Nanophotonics class 6 - Microcavities
November 19th 2010

Assignment:

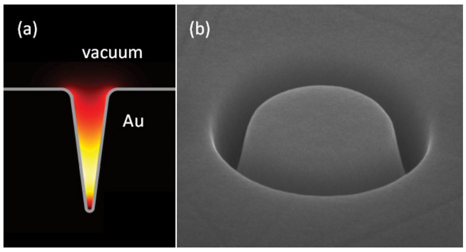

Figure 1. (a) Electric field intensity $|E|^2$ of a plasmonic groove mode at λ=800 nm in a 500 nm deep groove in Au. (b) A circular groove having a diameter of 600 nm acting as an SPP resonator.

The quality factor Q is defined as $Q = \frac{\omega_0}{\Gamma}$. For a low-loss cavity, this is equivalent to $Q = 2\pi \frac{StoredEnergy}{EnergyLostPerOptCycle}$.

1. Explain why this expression is not accurate for cavities with high losses.

Surface plasmon polaritons (SPPs) can be guided by a linear groove in a Au surface, which thereby serves as an SPP waveguide (Fig. 1a). An SPP ring resonator can be made from a groove waveguide that is bent into a circle (Fig. 1b). Groove plasmon waveguides have a bending loss that is much lower than the bending loss in conventional waveguides. Therefore, ring resonators can be made with very small diameter, down to a size where the circumference fits only one wavelength.

Consider a resonator of a few microns in diameter in which a groove plasmon mode is excited with $\lambda_{free\text{-}space}$=1550 nm, such that the circumference of the ring equals 10 plasmon wavelengths. The quality factor Q=75.

2. What percentage of the energy stored is lost in one roundtrip?

For the remainder of the exercise, you might want to use slide 14 from the class presentation, and section 3.3.2 of the Ph.D. thesis by Kippenberg, http://www.mpq.mpg.de/~tkippenb/TJKippenbergThesis.pdf

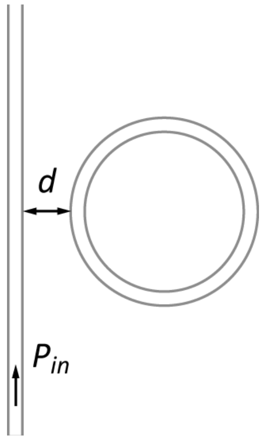

Figure 2. Optical fiber and ring resonator, separated by distance *d*

An optical fiber is positioned at a distance d from the ring (Fig. 2). Through the waveguide light is input at $\lambda_{free\text{-}space}$ = 1550 nm. At $d = d_{crit}$ critical coupling is reached between the fiber and the ring resonator.

3. The fiber is brought closer to the ring resonator. The transmission through the fiber goes to zero at distance d_{crit}. Explain why and discuss the role of τ_{ex} and τ_0. Why does the transmission through the fiber increase as it is brought even closer?

4. How many plasmons (which are quanta, just like photons) are stored in the resonator at critical coupling? The power input in the waveguide is P_{in} = 1 mW.

5. Plasmons circulating in a ring resonator with a smaller diameter suffer from increased loss. In order to reach critical coupling with this resonator, does d_{crit} become larger or smaller? Explain.

6. High-Q microcavities are ideal geometries to study nonlinear optical effects. Explain why a nanoscale plasmonic resonator with moderate Q could still be an attractive geometry for such effects.

We now consider a ring resonator (diameter 450 nm) which has a resonance at 650 nm free-space wavelength. At this wavelength, SPPs experience an increased absorption in the metal. Moreover, the short bending radius causes an increased radiation loss. As a result, the quality factor is now Q = 8.
A fast electron impinges on the ring and excites the plasmon resonance.

7. How long does it take before the energy stored in the resonator has decreased to 10% of its original value?

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