Second-Order Coherence Measurement of a Metallic Coaxial Nanolaser

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Abstract: The second-order coherence function is measured for a metallic coaxial nanolaser using a modified Hanbury Brown-Twiss technique. The results indicate that such nanoscale lasers can indeed generate coherent radiation.

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In recent years, there has been tremendous progress towards the development of metallic and metallo-dielectric nanoscale lasers [1]. These advances are largely motivated by their small footprint and their potential for high-speed operation, which make such nanolasers great candidates for on-chip sources in photonic integrated circuits. Through the use of metal as cladding, the volume of the laser cavity can be reduced to subwavelength dimensions without significantly compromising the mode confinement (Γ). If designed properly, the portion of the spontaneous emission coupled into the lasing mode (β) can even approach unity, in which case the laser is known to be "thresholdless" [2]. However, there has been a debate whether the emitted light from such structures is truly coherent. Generally, these viewpoints are motivated by the relatively broad linewidths of the emission, and the lack of readily distinguishable regions in the light-light (L-L) curve for lasers with high β. An unambiguous measure to determine the nature of a given emission is the second-order coherence function ($g^2(\tau) = \langle I(t)I(t+\tau)\rangle / \langle I(t)\rangle^2$), where intensity fluctuations of light are classified as chaotic ($g^2(0) > 1$), coherent ($g^2(0) = 1$), or sub-Poissonian ($g^2(0) < 1$) [3]. Clearly, this function can be used to characterize the emission properties of nanolasers, where below threshold the light is super-Poissonian, and near the classically defined threshold it transitions to coherent radiation.

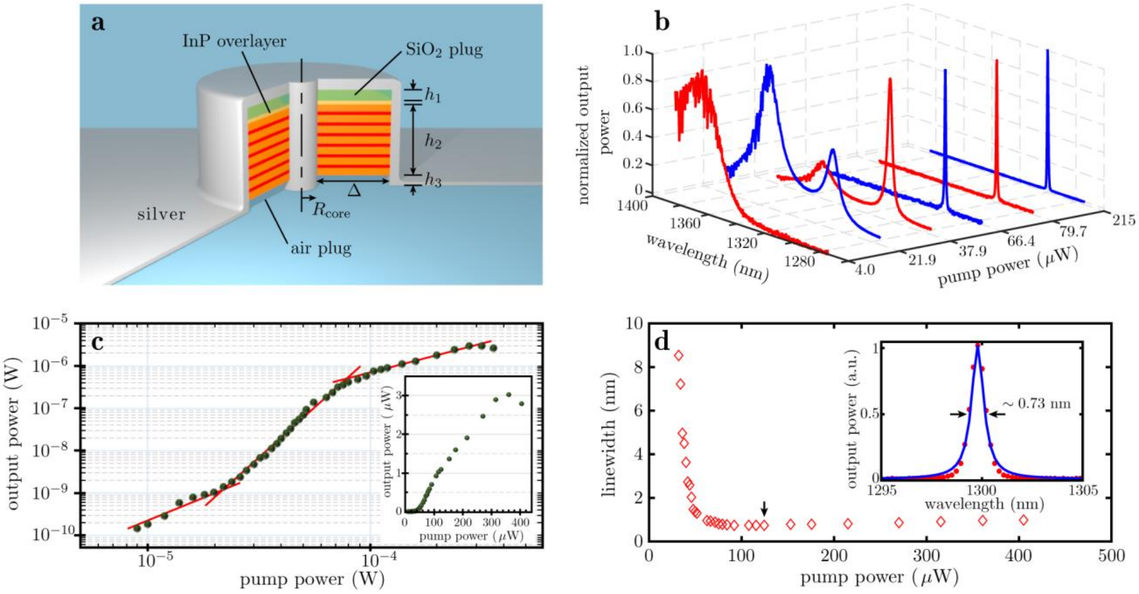

Fig 1. (a) Illustration of the metallic coaxial nanolaser under study. **(b)** The spectral evolution of the laser. **(c)** The light-light curve in a logarithmic scale and linear scale (inset). **(d)** The linewidth versus pump power. The Lorentzian fit used to estimate the linewidth (inset).

Figure 1a shows a schematic of the metallic coaxial nanolaser under study (R_{core}: 50 nm, Δ: 200 nm, h_2: 210 nm). The gain-medium consists of six vertically stacked InGaAsP quantum wells with an overall height of 200 nm covered by a 10 nm thick InP overlayer. The upper and lower ends of the ring are terminated by silicon dioxide (SiO$_2$) and air plugs (h_3: 30 nm and h_1: 20 nm, respectively).The coaxial laser are fabricated using the method outlined in [2], and is characterized in a micro-photoluminescence (μ-PL) set-up to collect the evolution of the spectrum (Fig. 1b), L-L curve (Fig. 1c), and the linewidth (Fig. 1d). The nanolaser is pumped optically using a continuous wave (CW) single-mode fiber laser operating at 1064 nm and is cooled to a temperature of 77 K – mainly to boost the laser efficiency in order to be able to perform the subsequent second-order coherence measurements. The three characteristic regions of the logarithmic L-L curve are emphasized with lines plotted in Fig. 1c – the PL near the lower left corner, the amplified spontaneous emission (ASE) in the center, and the lasing in the upper right. The upsurge in output power that is expected in the ASE region begins around 20 μW and softens at 70 μW, where the device appears to transition into lasing operation. Finally, the measured linewidth of the emitted light is plotted in Fig. 1d. The inset of Fig. 1d displays the Lorentzian fit used in determining the linewidth. For the above reported laser, the finite element simulations indicate that $\beta \approx 0.048$ and $\Gamma \approx 0.65$.

To investigate the nature of the radiation from nanolasers, a modified Hanbury Brown-Twiss (HBT) set-up is prepared. In order to measure the second-order coherence of broad linewidth sources, the emission must first be spectrally filtered such that its temporal coherence (τ_c) becomes larger than the timing resolution of the single-photon detectors and the time correlating single-photon counting module. To achieve this, a diffraction grating is used in conjunction with a Fabry-Perot filter to increase τ_c to $\sim$3.75 ns. A test of the set-up is then carried out with an ASE source (Amonics) centered at 1550 nm, where the $g^2(0)$ is found to be 1.864 ± 0.025. Figure 2a and b show the normalized spectrum of the ASE source (dashed: original, and solid, filtered) as well as its measured $g^2(\tau)$.

Next, the second-order coherence function is obtained for the above coaxial nanocavity – the results are shown in Fig. 2c-f. Far above threshold at a pump power of 215 μW (spectrum is given in Fig. 2c), the measured $g^2(0)$ is 1.009 ± 0.038 (Fig. 2d) – confirming that the coaxial structure under study is a laser. A similar measurement at a pump power of 66.4 μW (spectrum given in Fig. 2e), slightly below threshold, yields an increased $g^2(0)$ of 1.081 ± 0.033 (Fig. 2f). The observed behavior agrees well with the theoretical investigations suggesting a gradual change in the $g^2(0)$ as a device with a large β transitions to lasing operation. The results presented here unambiguously confirm that nanoscale metallic cavities can indeed generate coherent radiation.

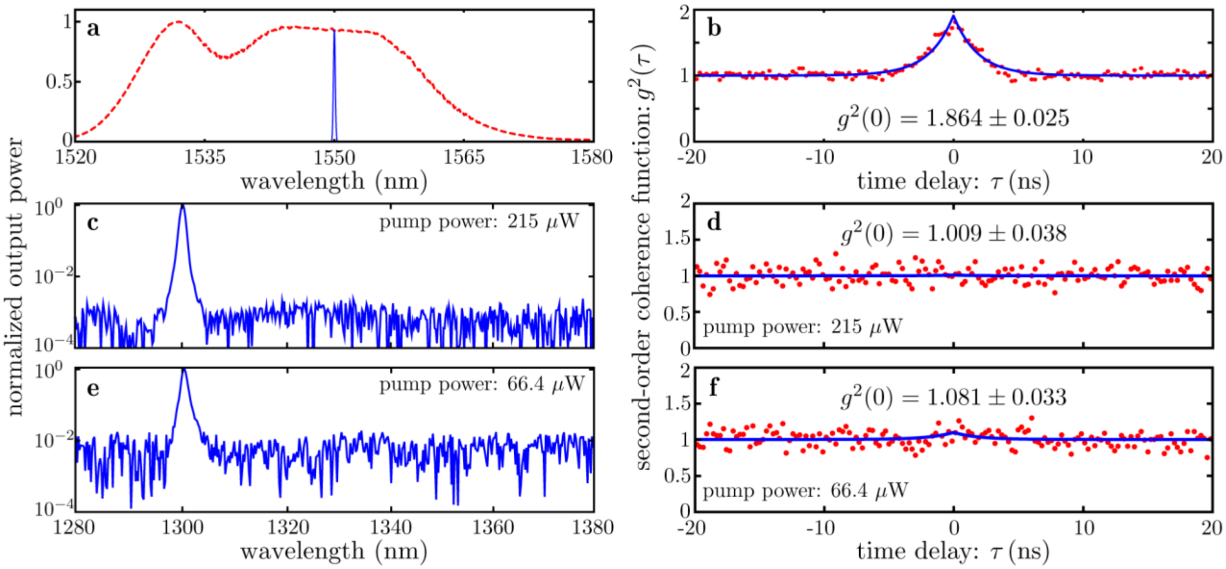

Fig. 2. (a) Output spectrum (dashed) and filtered emission for the ASE source (Amonics ALS-CL-20), and (b) its second-order coherence measurement. The lasing spectrum (c,e) and $g^2(\tau)$ measurements (d,f) for the coaxial nanolaser at pump powers of (c) 215 μW and (d) 66.4 μW respectively.

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