Spatial Interference of light: a method to generate structured environments to study quantum dynamics

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We report the observation of interference in position and transverse momentum variables between two parallel-propagating gaussian beams separated by an arbitrary distance [1]. This resembles the Alford and Gold effect that has been reported for the time-frequency degree of freedom [2], and constitutes a method for spatial intensity shaping of light beams. We observe this interference by using a tunable beam displacer [1], which plays the role of a Michelson interferometer for the transverse spatial variables. We propose this method for engineering environments in the study of dynamics of open quantum systems, in particular, generation of Markovian and non-Markovian dynamics [3].

Motivation

We introduce a Tunable Beam Displacer to change arbitrarily the transverse distance between two parallel-propagating beams.

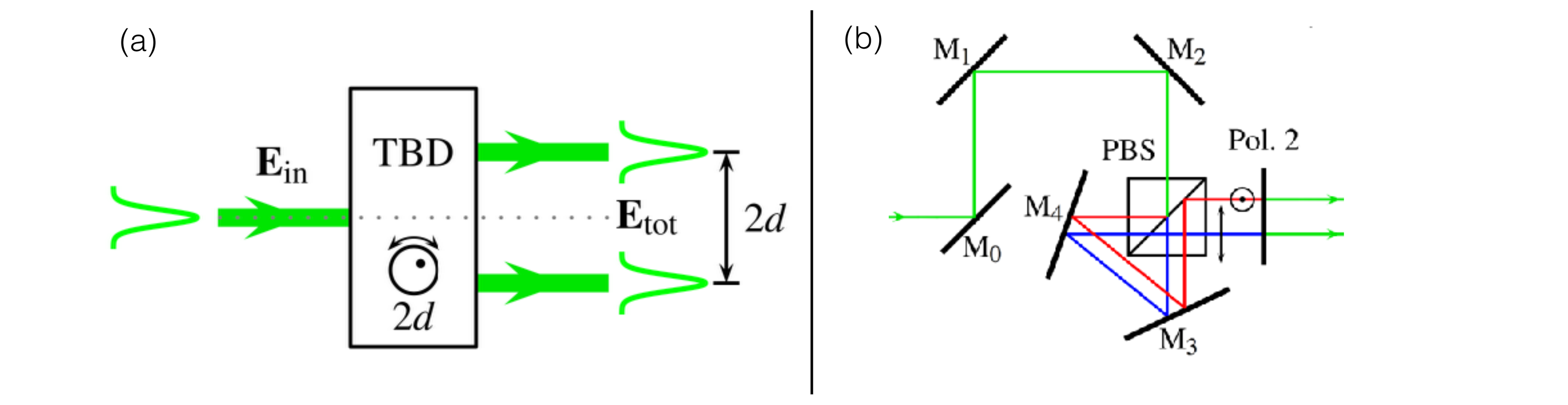

Figure 1: (a) Tunable Beam Displacer Sketch (TBD), with a controllable separation of $2d$. (b) Experimental setup of a physical realization of a TBD [1].

Experimental setup

The experimental setup in Fig. 2 was implemented using:

- a CW laser that produces a Gaussian beam with $w_0 = 0.87$mm.
- Tunable Beam Displacer
- A 50-50 beam splitter, to measure position and momentum distributions simultaneously.
- A power meter, for measuring the position interference.
- A $2f$-system, with $f = 75$cm, to generate the transverse momentum distribution.
- A CCD camera, to register the positions of the beam in the momentum variables.

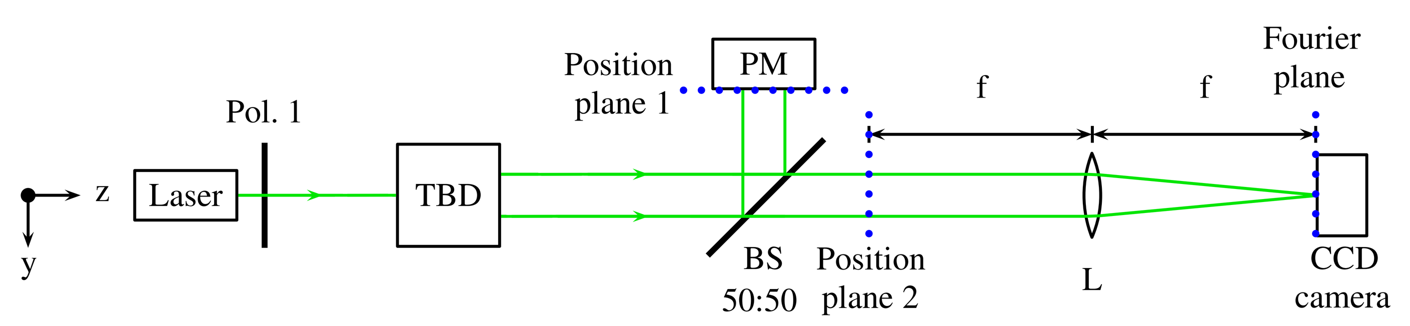

Figure 2: Experimental setup with measurement and tunability of separation.

Interference in Position

Following the setup of Fig. 2, we set an Incoming gaussian beam:

$$E_{in}(y) = E_0 \exp\left(-y^2/w_0^2\right) \exp\left(i q_0 y\right), \quad (1)$$

where

- w_0 is the beam waist.
- q_0 will be determined from our measurements.

The output electric field is

$$E_{out}(y, d) \propto E_{in}(y - d) + e^{i\phi} E_{in}(y + d). \quad (2)$$

After the TBD, the intensity will be

$$I_{out}(d) = \frac{|E_0|^2}{2}\left[1 + \exp\left(-\frac{2d^2}{w_0^2}\right)\cos\left(2q_0 d + \phi\right)\right]. \quad (3)$$

Eq. (3) shows interference in position modulated by d.

Interference in Transverse momentum

The interference in the conjugate variable is obtained by taking the Fourier transform of $E_{out}(y, d)$. The intensity $S_{out}(q, d)$ in the Fourier plane yields:

$$S_{out}(q, d) \propto \exp\left[-\frac{w_0^2 (q - q_0)^2}{2}\right][1 + \cos(2qd + \phi)], \quad (4)$$

.

We see:

- There is a modulation of the intensity in the Fourier plane, which is given by the cosine term.
- If $d = 0$ and $\phi = \pi$, the spectral intensity will vanish.
- As d becomes larger than w_0, there will appear a set of oscillations within the Gaussian envelope.

Experimental results

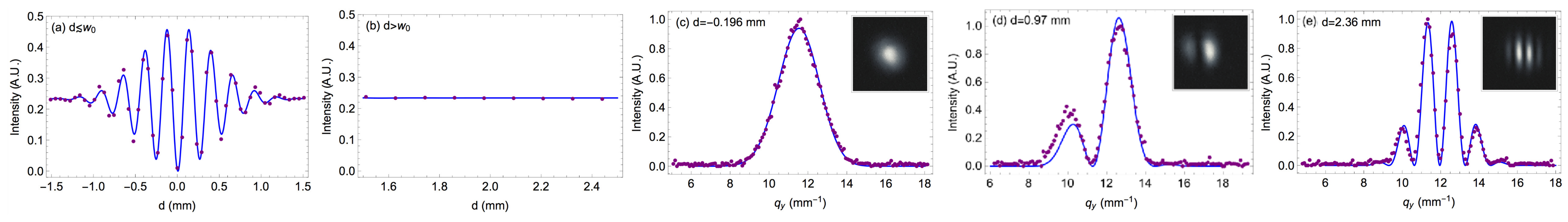

Figure 3: Experimental results (circles) of two-beam interference in position (a,b) and momentum (c,d,e) variables. Insets in (c), (d), (e) correspond to the images recorded in the CCD camera.

- Interferences are seen in Fig. 3(a), but not in (b), when the two beams not overlap in position.
- In the Fourier plane, the intensity modulation appears when $d > w_0$, as can be seen in Fig. 3(e), but not in Fig. 3(c), where $d < w_0$. These results show a modulation in the transverse momentum distribution.
- Environments like in Fig. 3 (d),(e) are used in Poster **QT6A.32** to explore the transition between Markovian and non−Markovian quantum dynamics.

Conclusions

- We report the interference of light in its spatial degree of freedom for an arbitrary, tunable separation of two beams.
- We introduce a method for the spatial intensity shaping of laser beams, which permit environment engineering for Open Quantum Systems.

References

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