Supplementary Information for

Gain assisted propagation in a plasmonic waveguide at telecom wavelength

Jonathan Grandidier, Gérard Colas des Francs, Sébastien Massenot, Alexandre Bouhelier, Laurent Markey, Jean-Claude Weeber, Christophe Finot and Alain Dereux*

Institut Carnot de Bourgogne, UMR 5209 CNRS et Université de Bourgogne, 9, av. A. Savary, BP 47870, 21 078 Dijon, France

*Corresponding author. E-mail: gerard.colas-des-francs@u-bourgogne.fr

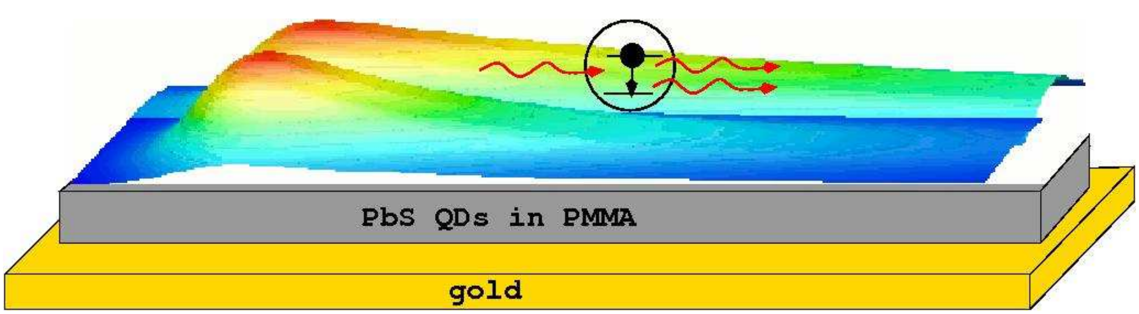

Figure S1 Concept of plasmon loss compensation in confined geometry. The intensity distribution of a plasmon propagating in a QDs doped DLSPPW is calculated when QDs are in their fundamental (front) or are optically pumped to an excited state (back). Stimulated emission of SPPs significantly increases the mode propagation length.

Figure S1 schematically describes the plasmon propagation assisted by stimulated emission investigated in this letter. A plasmon mode propagates along a gold surface and is laterally confined by a PMMA strip doped with PbS nanocrystals. The intensity is calculated 50 nm above the waveguide with the Differential method[1] for a passive (ε"=0) and gain (ε"=-0.007) medium. When the QDs are optically pumped, stimulated emission of SPP significantly increases the propagation length of the guided SPP.

Doped DLSPPW fabrication

A dielectric-loaded surface plasmon polariton waveguide doped with PbS nanocrystals is fabricated on a gold film by deep UV lithography according to the following process. A stock solution of PMMA/QDs is first prepared by dissolving 600 µL of PbS solution (10 mg/mL, toluene solvent, Evident Technologies) into 2.4 mL of PMMA solution (4% w/w in chlorobenzene). Since the toluene dissolves efficiently the PbS nanocrystals and does not phase separate with chlorobenzene, an homogeneous dispersion of the QDs into the PMMA solution is obtained. A 40-nm thick gold film is then prepared by thermal evaporation onto a glass cover slip. A 600 nm thick PMMA/QDs film is then deposited by a two-step spin coating process (1800 rpm, thermal annealing at 170 °C after each spin coating). The 400 nm width waveguides were prepared by deep UV exposure (250 nm wavelength, 1900 mJ/cm^2) using a vacuum contact mask aligner (Süss Microtech MJB4) and a commercial chromium mask (Photronics), followed by a chemical development.

Characterization of the mode linewidth in the Fourier plane

Figure S2 schematically represents the leakage radiation microscopy setup. Apart from imaging in the direct plane, it is also possible to investigate the mode propagation in the Fourier plane.

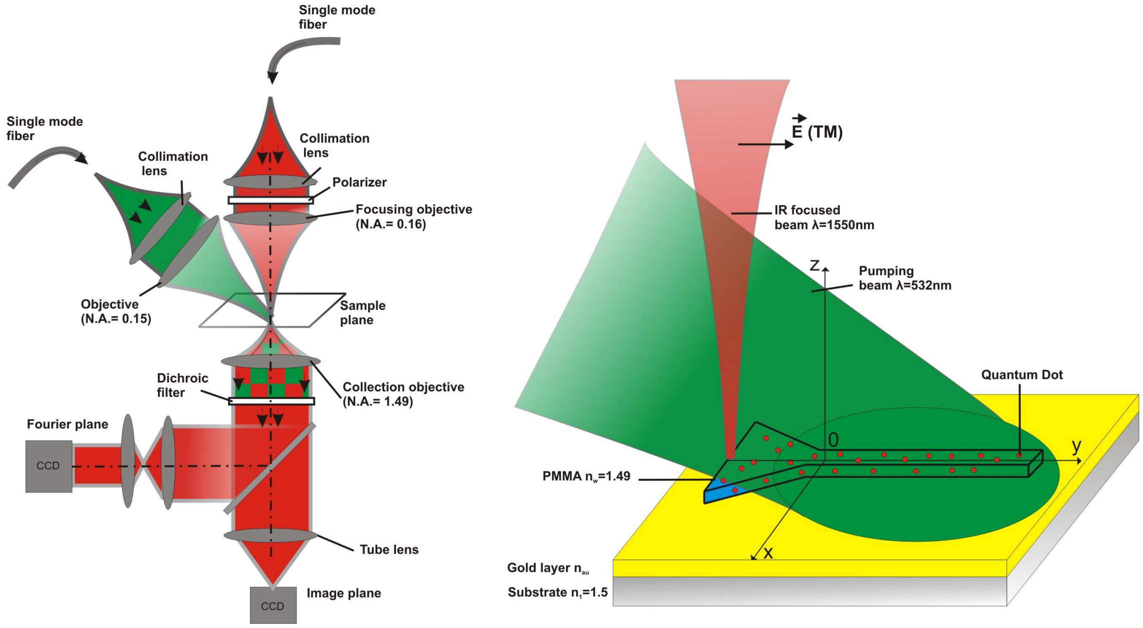

Figure S2 Leakage radiation microscopy setup. The DLSSPW is excited with an infrared laser beam focused on the PMMA tapering portion. A 532 nm laser pump the QDs in their excited state. The signal transmitted below the surface is recorded in the image and Fourier plane at near infrared frequencies. We used a cooled charge-coupled device (CCD) camera to obtain well-defined leakage radiation microscopy images.

Strictly speaking, the signal recorded in the Fourier plane is the Fourier transform of the signal recorded in the image plane as reported in eq. (2) and (3) of the letter. More precisely, direct comparison of eq. (2) and (3) shows that the FWHM Δn_{eff} in the effective index plane is related to the mode propagation length L_{SPP} measured in the image plane at a given wavelength λ by

$$L_{SPP}=\lambda/(2\pi\Delta n_{eff}) \quad (S1).$$

This relation is satisfied for λ=1.55µm as can be seen from Fig. 3 (L_{SPP}=13.5 µm) and Fig. 4 ($\Delta n_{eff}=1.8.10^{-2}$) of the letter.

We propose here to link the signal recorded in the wave-vector plane to the frequency spectrum. This is made possible by the dispersion of the mode $\omega_{SPP}=f(k_{//})$ relating mode frequency to wave-vector.

Figure 4c in the letter represents the DLSPPW mode dispersion relation. For simplicity, we assume that both QDs emission spectrum F(ω) and the recorded intensity in the Fourier Plane $I(\omega, k_{//})$ have Lorentzian shapes:

$$F(\omega)= \frac{\Delta\omega}{(\omega - \omega_{\text{fluo}})^2 + \Delta\omega^2} \quad \text{(S2)}$$

$$I(\omega, k_{//})= \frac{\Delta\omega(k_{//})}{[\omega - \omega_{\text{SPP}}(k_{//})]^2 + \Delta\omega(k_{//})^2} \quad \text{(S3)}$$

where ω_{fluo} is the emission peak of the QDs.

Therefore, QDs decay into DLSPPW modes is a convolution of these two Lorentzians[2],

$$I(k_{//})=\int d\omega F(\omega) I(\omega, k_{//}) = \frac{\Delta\omega + \Delta\omega(k_{//})}{[\omega_{fluo} - \omega_{\text{SPP}}(k_{//})]^2 + [\Delta\omega + \Delta\omega(k_{//})]^2} \quad \text{(S4).}$$

Since we characterized the waveguide mode in the effective index plane (Fourier plane), it is useful to rewrite Eq. (S4) as a function of $k_{//}$. To this aim, using the group velocity of the mode v_g, we approximate the dispersion relation to

$\omega_{\text{SPP}}(k_{//})= \omega_{\text{fluo}}+v_g[k_{//}- k_{//}(\omega_{\text{fluo}})]$ near the QDs emission wavelength so that Eq. S4 becomes

$$I(k_{//})=\frac{\Delta\omega + \Delta\omega(k_{//})}{v_g^2[k_{//} - k_{//}(\omega_{fluo})]^2 + [\Delta\omega + \Delta\omega(k_{//})]^2} \quad \text{. (S5)}$$

$I(k_{//})$ has also a Lorentzian shape in the momentum plane. Let us note that the QDs emission is better fitted with a Gaussian profile so that the convoluted intensity is a Voigt profile, which is not analytical. However, the above discussion gives a physical understanding of the signal recorded in the Fourier plane and roughly explains the effective index broadening measured in Fig. 4b below the transparency threshold.

References

1. Grandidier, J.; Massenot, S.; Colas des Francs, G.; Bouhelier, A.; Weeber, J.C.; Markey, L.; Dereux, A.; Renger, J.; Gonzalez, M.U.; Quidant R. *Physical Review B* **78,** 245419 (2008).

2. Chang, S.W.; Adrian Ni, C.Y.; Chuang, S.L. *Optics Express* **16**, 10580-10595 (2008).