Single Photon Transistor

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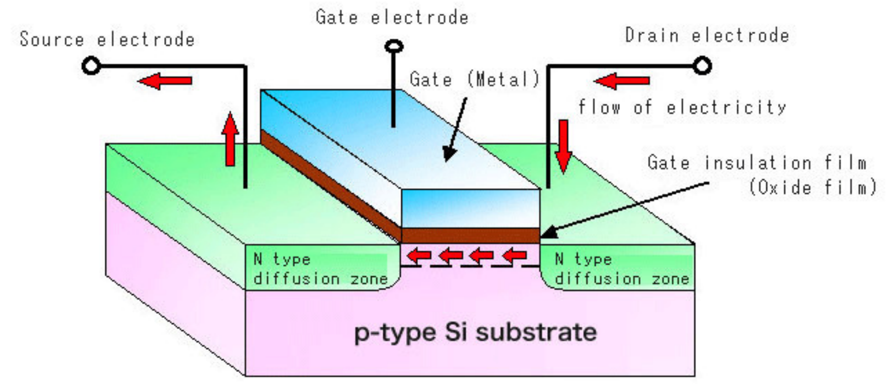
Transistors



Construction of MOSFET

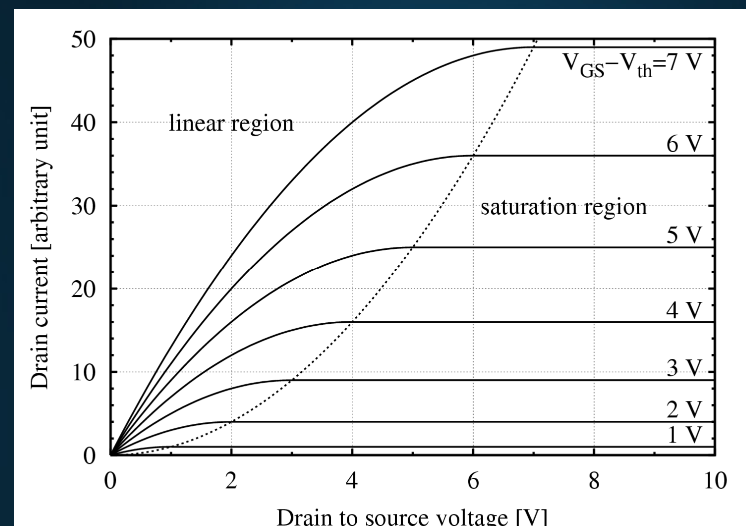
A transistor in general is a 3 port device in which a control at one of those ports can manage the flow between the other 2 points.

The interaction between the “gate” port and the flow between the “source” and “drain” is non-linear

Electrical MOSFET Transistor

Three regions of operation
- cutoff
- triode (linear)
- saturation

Two types of use
- switch
- amplifier



Switch

- cutoff or saturation (off or on)

Amplifier

- triode region, gain = $g_m = \dfrac{2I_d}{V_{gs} - V_{tn}}$

Optical Transistor Concept

Similar Idea. Control an optical “signal” propagating across some channel via a “control” at a gate.

The optical signal for this may be as simple as a stream of photons, perhaps at some frequency, and in general the control is also some number of photons.

Unfortunately, unlike electrons, photon have very weak non-linear interactions with one another.

The concept shown here is only one such method of creating a strong non-linear interaction between photons.

The hopeful solution proposed here is to utilize a tight concentration of optical fields in conjunction with guided surface plasmons along a conducting nanowire in order to achieve strong non-linear interactions between optical emitters.

Nanowires

Definition: A nanostructure with diameter on the scale of nanometers.

Also known as
“Quantum Wires”

Can be made of many
Different materials
- Organic nanowire
- Metallic nanowire

At this scale Quantum Mechanical Effects are most important

Surface Plasmons

A plasmon is a quantum of plasma oscillation. The plasmon is a quasi particle resulting from the quantization of plasma oscillations. Plasmons can also couple with photons to create a new quasiparticle called a plasma polarition

Surface plasmons are surface electromagnetic waves that propagate in the direction parallel to a metal dielectric interface.

For this case, the interface in question is the metallic nanowire and a vacuum (dielectric). Creates surface plasmons that will propagate along the nanowire

Properties of plasmons in a nanowire

Surface plasmons exhibit a unique property that they can be confined to sub-wavelength dimensions. This means the radius of the nanowire can be very very small.

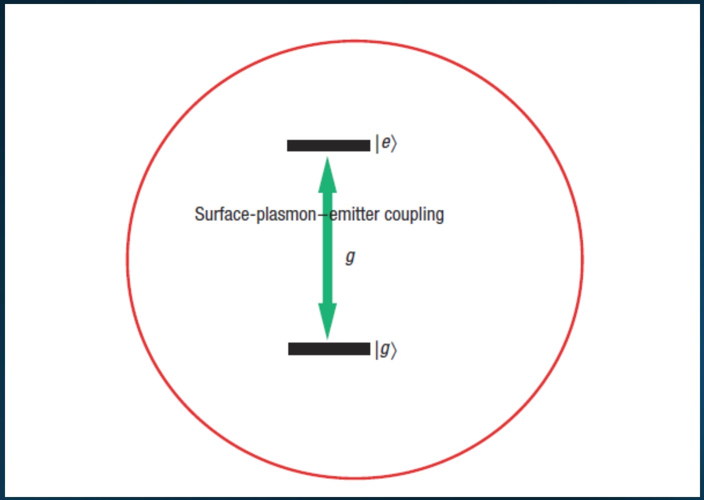
This allows for strong coupling between an “emitter” and the surface plasmons.

Purcell Factor: “The enhanced radiative rate of an emitter within a microcavity relative to its value in free-space.” This will be very large as a result of the narrow confinement and strong coupling.

Purcell Factor for this system will be on the order of 10^3

Coupling here is due to geometrical methods, and as such, is not frequency dependant, and the system is broadband.

Emitter



The emitter will be a single atom. To start, let this atom be able to assume two states. g and e. This atom will be coupled to the surface plasmons.

When in g, acts as a near-perfect reflector

When in e, transmits with no effects

Emitter

State g

For low incident power levels

On resonance, which occurs when the surface plasmons are excited by light, the reflection coefficient reduces to approximately

$$r \approx -1\left(1 - 1/P\right)$$

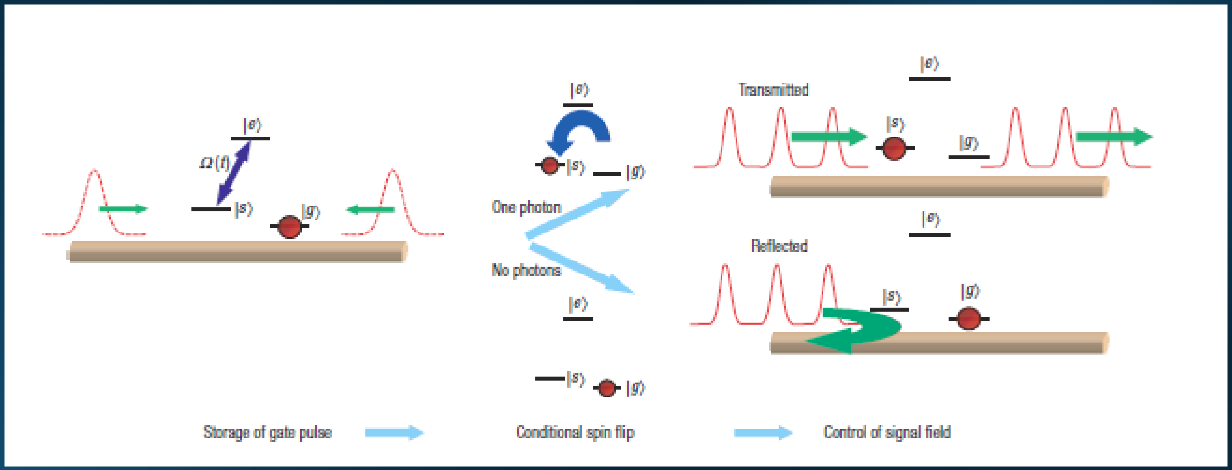
In this equation P is the purcell factor, which as stated before is very high, hence r ≈ -1. Perfect Reflection, and π phase shift

State e

Occurs when the emitter “saturates” with high incident power levels. When in e, this emitter will act like an open gate with no modification to incident signals. This is undesirable behavior.

Ideal Single Photon Transistor

Modify current emitter by adding a state s. This state will be decoupled from the surface plasmon, and metastable.



When the emitter is now in state s, it is decoupled and will then allow incident signals to pass through unchanged and it is metastable. This emitter will be in either g (no transmittance, transistor off) or in s (perfect transmittance, transistor on)

Storing a photon in the emitter

The idea is to be able to control whether the emitter is in e or s by the presence or absence of a single photon. The solution is to store (or not store) a control photon in the emitter by having the emitter change states dependant on the photon existence.

The system is initialized in state g. The a control pulse is sent (may or may not have a photon), and simultaneously with the photon arriving at the surface plasmon, an optical control field will be applied.

If there was a photon present, the emitter will undergo a spin slip from g to s, and remain unchanged otherwise.

The optical control signal must be at the Rabi Frequency, and also must be impedance matched.]

If a photon was present, emitter in e, perfect transmission

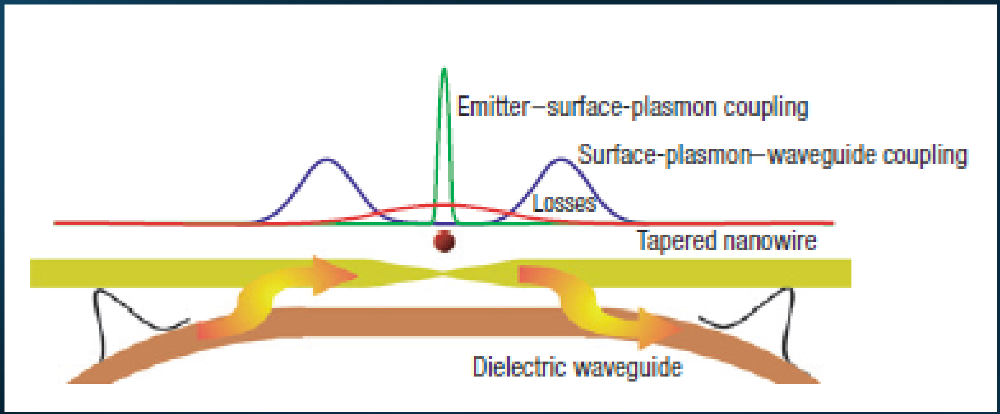
If no photon was present, emitter in g, perfect reflection

Limitations of operation

When the emitter is in state g and reflection is desired, after some number of photons, the emitter may be “charge pumped” into s.

This number of photons corresponds to the effective “gain” of the transistor.

Also, as the signal propagates in the plasmon, it incurs losses, similar to electrical signals due to resistance. In order to avoid this, the signal can be made to propagate in a conventional waveguide. In order to due to achieve this, the signal needs to be rapidly coupled into and out of the surface plasmons, via evanescent coupling. This reduces the losses provided the distnace within the plasmon is very small.



Why Optical?

There a number of reasons to want an optical transistor.

- Broadband
- Very Very small
- Many applications must us optical signals

A very important reason that optical signals are desired is that in current integrated systems using electrical transistors, the electrons can only travel a fraction of the speed of lights, but photons will truly travel AT the speed of light

Has been called the “holy grail” of optical computation.