# Control of Young's fringes visibility by stimulated down-conversion

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The stimulated parametric-down-conversion luminescence is used as a light source with controlled spatial coherence. Performing the double-slit Young experiment, we show that the interference-pattern visibilities can be controlled by varying the inducing laser intensity. The results indicate that down-conversion light statistics change during this variation. A simple theoretical description is also shown.

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## I. INTRODUCTION

In parametric-down-conversion luminescence, one photon incident in a nonlinear crystal is spontaneously converted in two simultaneous photons [1]. In this process energy and momentum of the photons are conserved. It was recently shown that the down-converted light has similar coherence area properties as the ones of an incoherent light source [2]. Interference patterns were produced in Young's double-slit experiments with visibilities controlled by the distance between source and slits, as in a thermal-like source, despite the high degree of directionality ($\sim 1$ mrad ) of the downconverted light around a given wavelength.

Moreover, it was also shown that interference patterns can be detected performing *coincidence* measurements between a conjugated *signal* and *idler* pair. The degree of visibility obtained with a double slit placed at the *signal* beam can be nonlocally controlled through the *idler* beam [3].

In this work it is shown that the degree of visibility of the interference fringes produced by a *signal* beam transmitted through a double slit, can be also controlled by aligning an auxiliary laser with the *idler* beam, with the same wavelength and varying its power. In this case, the degree of coherence of the source is varied directly by the inducing laser intensity without performing any measurements on the *idler* beam.

## II. EXPERIMENTAL SETUP

An argon-ion laser beam of wavelength 3511 Å ($\sim 100\,\mathrm{mW}$), is incident on a $LiIO_3$ crystal to produce parametric-down-conversion luminescence. A 3-mW He-Ne laser, aligned with the 6328-Å down-converted beam, stimulates the 7887 Å (*signal*)–6328 Å (*idler*) conjugate pair emission. See Fig. 1.

The double slit is positioned at 8 cm from the crystal in the path of the 7887-Å *signal* beam. The interference-pattern distribution is measured with a photomultiplier (PMT), 35 cm far from the slits, mounted on a $z$-axis translation stage. The scans are performed with a 300-$\mu$m slit at the PMT entrance. An interference filter placed at the PMT entrance, with 100 Å bandwidth and centered on 7887 Å, assures that the detected light is almost monochromatic. The PMT pulses are sent to photon counters and to a computer, where data is processed. The inducing laser intensity is controlled by neutral filters placed before the crystal.

## III. THEORY

The intensity distribution of the interference pattern for a typical Young's double-slit experiment is given by [4]

$$I(Q) = I_1(Q) + I_2(Q) + \sqrt{I_1(Q) I_2(Q)}\ |\mu_{12}| \times\cos[\alpha_{12}(\tau) - \delta], \quad (1)$$

where $I_1(Q)$ and $I_2(Q)$ are the single-slit diffraction pat-

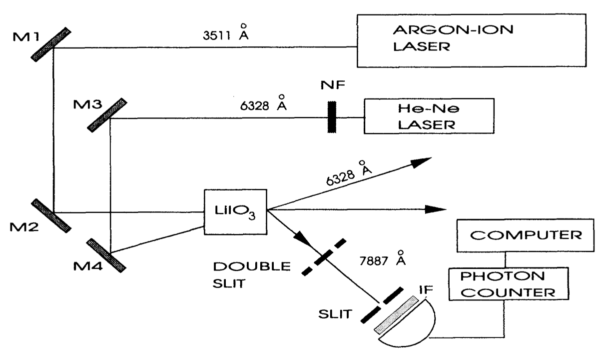


FIG. 1. Schematic diagram of the experimental setup for Young's double-slit experiment. $M_1$, $M_2$, $M_3$, $M_4$ are mirrors, IF is an interference filter, and NF is a neutral filter.

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terns for each slit, $\delta$ is the phase path difference between each slit and the observation point $Q$, $\mu_{12}$ is the normalized mutual intensity, and $\alpha_{12}$ is its phase.

The modulus of the normalized mutual intensity gives us the visibility of the interference fringes, and is defined as

$$\mu_{12} = \frac{\langle \mathbf{E}^*(\mathbf{r}_1) \cdot \mathbf{E}(\mathbf{r}_2)\rangle}{\sqrt{\langle \mathbf{E}^*(\mathbf{r}_1) \cdot \mathbf{E}(\mathbf{r}_1)\rangle \langle \mathbf{E}^*(\mathbf{r}_2) \cdot \mathbf{E}(\mathbf{r}_2)\rangle}}, \tag{2}$$

where $\mathbf{E}$ is the electric field and $\mathbf{r}_1$,$\mathbf{r}_2$ specify the position of the slits.

The light produced in the stimulated down conversion is a superposition of a coherent and an incoherent field,

$$\mathbf{E}(\mathbf{r}) = \mathbf{E}_c(\mathbf{r}) + \mathbf{E}_i(\mathbf{r}). \tag{3}$$

With this sum of fields, the expression for the mutual intensity gives

$$\begin{aligned}\langle \mathbf{E}^*(\mathbf{r}_1) \cdot \mathbf{E}(\mathbf{r}_2)\rangle = & \langle \mathbf{E}_c^*(\mathbf{r}_1) \cdot \mathbf{E}_c(\mathbf{r}_2)\rangle \\ & + \langle \mathbf{E}_i^*(\mathbf{r}_1) \cdot \mathbf{E}_i(\mathbf{r}_2)\rangle \\ & + \langle \mathbf{E}_c^*(\mathbf{r}_1) \cdot \mathbf{E}_i(\mathbf{r}_2)\rangle \\ & + \langle \mathbf{E}_i^*(\mathbf{r}_1) \cdot \mathbf{E}_c(\mathbf{r}_2)\rangle. \end{aligned} \tag{4}$$

The correlation functions with $\mathbf{E}_c$ and $\mathbf{E}_i$, will sum up to zero because the incoherent field phase is random and the coherent field phase is not. Thus, only the terms with the same kind of fields will give a nonzero contribution. The expression for the normalized mutual intensity will be

$$\mu_{12} = \frac{\mu_i I_i + \mu_c I_c}{I_i + I_c}, \tag{5}$$

where $\mu_i = \langle \mathbf{E}_i^*(\mathbf{r}_1) \cdot \mathbf{E}_i(\mathbf{r}_2)\rangle / I_i$, is the normalized mutual intensity for the incoherent field, $\mu_c = \langle \mathbf{E}_c^*(\mathbf{r}_1) \cdot \mathbf{E}_c(\mathbf{r}_2)\rangle / I_c$ is the normalized mutual intensity for the coherent field, $I_i = \langle \mathbf{E}_i^*(\mathbf{r}_1) \cdot \mathbf{E}_i(\mathbf{r}_1)\rangle = \langle \mathbf{E}_i^*(\mathbf{r}_2) \cdot \mathbf{E}_i(\mathbf{r}_2)\rangle$ is the intensity of the incoherent field at the slits and $I_c = \langle \mathbf{E}_c^*(\mathbf{r}_1) \cdot \mathbf{E}_c(\mathbf{r}_1)\rangle = \langle \mathbf{E}_c^*(\mathbf{r}_2) \cdot \mathbf{E}_c(\mathbf{r}_2)\rangle$ is the analog for the coherent field. The intensitites at the two slits were considered equal because the distance beween them (90 $\mu$m) is much smaller than the distance between source and slits (8 cm).

Finally, we make use of the *average occupation number per mode* [5] that can be expressed in terms of the ratio of the coherent to incoherent intensities $\mathcal{N} = I_c/I_i$, to obtain a final form for the normalized mutual intensity

$$\mu_{12} = \frac{\mu_i + \mu_c \mathcal{N}}{\mathcal{N} + 1}. \tag{6}$$

## IV. RESULTS

The interference patterns shown in Fig. 2(a) and Fig. 2(b) were obtained by varying the inducing (He-Ne) laser intensity ($I_s$). The slits were placed at a distance from the light source such that the coherence area for the spontaneous emitted light is smaller than the distance between the slits [2]. Thus the visibility for $I_s = 0$, that corresponds to $\mathcal{N}$=0, is nearly zero. We see clearly that the increase of $I_s$ produces interference patterns with increasingly visibilities. In this way we can control the spatial coherence of the *signal* beam by varying the intensity of the laser beam aligned with the *idler* beam. The visibilities are obtained from the interference patterns by a fit to Eq. (1) and considering the finite size of the detector.

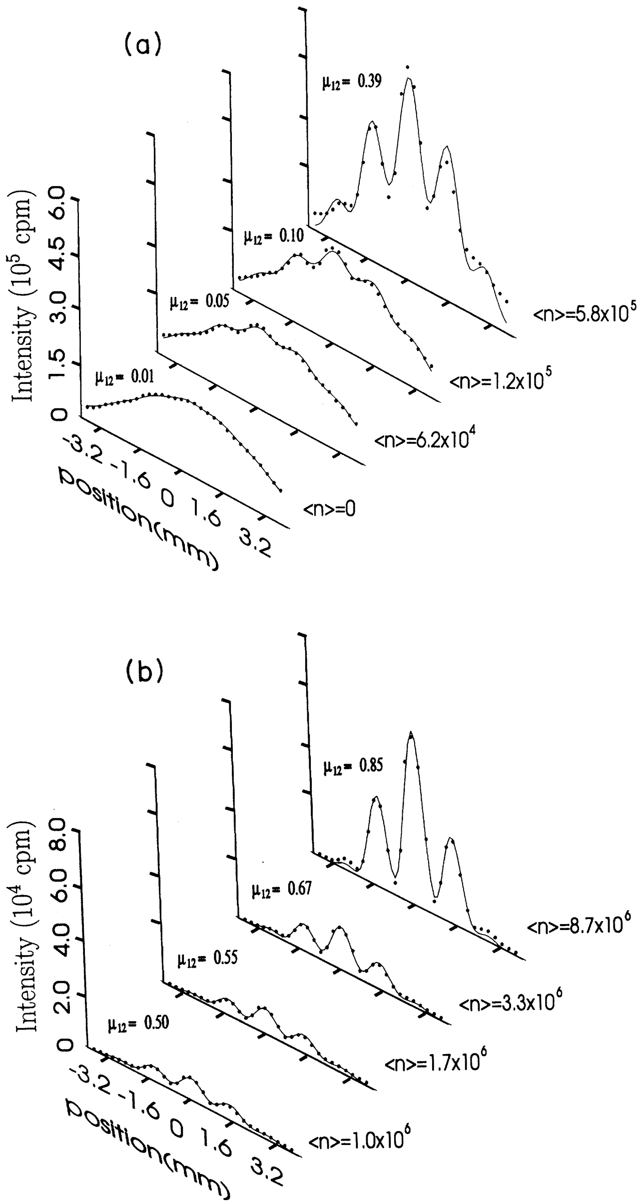


FIG. 2. Experimental points showing the intensity patterns as a function of the detector position (circles), and fittings (line). Errors bars are the same size as the circles.

To compare theory and measurements we should calculate the *average occupation number per mode* $\mathcal{N}$, that is given by [5]

$$\mathcal{N} = (2\pi)^2 |\phi(\omega_p, \omega_s, \omega_i; \mathbf{K}_p, \mathbf{K}_s, \mathbf{K}_i)|^2 |W|^2, \tag{7}$$

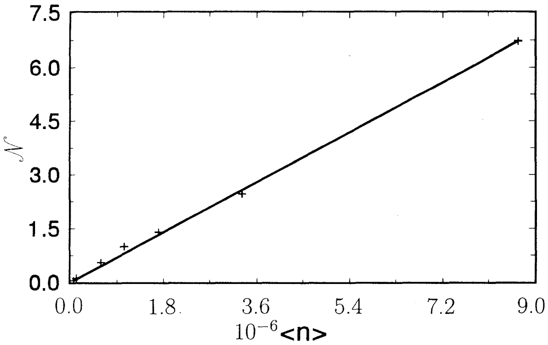


FIG. 3. Experimental occupation numbers $\mathcal{N}$ as a function of $\langle n \rangle$ the inducing laser mean photon number. A fit to Eq. (8) gives $\beta = (7.74 \pm 0.11) \times 10^{-7}$. Errors bars are the same size as the symbols.

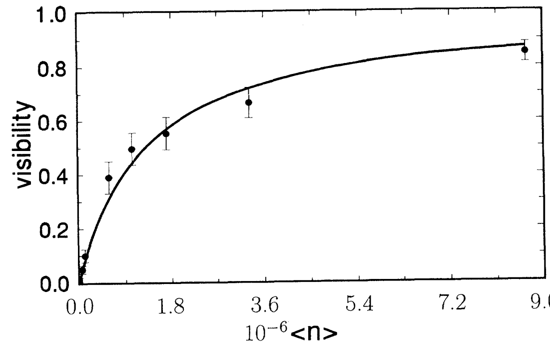


FIG. 4. Experimental results (circle) and theory (line) for the Young's fringes visibilities as a function of the mean photon number $\langle n \rangle$ of the inducing laser.

where $\phi(\omega_p, \omega_s, \omega_i; \mathbf{K}_p, \mathbf{K}_s, \mathbf{K}_i)$ is the spectral density function for the down conversion and $|W|^2$ is the photon rate of the inducing laser. The indexes $p$, $s$, and $i$ refer to pump, signal, and idler, respectively. This calculation does not take into account the coupling efficiency between laser and down-conversion field modes. However, the above equation shows us that we can use a function

$$\mathcal{N} = \beta \langle n \rangle, \tag{8}$$

to fit measured values of $\mathcal{N}$ as a function of the inducing laser mean photon number $\langle n \rangle$, which is proportional to $|W|^2$. $\langle n \rangle$ is the number of photons within one coherence volume and it was obtained by measuring the inducing laser power and its coherence time and multiplying the laser power in photons per unit of time by the coherence time. $\beta$ is the coupling parameter, obtained from the plot of $\mathcal{N}$ versus $\langle n \rangle$. This is shown in Fig. 3.

The measured visibilities are compared with the theory given by Eq. (6) in Fig. 4, showing a reasonable agreement. When the stimulated down conversion is produced, we obtain a light beam that is partially coherent in the spatial sense, because it is a superposition of coherent and incoherent light. Since the coherent to incoherent light intensity ratio in the signal beam is dependent on the inducing laser intensity, we can control the spatial coherence in the signal beam through the laser aligned with the idler beam. The degree of visibility of the patterns is a measure of the correlation function of the fields at the two slits and it shows us the degree of spatial coherence of the light source. The increase of the inducing laser intensity makes the light source increasingly coherent in the spatial sense, until it behaves approximately as a laser beam, spatially coherent.

The experimental data indicate a change in the down-conversion radiation field statistics from thermal-like to laserlike, as the transition from spontaneous to stimulated regime occurs.

## V. CONCLUSIONS

We performed the Young's double-slit experiment with light produced in the stimulated down conversion. We studied the degree of visibility of the interference patterns as a function of the *mean occupation number per mode* $\mathcal{N}$, or the inducing laser intensity $I_s$, and we demonstrated that the spatial coherence in the signal beam can be controlled by means of its conjugated pair.

## ACKNOWLEDGMENT

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