to achieve amplitude and phase modulation using digital holograms, a selection of methods for producing these can be found in [Opt. Express 24, 6249-6264 (2016).]. This paper is very clear in how I can realise this technique, but as an SLM user, I would like also to know the advantages and disadvantages that this method has over digital holograms. You might talk about the efficiency of your system, which might be greater than the typical 85% found for digital holograms, though this is not clear as you use a pillicle to couple your beam in. In any case, I would like to see a discussion of the advantages and disadvantages of this method. A smaller note, is that you do not mention how to account for the input beam amplitude, if you have for instance a Gaussian beam shape hitting the SLM, then your phase pattern should change to take this into account to achieve the best possible output beam, have you considered how to account for this?*

Respond to reviewer **#**1:

We would like to answer minor concerns of reviewer #1 by introducing the following sentences at the introduction section.

In this context, some well-established methods to produce phase and amplitude modulation rely on the use of digital holograms6. A common point in all these methods is the necessity of generating a spatial offset to separate the desired output beam from the zeroth-order coming from the reflection of light at the SLM display. So, these methods are basically off-axis (they usually apply for the first diffraction order of the grating), employing phase grating not only to encode the phase, but also to introduce necessary amplitude modulation. In particular, amplitude modulation is performed by spatially lowering the grating height, which clearly degrades the diffraction efficiency. The hologram reconstruction process mostly gets an approximate, but not exact, reconstruction of the amplitude and phase of the desired complex field. Discrepancies between theory and experiment seem to appear from an inaccurate encoding of the amplitude information as well as other experimental issues happening during the spatial filtering of the first diffraction order or due to SLM pixelation effects. In addition, the intensity profile of the input beam can introduce restrictions on the output power.

In contrast, with the introduced method7 all light management is carried out on-axis, which is very convenient from an experimental point of view. Additionally, it takes advantage of considering, in the paraxial approximation, the complex field associated with laser beams as a sum of two uniform waves. The amplitude information is synthetized by the interference of these uniform waves. In practice, such interference is carried out by spatial filtering of light frequencies at the Fourier plane of a given imaging system. Previously, the phase patterns associated with the uniform waves are spatially multiplexed and encoded into a phase-only SLM (placed at the entrance plane of this imaging system). Hence, the whole optical setup can be regarded as a common-path interferometer (very robust against mechanical vibrations, temperature changes, or optical misalignments). Please, note that the above-mentioned interference process can be alternatively accomplished by using other optical layouts. For instance, with a couple of phase-only SLMs properly placed within a typical two-arm interferometer, or by time sequentially encoding the two phase patterns into the SLM (previous introduction of a reference mirror in the optical setup). In both cases there is not necessity of spatial filtering, and consequently no loss of spatial resolution, at expense of increasing the complexity of the optical system, as well as the alignment process. Here, it should be also emphasized that by using this encoding method, the full spectrum of the desired complex field can be **exactly retrieved** at the Fourier plane, after filtering all diffraction orders but the zero one.

On the other hand, the efficiency of the method depends on several factors, including the manufacturer’s specifications of the SLM (for instance: fill factor, reflectivity, or diffraction efficiency), the size of the encoded pattern, and the way at which the light impinges onto the SLM (reflection with a small hitting angle, or normal incidence by using a beam splitter). At this point, under proper experimental conditions, the measured total light efficiency can be more than 30%. Please, take into account that the total light efficiency just due to the use of the SLM can be less than 50%. The lack of random or diffuser elements within the optical setup allows retrieving amplitude and phase patterns without coherent noise (speckle). Other significant aspects to point out are the utilization of a direct codification algorithm rather than iterative procedures, or its ability to perform arbitrary and independent amplitude and phase modulation at the frequency refresh time of the SLM (up to hundreds of Hz according to the current technology).

In principle, the method7 is intended to be used with input plane waves, but it is not limited to that. For instance, if a Gaussian beam is hitting the SLM, it is possible to modify its irradiance shape at the output of the system by encoding a suited amplitude pattern into the SLM. However, as the intensity of the output beam cannot exceed that of the input beam at any transversal position (x, y), the shaping of the amplitude is performed by intensity losses originated by a partially destructive interference process.

**ADDED REFERENCE:**

6. W. Clark, T., F. Offer, R., Franke-Arnold, S., S. Arnold, A., and Radwell, N. Comparison of beam generation techniques using a phase only spatial light modulator. Optics Express. **24** (6), 6249-6264 (2016).

7. Mendoza-Yero, O., Mínguez-Vega, G., and Lancis, J. Encoding complex fields by using a phase-only optical element. Optics Letters. **39** (7), 1740-1743 (2014).

**Comments of reviewer #2:**

*Manuscript Summary:*

*The manuscript describes how to encode and decode fully complex image data from a phase only SLM onto a video camera. The complex data is detected on the camera and decoded using the well known phase shift interferometry method. The complex data is encoded on two spatially interleaved phase only modulations. By blurring the images together using a low enough bandwidth spatial filter, the two phase patterns interfere to produce the desired amplitude and phase on the camera. There is some nice improvement, specifically cancelling fringes from glass surfaces, by using a quasimonochromatic source. The pulsed light source could be useful for avoiding vibration but it looks light even an LED could be used when vibration effects are controlled.*

*Major Concerns:*

*The method is sound, but is it very useful. Since one has a phase shift interferometer (with the inclusion of a reference mirror), the two images could be sensed time sequentially eliminating the spatial filter and still reconstructed digitally. In this case with no loss of resolution. One could even directly record the amplitude and phase on just the phase, time sequentially and decode them with the interferometer. From an educational or tutorial standpoint, the system is very useful. Perhaps these various modifications, pros and cons, could be briefly discussed.*

*Minor Concerns:*

*The polarization phase shifter mentioned should be included in the schematic. A little more math should be shown on how the Amplitude and Phase are derived from the two phase functions. Also the conclusions section that describes applications of the system is not very well explained. It would be desirable to provide clearer explanation of the benefits of representing complex fields in this way. Is there an application where a designed complex field at the camera plane provides some value?*

Respond to reviewer **#**2:

Major concerns:

We would like to thanks reviewer #2 for the nice comments addressed to improve the encoding method. From a practical point of view, the use of a single-arm interferometer (very robust against unwanted effects, such as mechanical vibrations, temperature changes, or hard alignment processes at micrometric scale) is the main reason for carrying out the coherent mix of uniform waves by spatial filtering of light frequencies at the Fourier plane. Of course, as you mentioned, the use of a spatial filter causes certain loss of spatial resolution due to the convolution operation. Yes, it is possible to avoid this loss of spatial resolution by time sequentially encoding the two phase functions (corresponding to the uniform waves) into the SLM, but above-mentioned problems related to the utilization of two arm interferometers (because of the inclusion of a reference mirror) should appear.

In order to discuss a little bit this important issue, we have included in the introduction section the following sentences:

… The amplitude information is synthetized by the interference of these uniform waves. In practice, such interference is carried out by spatial filtering of light frequencies at the Fourier plane of a given imaging system. Previously, the phase patterns associated with the uniform waves are spatially multiplexed and encoded into a phase-only SLM (placed at the entrance plane of this imaging system). Hence, the whole optical setup can be regarded as a common-path interferometer (very robust against mechanical vibrations, temperature changes, optical misalignments). Please, note that the above-mentioned interference process can be alternatively accomplished by using other optical layouts. For instance, with a couple of phase-only SLMs properly placed within a typical two-arm interferometer, or by time sequentially encoding the two phase patterns into the SLM (previous introduction of a reference mirror in the optical setup). In both cases there is not necessity of spatial filtering, and consequently no loss of spatial resolution at expense of increasing the complexity of the optical system, as well as the alignment process…

Minor concerns:

In accordance with the reviewer suggestions:

1. Two polarizers are now represented in **Figure 2**. However, please note that in the optical system used for shaping the amplitude and phase of laser beams, polarizers have nothing to do. The function of them is just the measurement of the already generated complex field through the phase shifting technique. That is why, in the first version of **Figure 2**, polarizers had not been placed.
2. We add and/or modify, in the introduction section, the following sentences (together with supported equations) to further clarify how the amplitude and phase are derived from the two phase functions:

Note that, the interference of uniform waves cannot happen if we do not mix the information contained in the phase element . In the present method, this is carried out by using a spatial filter able to block all diffraction orders but the zero one. In this way, after the filtering process at the Fourier plane, the spectrum  of the encoded phase function is related to the spectrum of the complex field  by the expression

 (6)

In Eq. (6),  denote coordinates in the frequency domain,  holds for the spatial filter, whereas the Fourier transform of a given function  is represented in the form . From Eq. (6), it follows that, at the output plane of the imaging system, the retrieved complex field , (without considering constant factors), is given by the convolution of the magnified and spatially reversed complex field  with the Fourier transform of the filter mask. That is:

 (7)

In Eq.(7), the convolution operation is denoted by the symbol , and the term  represents the magnification of the imaging system. Hence, the amplitude and phase of  is fully retrieved at the output plane, except for some loss of spatial resolution due to the convolution operation.

1. We improve, in the discussion section, the description of potential/future applications of the proposed method. Now, it appears like this

…Laser beams are intrinsically complex fields, so in most potential applications one should be able to modify their amplitude and phase, simultaneously. The present method allows to do that by means of a single phase element (implemented or not into a phase-only SLM). We believe that, in a near future, this method could be employed, for instance: in the illumination path of microscopes for simultaneous linear and non-linear excitation of different zones of biological samples, or in parallel micro-processing of materials. In both applications the role of amplitude modulation is apparent, meanwhile phase modulation can be utilized, at the same time, for compensation of optical aberrations at the sample/processing plane.

Finally, we would like to thanks both reviewers for their fruitful comments on the present manuscript. We really think that, the present version of the manuscript has been benefited from their suggestions.