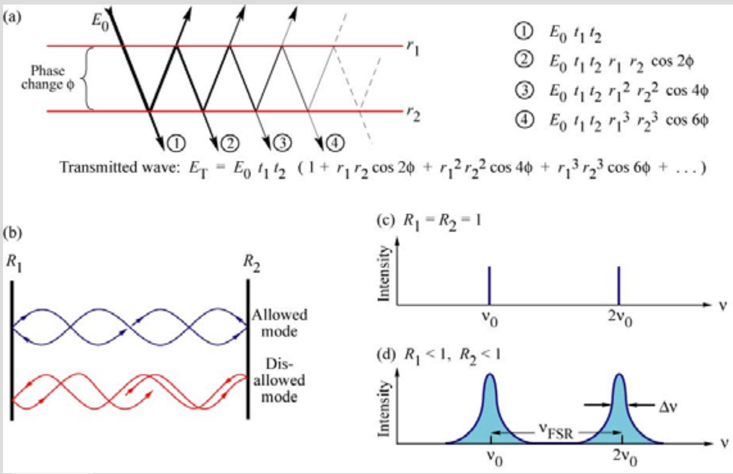
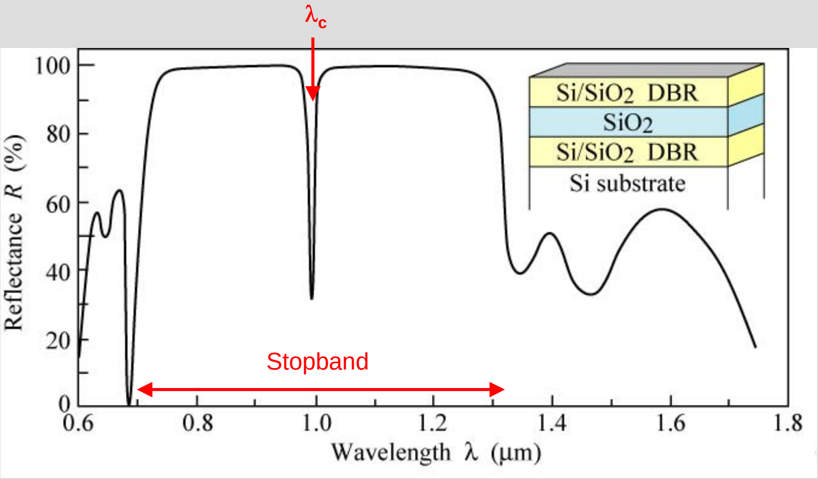
Transmission durch einen Fabry-Perot Resonator



(a) Transmission of a light wave with electric field ampltitude E_0 through a Fabry–Perot resonator. (b) Schematic illustration of allowed and disallowed optical modes in a Fabry–Perot cavity consisting of two coplanar reflectors. Optical mode density for a resonator with (c) no mirror losses ($R_1 = R_2 = 100\ \%$) and (d) mirror losses.

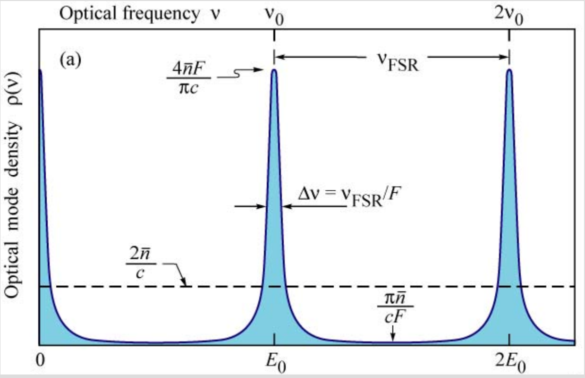
Reflektivität eines FP-Resonators



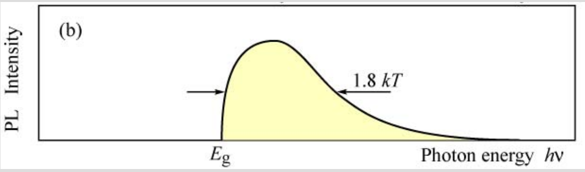
Der Fabry-Perot Resonator besteht aus zwei Si/SiO_2 Reflektoren und einer zentralen SiO_2 Region. Die Resonanzwellenlänge λ_c ist bei 1000 nm.

Optische Modendichte

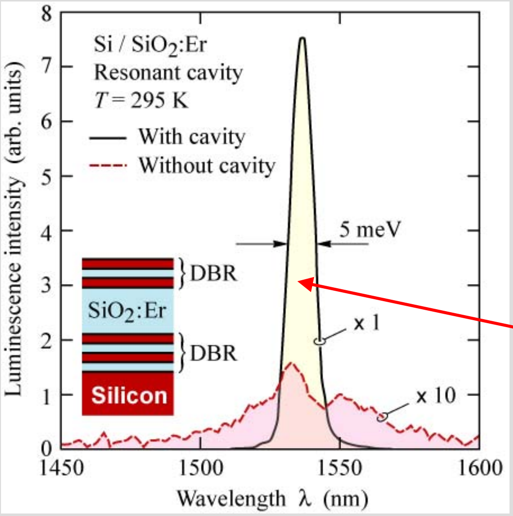
Optische Modendichte einer eindimensionalen ebenen Mikrokavität



Theoretische Form eines Lumineszenzspektrumes einer Volumenshalbleiters



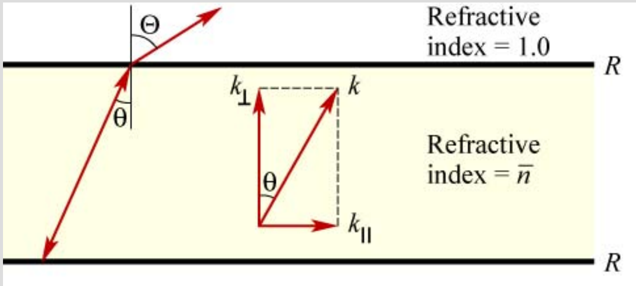
Photolumineszenz Er-dotierter RC



Emissionsverbesserungsfaktor größer 50 wird beobachtet

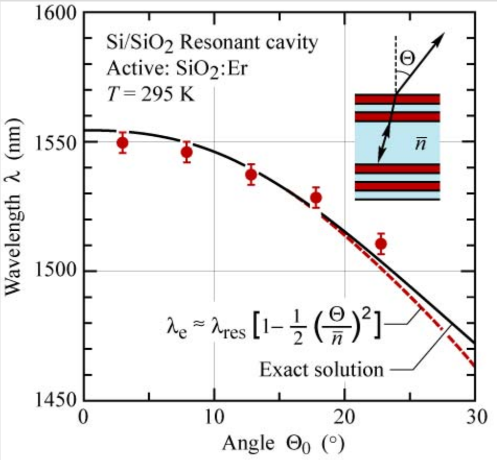
Interner Er-Übergang

Komponenten des Wellenvektors k



Perpendicular and parallel component of wavevector k for light propagating in resonant cavity.

Winkelabhängigkeit der Peakwellenlänge



Peak emission wavelength as a function of polar angle for a planar Si/SiO$_2$:Er resonant cavity (after Schubert *et al.*, 1992b).

AlGaInP RCLED

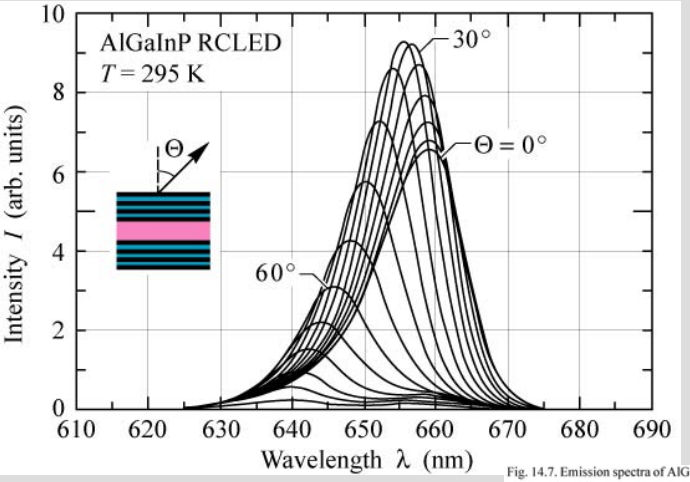
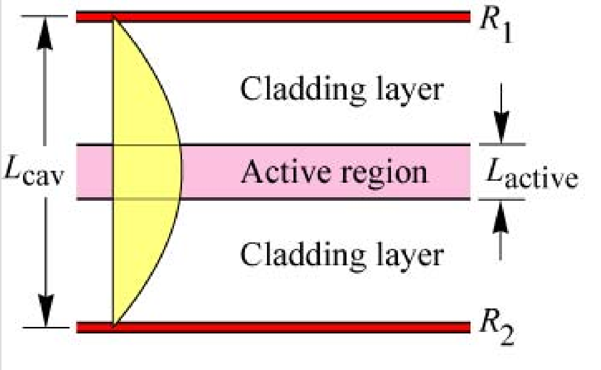


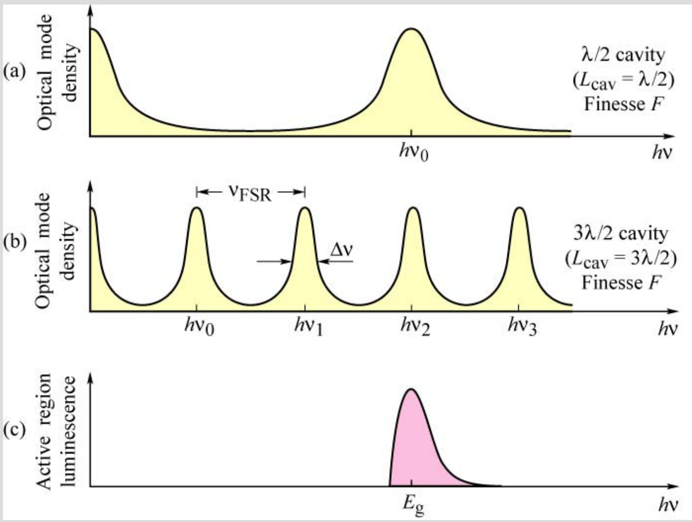
Fig. 14.7. Emission spectra of AlGaInP RCLED for different polar angles. The long-wavelength part of the QW emission is emitted in the forward direction (0°). The shorter wavelengths are emitted off-axis. When measured with an integrating sphere, an 18 nm wide spectrum (FWHM) is found (after Streubel *et al.*, 2002).

Schema einer resonanten Kavität



Schematic illustration of a resonant cavity consisting of two metal mirrors with reflectivity R_1 and R_2. The active region has a thickness L_{active} and an absorption coefficient α. Also shown is the standing optical wave. The cavity length is L_{cav} is equal to $\lambda/2$.

Optische Modendichte und Finesse



Optical mode density for (a) a short and (b) a long cavity with the same finesse *F*. (c) Spontaneous free space emission spectrum of an LED active region. The spontaneous emission spectrum has a better overlap with the short-cavity mode spectrum compared with the long cavity mode spectrum.

Spontanes Emissionspektrum eines VCSELs

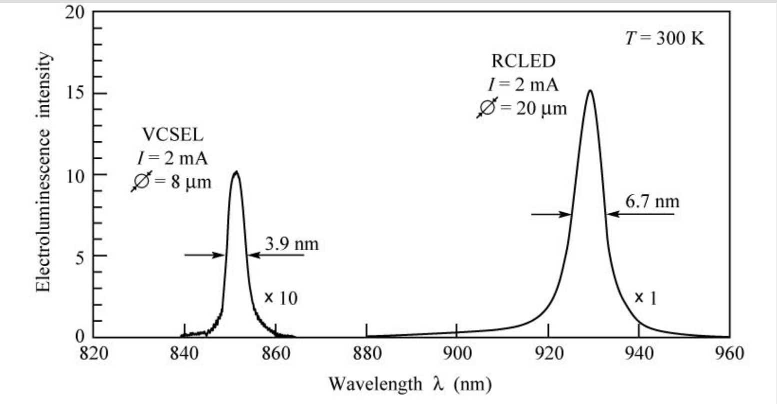
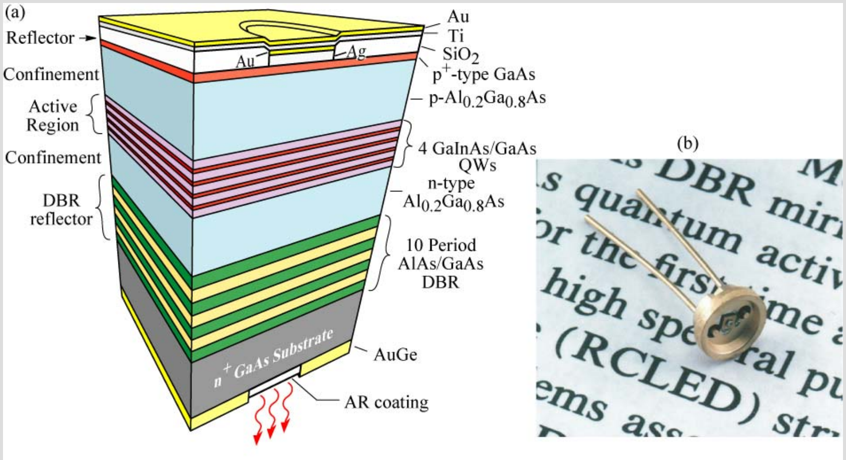


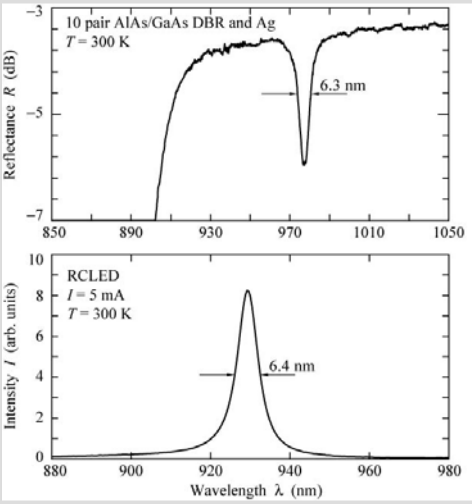
Fig. 15.3. Spontaneous electroluminescence spectrum of a vertical-cavity surface-emitting laser (VCSEL) emitting at 850 nm and of a resonant-cavity light-emitting diode (RCLED) emitting at 930 nm. The drive current for both devices is 2 mA. The VCSEL spectrum is multiplied by a factor of 10. The threshold current of the VCSEL is 7 mA (after Schubert *et al*., 1996).

GaInAs/GaAs RCLED



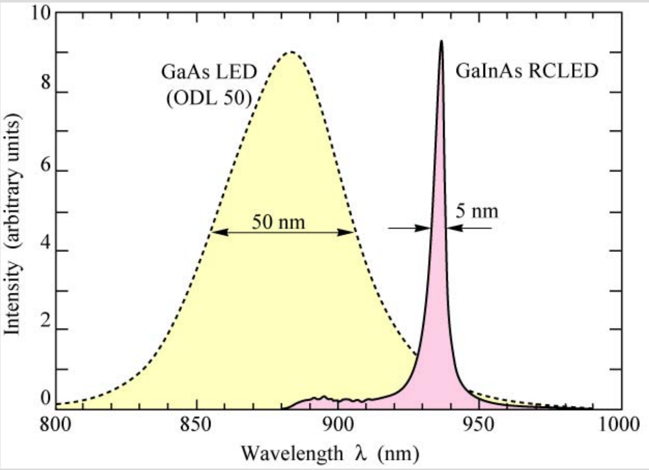
(a) Schematic structure of a substrate-emitting GaInAs/GaAs RCLED consisting of a metal top reflector and a bottom distributed Bragg reflector (DBR). The RCLED emits at 930 nm. The reflectors are an AlAs/GaAs DBR and a Ag top reflector. (b) Picture of the first RCLED (after Schubert *et al*., 1994).

Reflektivität und Emission eines AlAs/GaAs DBRs



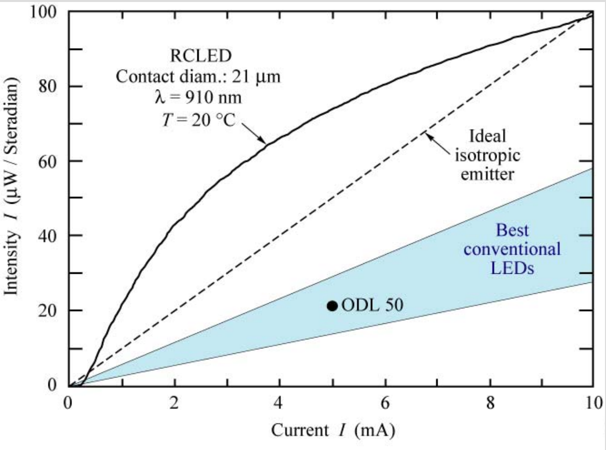
(a) Reflectance of a resonant cavity consisting of a 10-pair AlAs/GaAs distributed Bragg reflector and an Ag reflector. (b) Emission spectrum of a RCLED consisting of a 10-pair AlAs/GaAs distributed Bragg reflector and an Ag reflector (after Schubert *et al*., 1994).

Vergleich LED und RCLED



Comparison of the emission spectra of a GaAs LED emitting at 870 nm (AT&T ODL 50 product) and a GaInAs RCLED emitting at 930 nm (after Hunt *et al.*, 1993).

L-I Kurven



Light-versus-current curves of a GaInAs/GaAs RCLED and of the *ideal isotropic emitter*. The ideal isotropic emitter is a hypothetial device emitting light isotropically with a quantum efficiency of 100%. The shaded region shows the intensity of the best conventional LEDs. The ODL 50 is a commercial LED product (after Schubert *et al.*, 1994).

Struktur einer rot emittierenden MQW RCLED

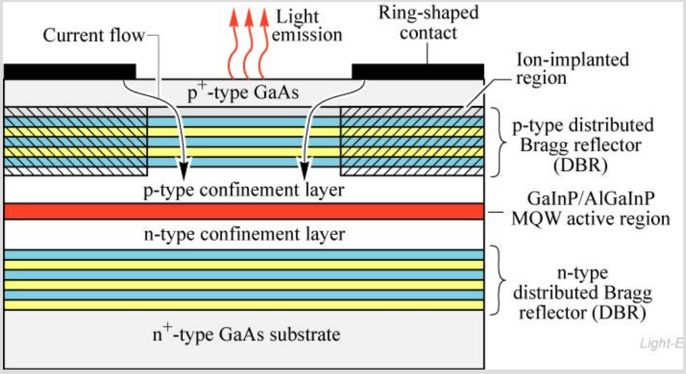
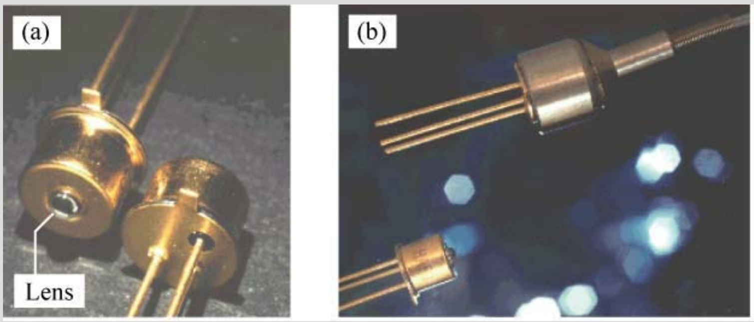


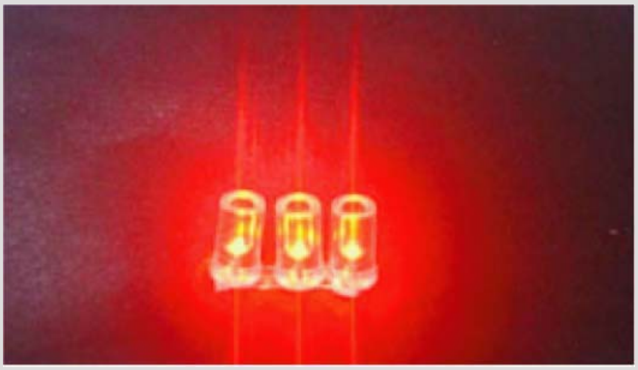
Fig. 15.9. Structure of a GaInP/AlGaInP/GaAs MQW RCLED emitting at 650 nm used for plastic optical fiber applications (after Whitaker, 1999)

Verpackte RCLEDs



(a) Packaged (TO package) RCLED emitting at 650 nm suited for plastic optical fiber applications. (b) Pig-tailed RCLED (courtesy of Mitel Corporation, Sweden, 1999).

Gerichtetes Emissionsmuster einer roten RCLED



AlGaInP/GaAs RCLEDs emitting at 650nm. Note the forward-directed emission pattern similar to that of a semiconductor laser (courtesy of Osram Opto Semiconductors Corporation, Germany, 1999).

E. F. Schubert

Spektrum: RCLED vs LED

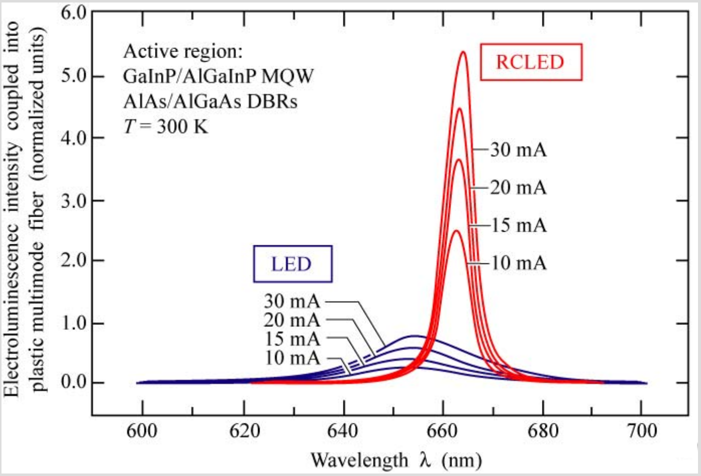
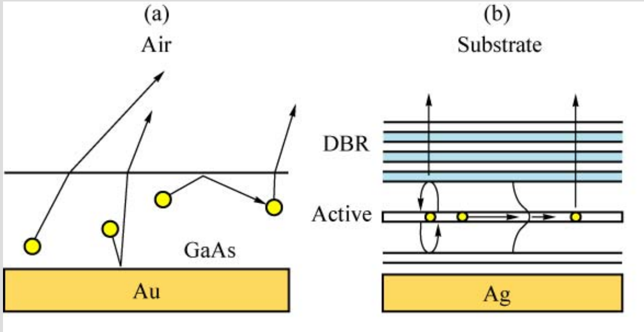


Fig. 15.12. Spectra of light coupled into a plastic optical fiber from an GaInP/AlGaInP MQW RCLED and a conventional GaInP/AlGaInP LED at different drive currents. Note the narrower spectrum and higher coupled power of the RCLED (after Streubel *et al.*, 1998).

Photonen Recycling



Two approaches to photon recycling LEDs. (a) Bulk epilayer placed on top of gold. Most spontaneous emission that does not escape into air is reabsorbed and has a chance to emit again. (b) Microcavity designed with a waveguiding active region. Waveguided light is reabsorbed after some tens of microns, and has a chance to reemit out of the top of the device.

L-I Kurven für Einmodenemission

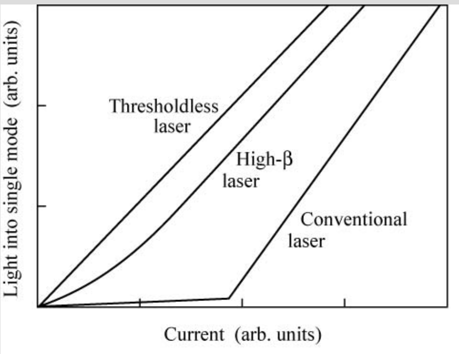


Fig. 15.14. Light-power-versus-current curves for single spatial-mode emission from a (*i*) conventional laser, (*ii*) a high β-factor laser, and (*iii*) a thresholdless laser. The conventional laser has a distinct current threshold. The high β-factor laser has a less distinct threshold. It would be noticeable in the spectrum and device modulation speed, however. A hypothetical thresholdless laser would have a β close to 1, and would somehow suppress all other lossy emission until the carrier density required for gain (or at least transparency) was achieved.