Generation and Detection of Single Photons and Photon Pairs

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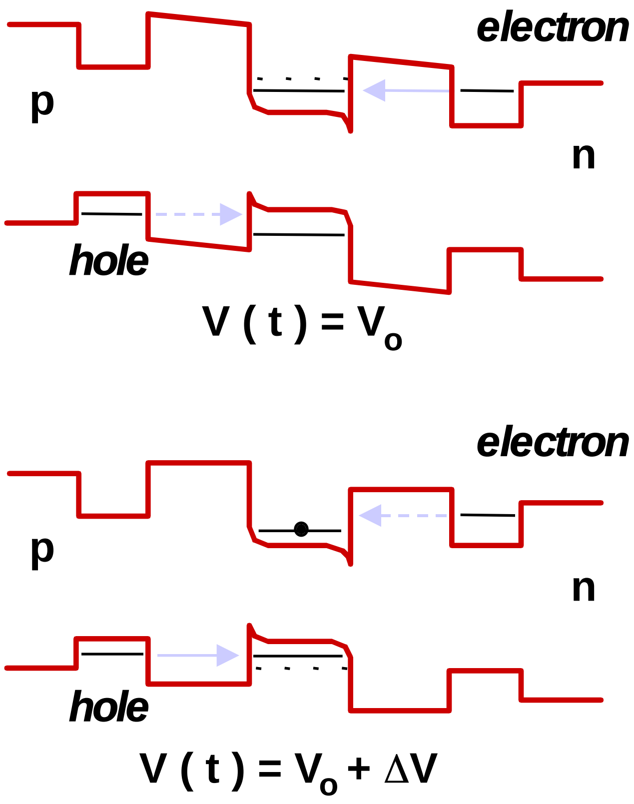
Contents

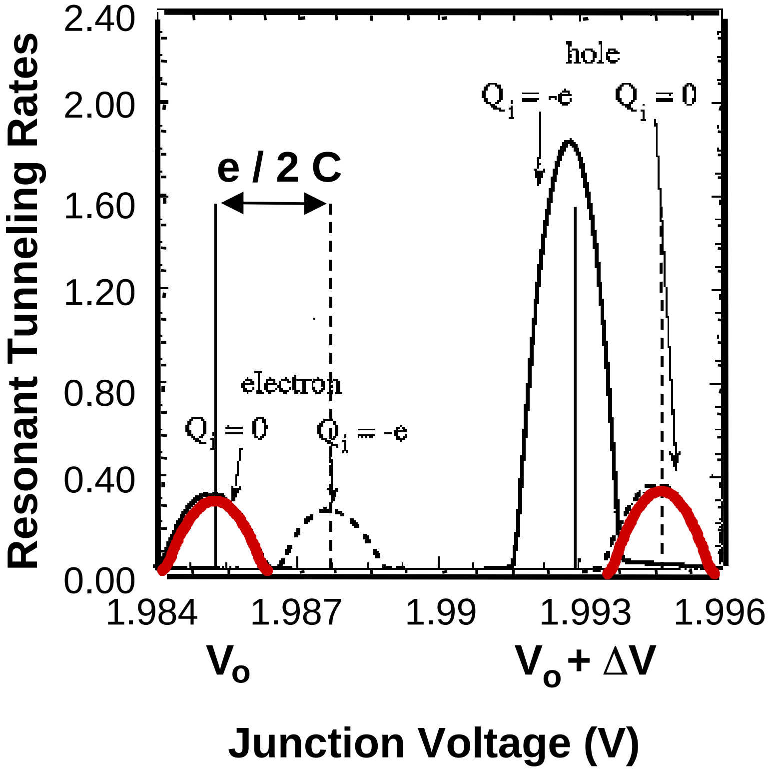
- Original solid-state single photon generation device
- “VLPC” high-efficiency solid-state photon counter
- New proposal for generation of single photons and single pairs of entangled photons

Single Photon Turnstile Device

A. Imamoglu and Y.Yamamoto, Phys. Rev. Lett. **72**, 210 (1994)



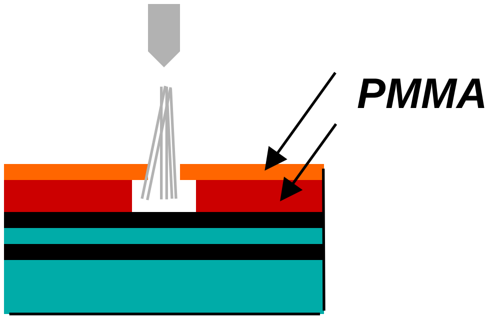
Operation Principle



Resonant Tunneling Rates

Device Fabrication

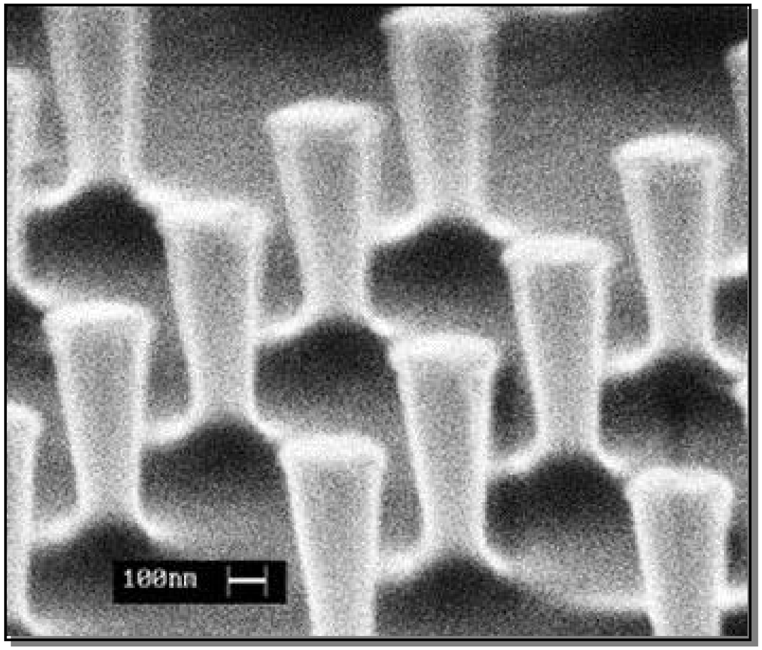
1



Bi-layer PMMA
E-beam Lithography

2

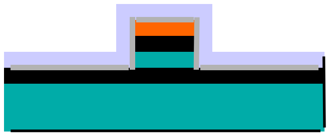
Metal Deposition
Standard Lift-off



3

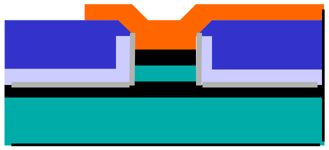
Highly Directional
Reactive Ion Etching

4



Sulfur Passivation
SiN Encapsulation

5



Planarization with
Polyimide, Depostion
of Contact Pads

First Demonstration

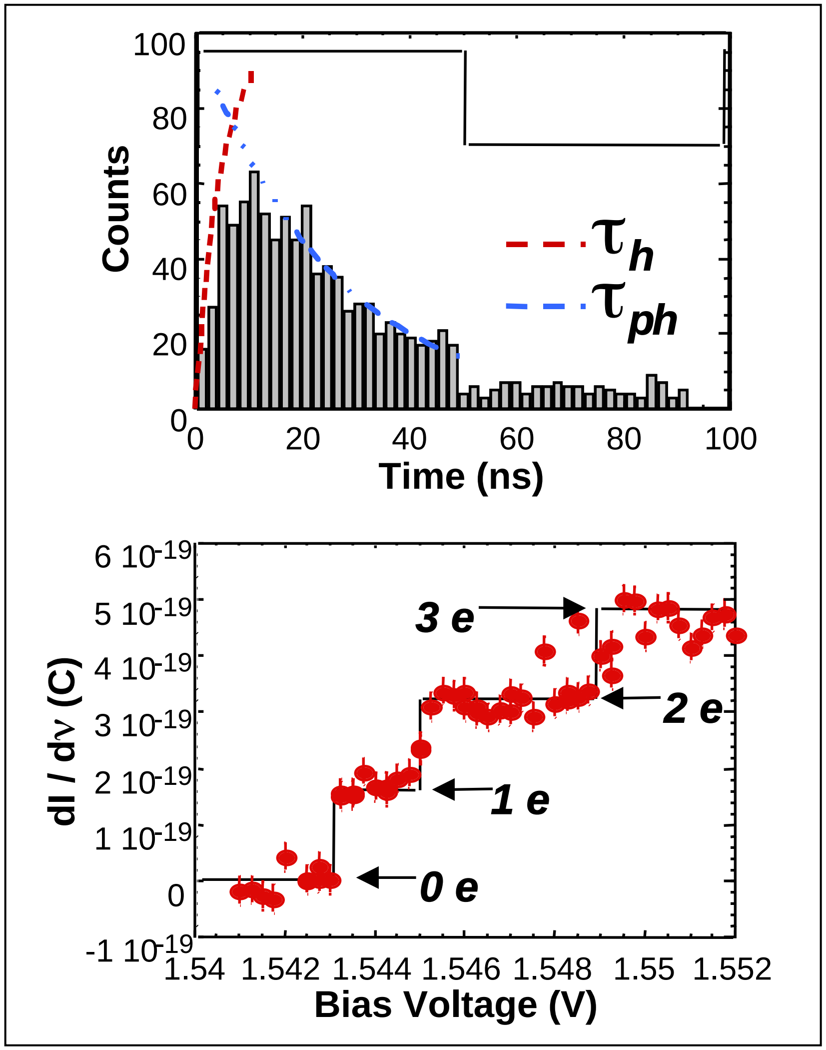
J. Kim, O. Benson, H. Kan & Y. Yamamoto, *Nature* **397**, 500 (1999)

Evidence for success:

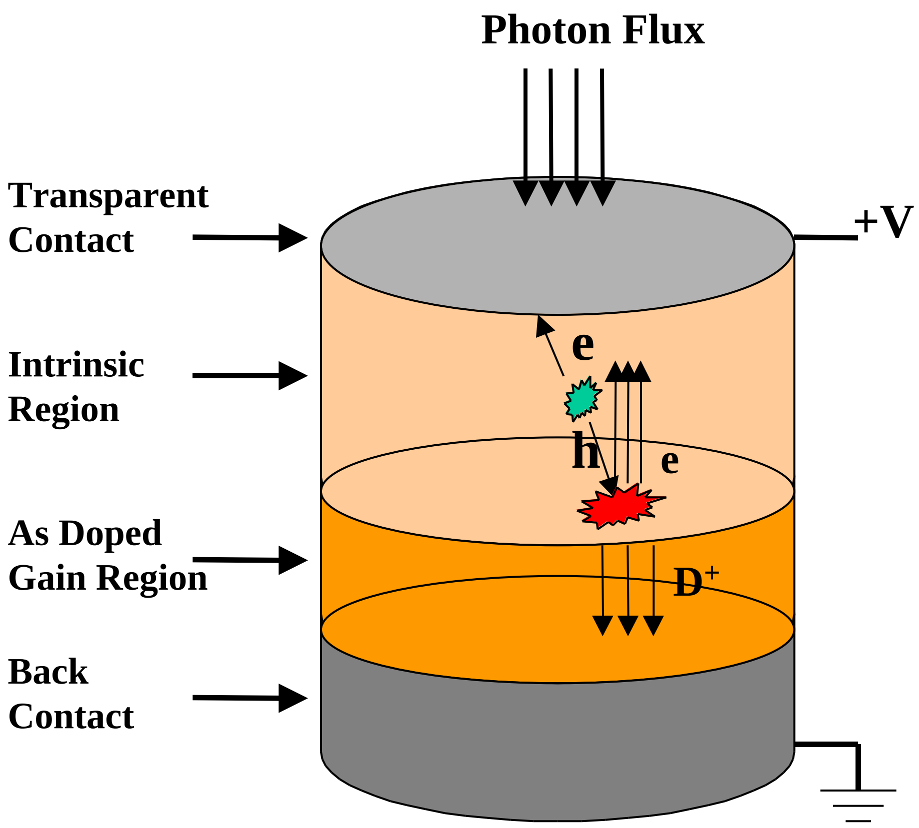
- Emitted photon histogram shows expected behavior;
- Frequency-dependent current.

Areas for improvement:

- Temperature (50mK),
- Recombination rate (25 nsec),
- Collection efficiency (10^{-4}).



The VLPC Detector



Principle of Operation

- Impact ionization of As doped impurities in Si (En ~ 54meV)
- Impurity band conduction (through conduction hopping at low temp.)
- Single carrier photomultiplication

Advantages of VLPC

- Quantum Efficiency ~ 90%
- Avalanche gain ~ 30,000
- Pulse duration ~ 1nsec
- Two photon detection capability

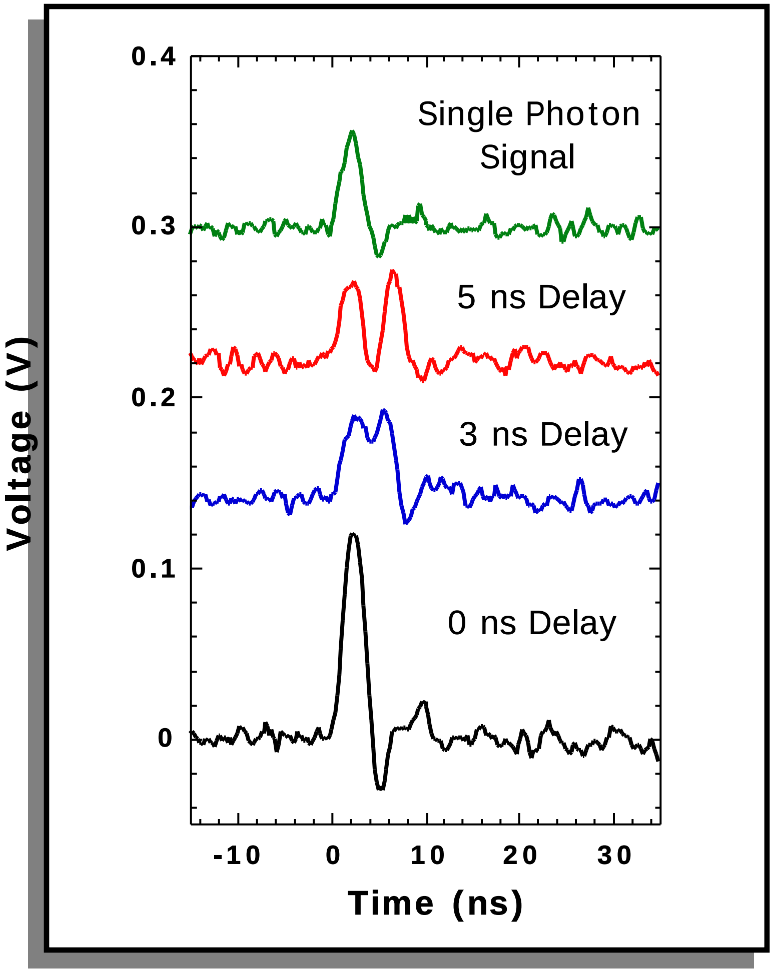
Disadvantages of VLPC

- High dark counts ~ 20,000/s at peak QE
- Difficult to use
  - 6 Kelvin operation temp.
  - Highly sensitive to room temp. IR photons

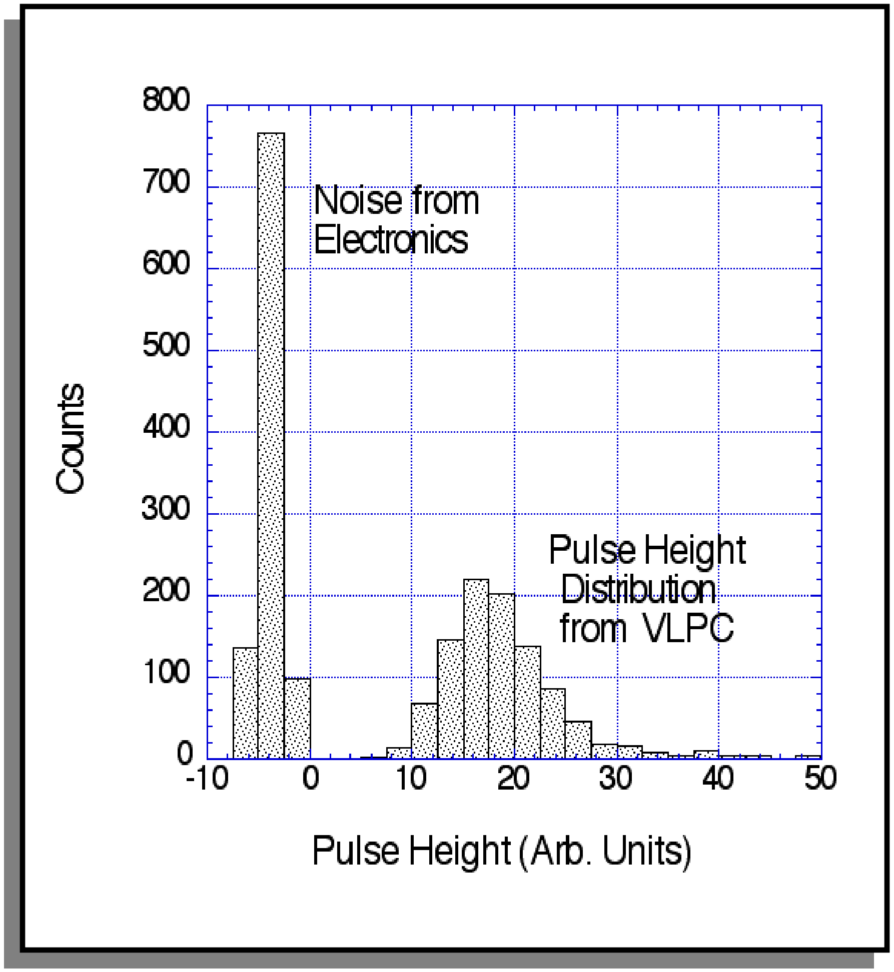
VLPC Properties

J. Kim, Y. Yamamoto and H. Hogue, APL **70**, 2852 (1997)
J. Kim, S. Takeuchi, Y.Yamamoto, H. Hogue, APL **74**, 902 (1999)

Two photon detection capability



Improved noise properties:



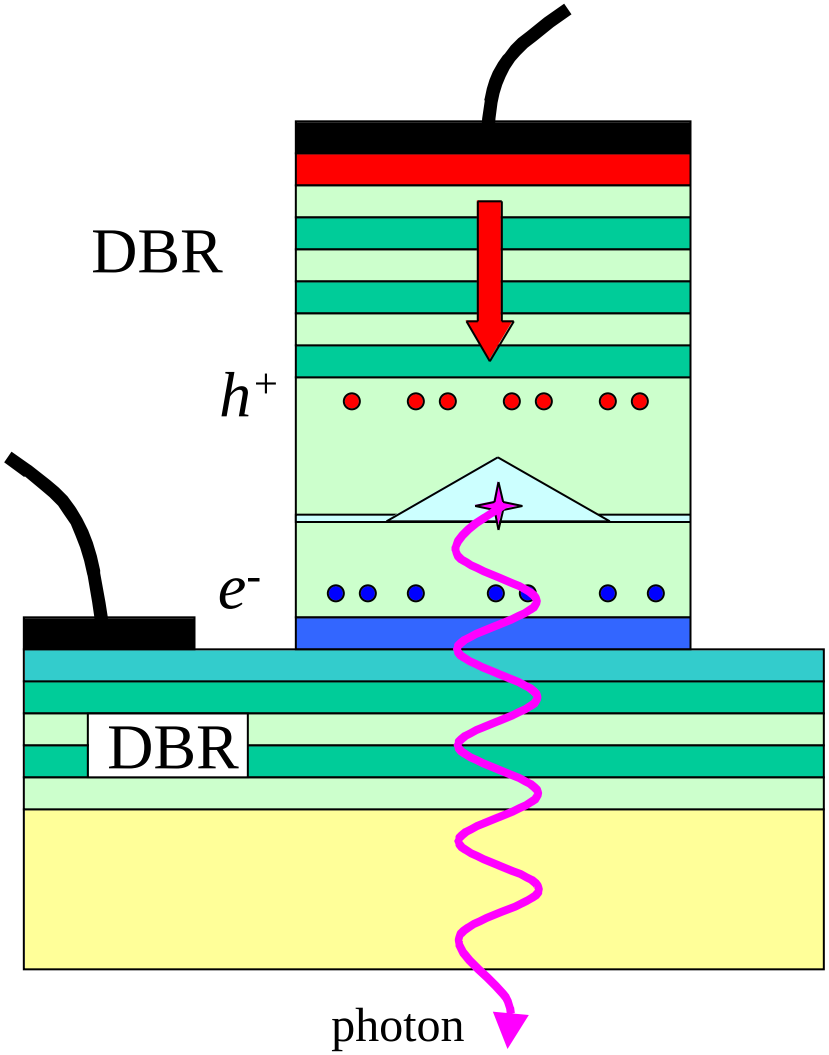
Quantum-Dot Turnstile Device

Advantages of QD over QW:

- Larger Coulomb blockade energy (20meV) allows for higher temperatures.
- Quantum confinement, combined with Pauli exclusion, allows for new modes of operation.
- 1nsec recombination lifetime.

High-β DBR cavity:

- Collection efficiency near unity is possible.
- Enhanced spontaneous emission.



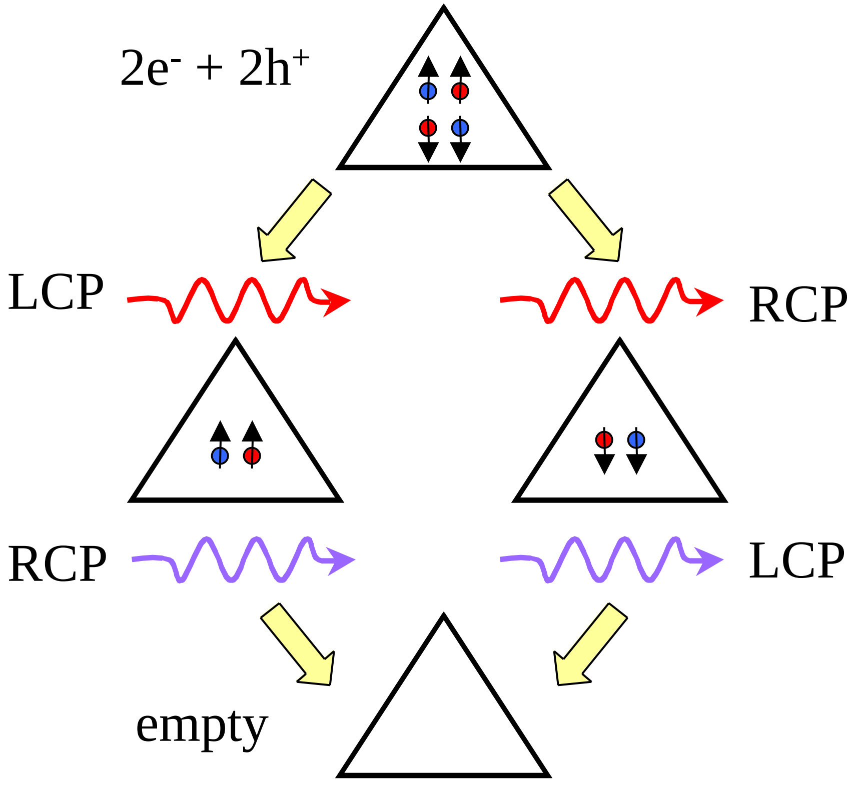
QD Entangled Photon Generator?

O. Benson, C. Santori, M. Pelton, Y. Yamamoto, PRL **84**, 2513 (2000)

- Angular momentum is transferred from electron-hole pairs to photon polarization in recombination events (“selection rules”).
- There are two paths for the dot to radiatively decay to the ground (empty) state.
- If no information remains in the dot as to which path was chosen,

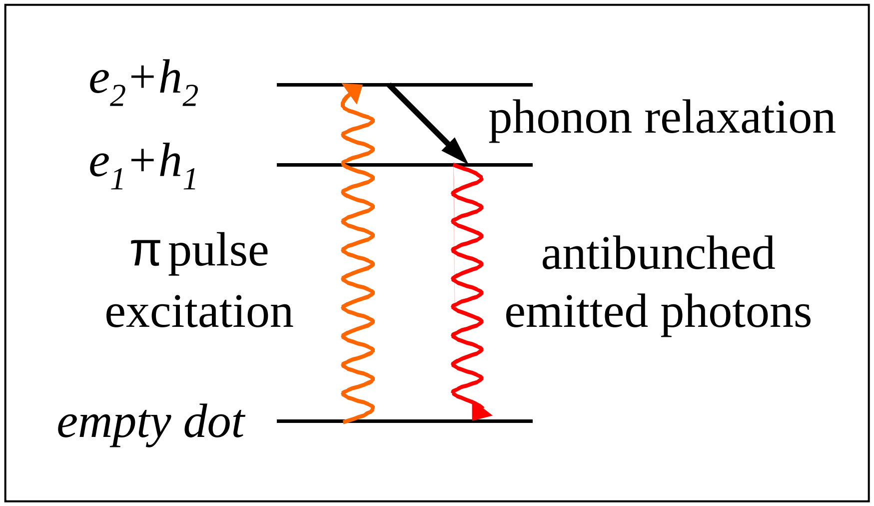
=> **Entangled photon pair!**

Requirement: ***Spin dephasing slower than recombination rate.***



$$\frac{1}{\sqrt{2}}\left[|R_1L_2\rangle + |L_1R_2\rangle\right]$$

Optically Pumped Regulated Photon Source



e_2+h_2

phonon relaxation

e_1+h_1

π pulse
excitation

antibunched
emitted photons

empty dot

- Coherent, pulsed excitation of the single-exciton e_2-h_2 state, followed by phonon relaxation, can be used to generate a single lower-energy photon for each pulse.

- Coherent, pulsed excitation of the bi-exciton e_2-h_2 state (this is possible if the pulse bandwidth exceeds the bi-excitionic energy shift) can be used to generate pairs of photons. If the recombination rate exceeds the spin-dephasing rate, then polarization-entangled photon pairs can be produced.

Summary

- We have demonstrated a solid-state source of regulated, single photons.
- We have a solid-state photon-counting system with a quantum efficiency approaching 95% and multiple-photon counting ability.
- We are developing an improved single-photon device based on a quantum dot, which might also be able to generate entangled photon pairs.