SUPPLEMENTARY MATERIALS – Electrical and optical switching in the bistable regime of an electrically injected polariton laser

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(Dated: January 6, 2017)
PACS numbers: 71.36.+c, 71.55.Eq, 73.21.Fg

Theoretical details

Neglecting spatial dynamics, the numbers of charged carriers \(n\), excitons \(n_x\), and condensed polaritons \(n_p\) evolve according to the coupled rate equations:\n
\[
\frac{\partial n}{\partial t} = P - W_1 n^2 + W_2 n_x - \gamma n + dP
\]
(\textbf{S1})

\[
\frac{\partial n_x}{\partial t} = W_1 n^2 - W_2 n_x - \gamma_x n_x - r(n_p + 1)n_x
\]
(\textbf{S2})

\[
\frac{\partial n_p}{\partial t} = r(n_p + 1)n_x - \gamma_p n_p
\]
(\textbf{S3})

where \(P\) is the electrical injection rate of charged carriers; \(W_1\) is the exciton bimolecular formation rate; \(W_2\) is the exciton dissociation rate; \(\gamma\) is the carrier decay rate; \(\gamma_x\) is the exciton decay rate; \(r\) is the polariton condensation rate; and \(\gamma_p\) is the polariton decay rate. With the injection of more carriers into the active region, a screening of the electric field by free carriers results in decrease of the carrier decay rate, modelled by\:^1:\n
\[
\gamma = \gamma_0 e^{-cn}
\]
(\textbf{S4})

where \(\gamma_0\) and \(c\) are constants. Extending the previous theory, \(dP\) in Eq. S1 is a stochastic noise term.

In the absence of noise the steady state of Eqs. S1-S3 is:

\[
P = W_1 n^2 - W_2 n_x + \gamma_0 e^{-cn} n
\]
(\textbf{S5})

\[
n = \sqrt{\frac{n_x}{W_1} (W_2 + \gamma_x + r(n_p + 1)n_x)}
\]
(\textbf{S6})

\[
n_p = \frac{rn_x}{\gamma_p - rn_x}
\]
(\textbf{S7})

This gives the dashed curve in Fig. 4 of the main text, where we used the parameters: \(r = 10^{-3}\text{ps}^{-1}\), \(\gamma_p = 1/15\text{ps}^{-1}\), \(\gamma_x = 0.5\text{ps}^{-1}\), \(W_1 = 2.93 \times 10^{-5}\text{ps}^{-1}\), \(W_2 = 0.168\text{ps}^{-1}\), \(\gamma_0 = 0.274\text{ps}^{-1}\), \(c = 0.0273\). Here \(r\), \(\gamma_p\) and \(\gamma_x\) were taken from Ref.\(^1\), while \(W_1\), \(W_2\), \(\gamma_0\), and \(c\) were obtained with a fitting algorithm, where we assumed a linear relationship between \(n_p\) and the experimentally measured intensity, and a linear relationship between \(P\) and the experimental current density (the resulting parameter choices from the procedure are similar to those in Ref.\(^1\)).

To model noise, we included a random variable \(dP\) (Gaussian distributed, with a cutoff for large fluctuations in agreement with experiment) in Eq. S1 and solved numerically in time. To obtain the hysteresis curves in Fig. 4, the pump power \(P\) is slowly increased and then decreased, while \(dP\) is updated over a finite correlation time (which we took to be 500ps). For increasing range of the random variable, that is, increasing noise strength, the hysteresis curves were found to narrow, matching the experimentally observed phenomenology.