quantum computing with graphene plasmons

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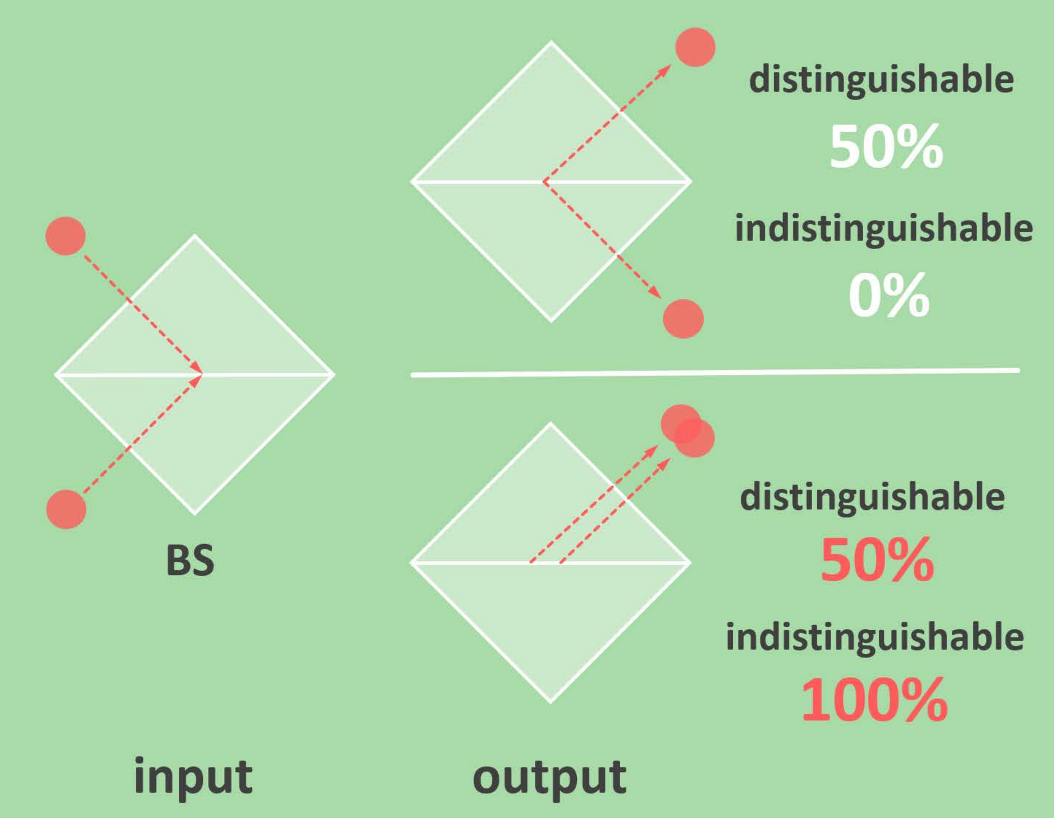
Among the various approaches to quantum computing, all-optical architectures are especially promising due to the robustness and mobility of single photons. However, the creation of the two-photon quantum logic gates required for universal quantum computing remains a challenge.
Here we propose a universal two-qubit quantum logic gate, where qubits are encoded in surface plasmons in graphene nanostructures, that exploits graphene's strong third-order nonlinearity and long plasmon lifetimes to enable single-photon-level interactions. In particular, we utilize strong two-plasmon absorption in graphene nanoribbons to create a "square-root-of-swap" that is protected by the quantum Zeno effect against evolution into undesired failure modes, reaching success rates well above the fault-tolerance threshold.



system

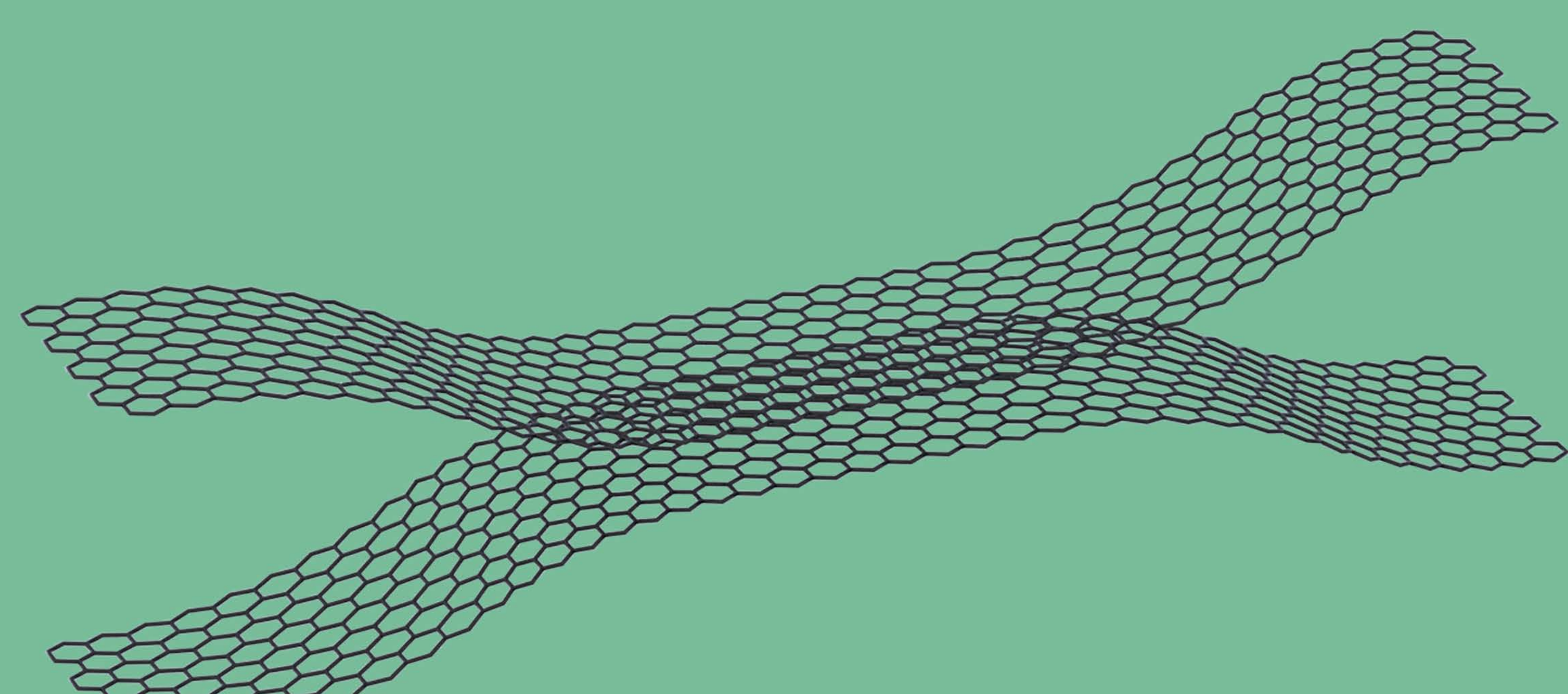
Two graphene nanoribbons are brought close to each other, so that the plasmons are coupled via Coulomb interaction. For a determined interaction length, a plasmon starting in one ribbon will always couple to the other ribbon, creating a SWAP. If the interaction length is halved, a $SWAP^{1/2}$ is created instead.

requirements for a successful $SWAP^{1/2}$:

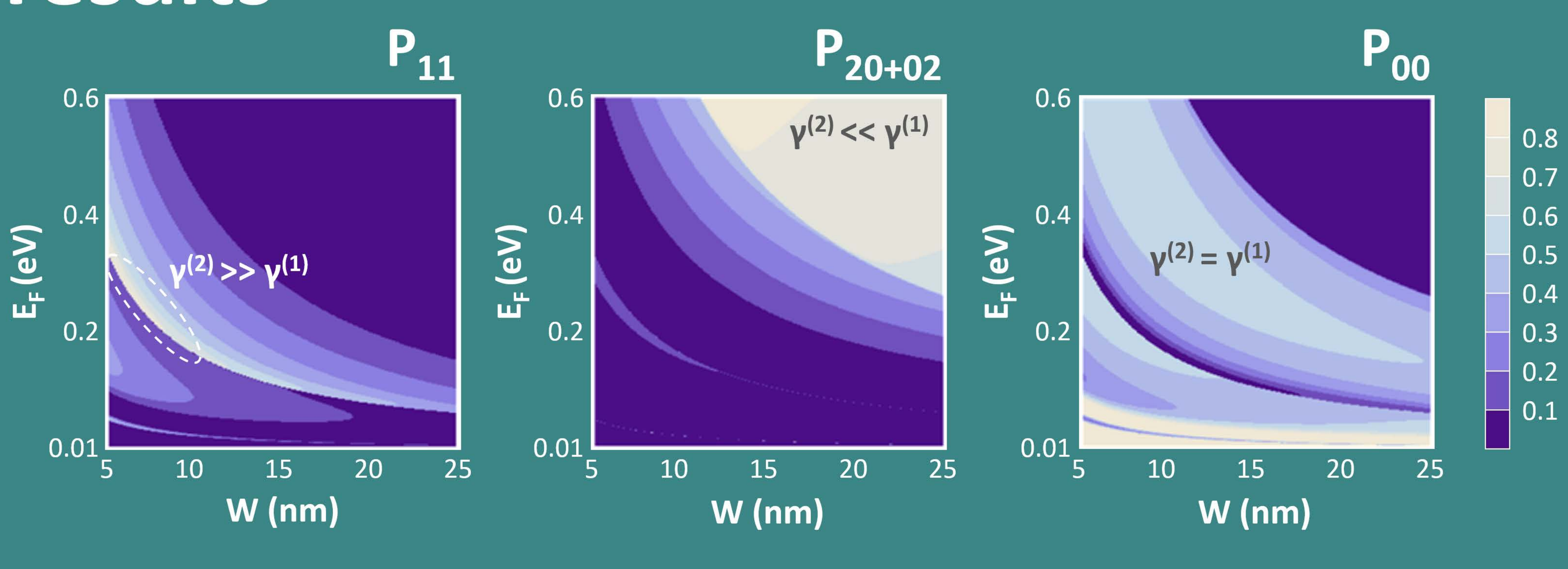
strong two-plasmon absorption + *strong Coulomb coupling*

$$\gamma^{(2)} \propto \left(\frac{\gamma^{(1)}}{Re\left\{\sigma_\omega^{(1)}\right\}}\right)^2 Re\left\{\sigma_\omega^{(3)}\right\} \qquad U_q \propto W^2 \left|\frac{E^p}{1/\eta_\omega^{(1)} - 1/\eta_q}\right|^2$$

where $\sigma_\omega^{(3)}$ is the third-order conductivity that depends on the electric field of the plasmon. *W is the nanoribbon width, E is the electric field of the plasmon and η is a function of σ.*



results



$\gamma^{(2)} << \gamma^{(1)}$
Strong plasmonic HOM effect is observed.

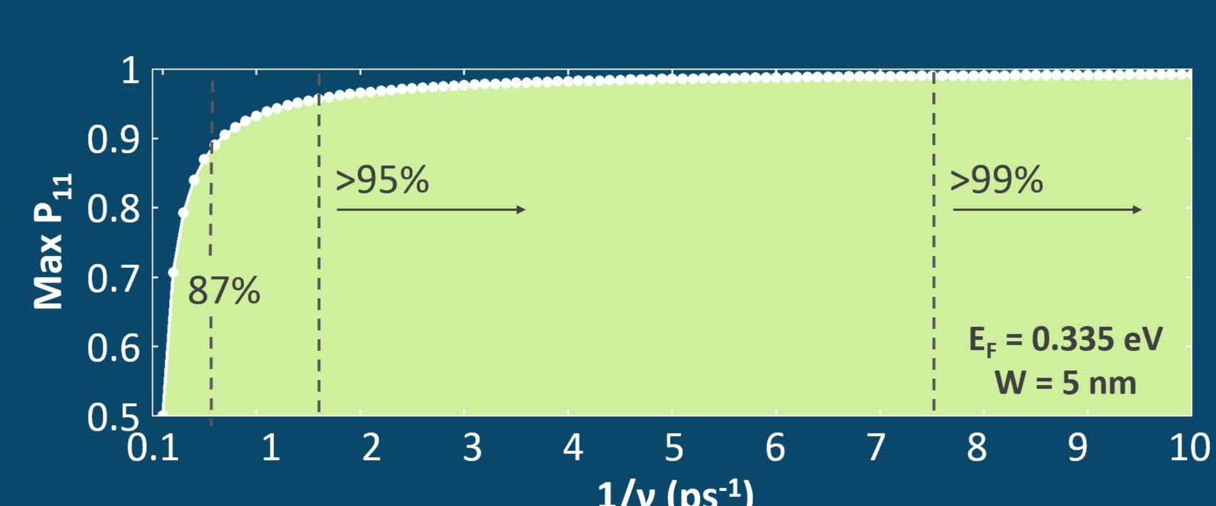
$\gamma^{(2)} = \gamma^{(1)}$
The two-plasmon absorption is not strong enough to drive a Zeno effect and the vacuum states are highly polulated.

$\gamma^{(2)} >> \gamma^{(1)}$
The strong two-plasmon absorption drives the Zeno effect preventing the system from evolving into undesired *20* and *02* states.

application

Our proposed gate achieves process fidelities in the fault-tolerant regime for relatively reasonable physical parameter. By combining ideas from quantum optics with nanoplasmonics, our work opens up an entirely new and promising avenue in the search for single-photon nonlinearities.

While we have studied the application of graphene nanoplasmonics to a quantum logic gate, this could also be used for deterministic optical implementations of quantum teleportation, cluster state generation, and single-photon sources, underlining the applicability of this platform.



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