Optika

Nobelovy ceny za fyziku 2005 a 2009

The Nobel Prize in Physics 2005
Roy J. Glauber, John L. Hall, Theodor W. Hänsch

The Nobel Prize in Physics 2009
Charles K. Kao, Willard S. Boyle, George E. Smith

The Nobel Prize in Physics 2012
Serge Haroche, David J. Wineland

Petr Malý
Katedra chemické fyziky a optiky
Matematicko-fyzikální fakulta UK

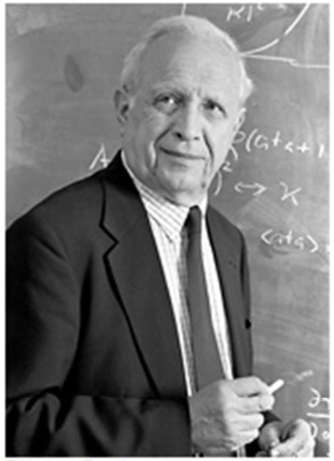


Photo: J.Reed

Roy J. Glauber

Photo: Sears.P.Studio

John L. Hall

Photo: F.M. Schmidt

Theodor W. Hänsch

The Nobel Prize in Physics 2005 was divided, one half awarded to Roy J. Glauber *"for his contribution to the quantum theory of optical coherence"*, the other half jointly to John L. Hall and Theodor W. Hänsch *"for their contributions to the development of laser-based precision spectroscopy, including the optical frequency comb technique"*.

Photo: U. Montan

Charles Kuen Kao

Photo: U. Montan

Willard S. Boyle

Photo: U. Montan

George E. Smith

The Nobel Prize in Physics 2009 was divided, one half awarded to Charles Kuen Kao *"for groundbreaking achievements concerning the transmission of light in fibers for optical communication"*, the other half jointly to Willard S. Boyle and George E. Smith *"for the invention of an imaging semiconductor circuit – the CCD sensor"*.

The Nobel Prize in Physics 2012
Serge Haroche, David J. Wineland

The Nobel Prize in Physics 2012

Serge Haroche

David J. Wineland

Photo: © CNRS Photothèque/Christophe Lebedinsky

Serge Haroche

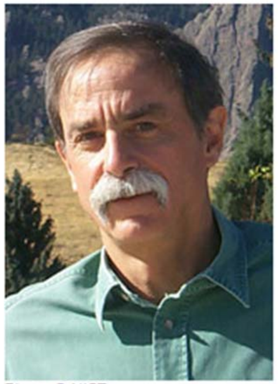


Photo: © NIST

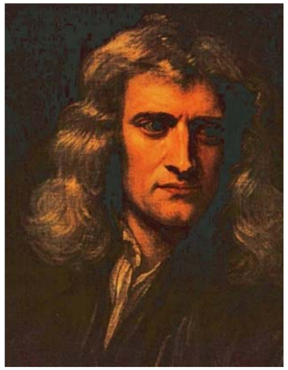
David J. Wineland

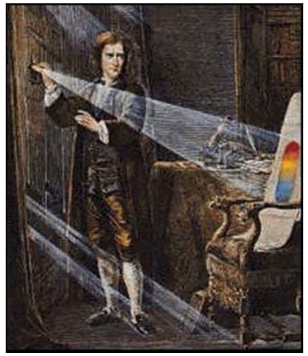
The Nobel Prize in Physics 2012 was awarded jointly to Serge Haroche and David J. Wineland *"for ground-breaking experimental methods that enable measuring and manipulation of individual quantum systems"*

Optika - zobrazování
- aplikace
- základní fyzikální otázky – např. test kvantové teorie
- interakce světla s látkou - optická spektroskopie

Co je světlo: vlnově částicový dualismus

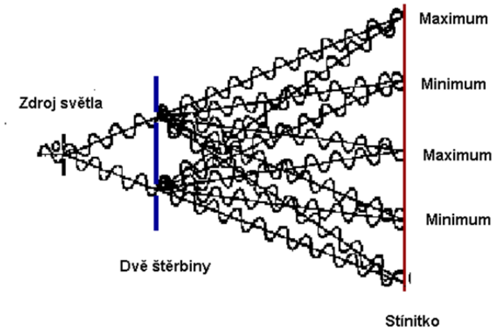
Světlo složeno z částic





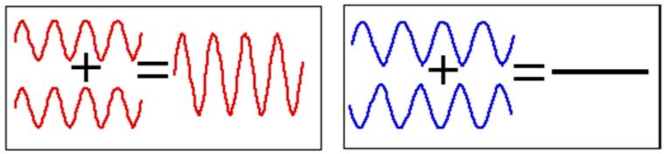
Isaac Newton (1643 - 1727)

Světlo jsou vlny



Youngův experiment

Thomas Young 1802



Konstruktivní interference

Destruktivní interference

Christian Huygens

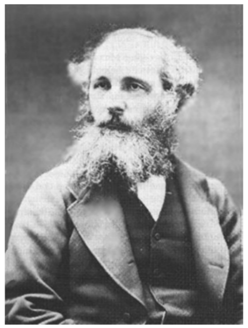
MAXWELLOVY ROVNICE

$$\nabla \times \vec{E} + \frac{\partial \vec{B}}{\partial t} = 0$$

$$\nabla \times \vec{H} - \frac{\partial \vec{D}}{\partial t} = \vec{j}$$

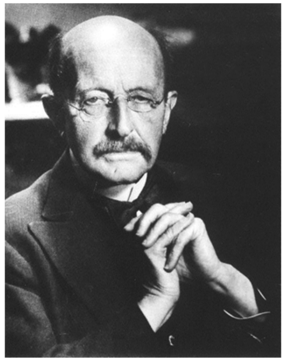
$$\nabla \cdot \vec{D} = \rho$$

$$\nabla \cdot \vec{B} = 0$$



James Clerk Maxwell
1864

Kvantová teorie – světlo: kvanta (fotony)



Max Planck

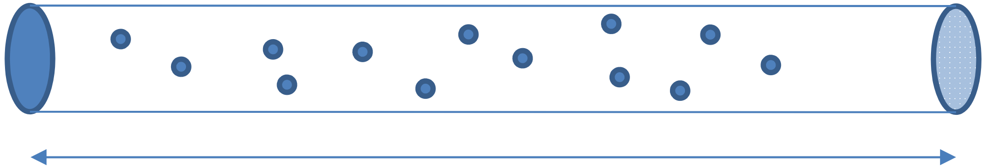
1900 záření černého tělesa

Albert Einstein

1905 fotoefekt

A. P. Dirac 1927 kvantování světla

3×10^9 fotonů

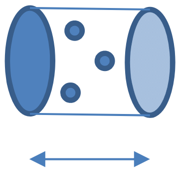


$1\ cm^2$

$c \times 1s = 3 \times 10^8\ m$

$I = 1\ nW\ cm^{-2}$

3 fotony



30 cm = 1 ns x c

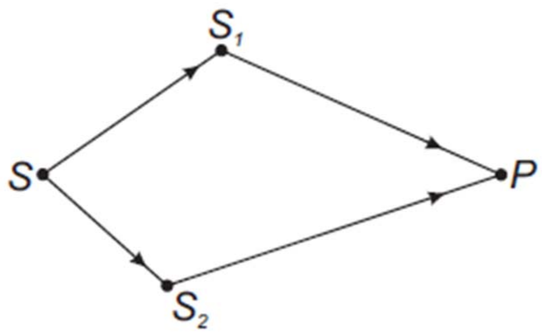
Energie zeleného fotonu = $3{,}7\ 10^{-19}$ J

(540 nm, $\varepsilon = hc/\lambda$)

Měření světla – interakce s látkou

Teoretický model	**Látka**	**Světlo**
Klasický	kmitající dipóly	vlna
Semiklasicý	kvantová teorie	vlna
Kvantový	kvantová teorie	fotony, kvantová teorie

Klasická teorie koherence



Interferenční experimenty

Vlny, měří se korelace mezi poli

$$E_P(t)=E_1(t-\tau_1)+E_2(t-\tau_2)$$

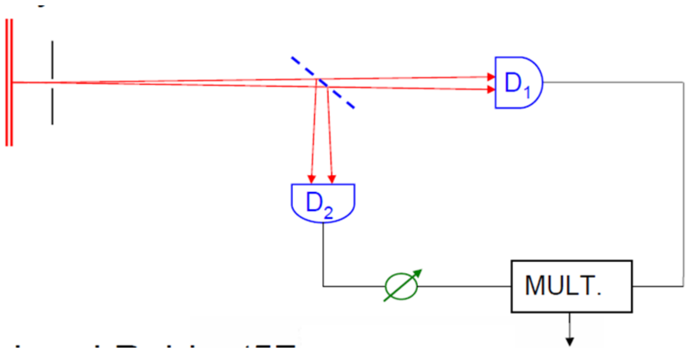
$$I_P = I_1 + I_2 + 2\,\mathrm{Re}\left\{\left\langle \widetilde{E}_1(t-\tau_1)\widetilde{E}_2^*(t-\tau_2)\right\rangle\right\}$$

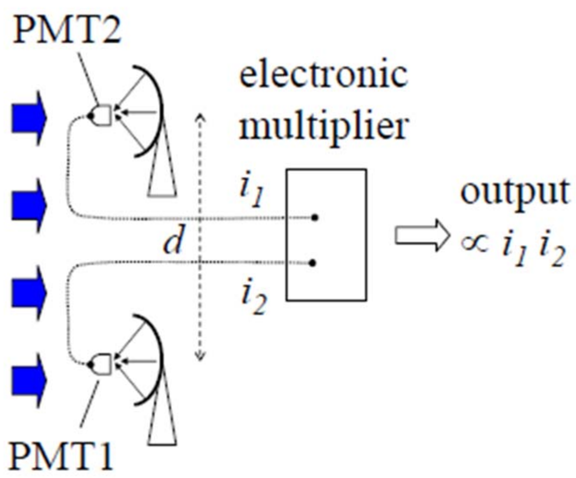
$$\widetilde{\Gamma}_{12}(\tau)=\left\langle \widetilde{E}_1(t)\ \widetilde{E}_2^*(t+\tau)\right\rangle$$

$$\widetilde{\gamma}_{12}(\tau)=\frac{\widetilde{\Gamma}_{12}(\tau)}{\sqrt{I_1 I_2}}$$

Obecná světelná pole – fluktuace, teorie koherence (klasická)

Intenzitní měření

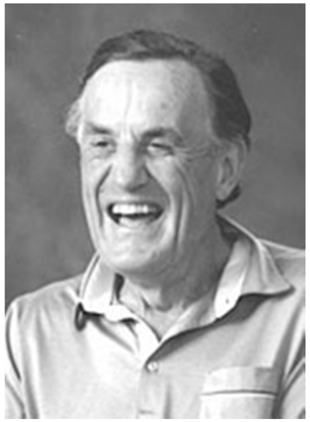




Intenzitní korelace

$$g^{(2)}(\tau) = \frac{\langle I(t)I(t+\tau)\rangle}{\langle I(t)\rangle\langle I(t+\tau)\rangle}$$

R. Hanbury Brown & R. Twiss, 1955-56



R. Hanbury Brown (1916-2002)

R. Q. Twiss
(1920-2005)

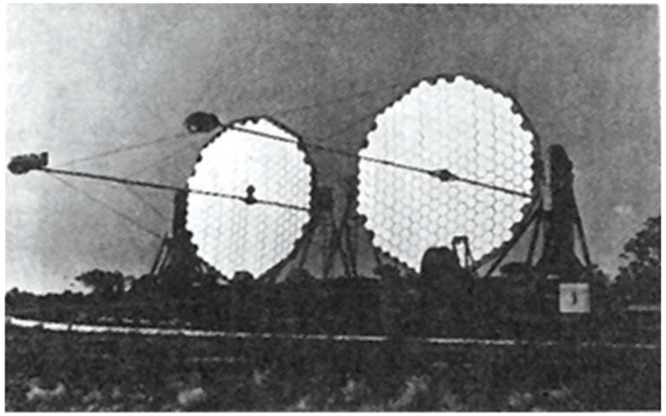
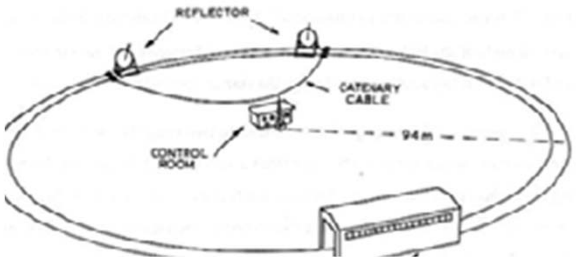
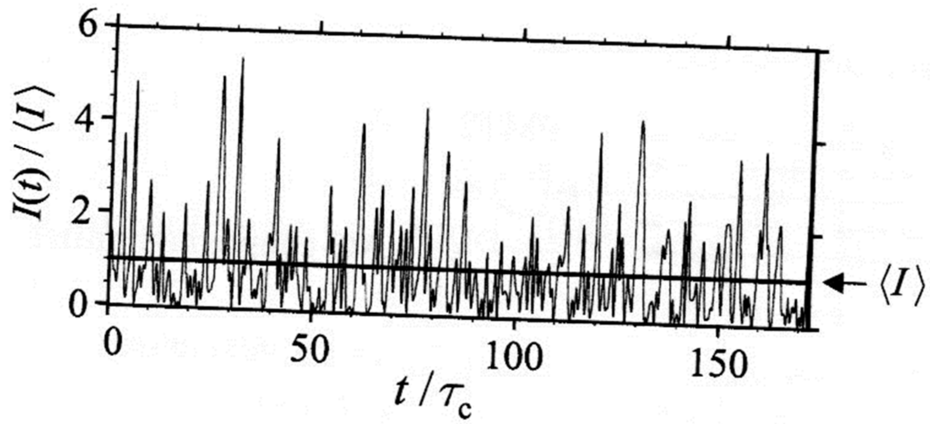


Figure 2. Picture of the two telescopes used in the HBT experiments. The figure was extracted from Ref.[1].

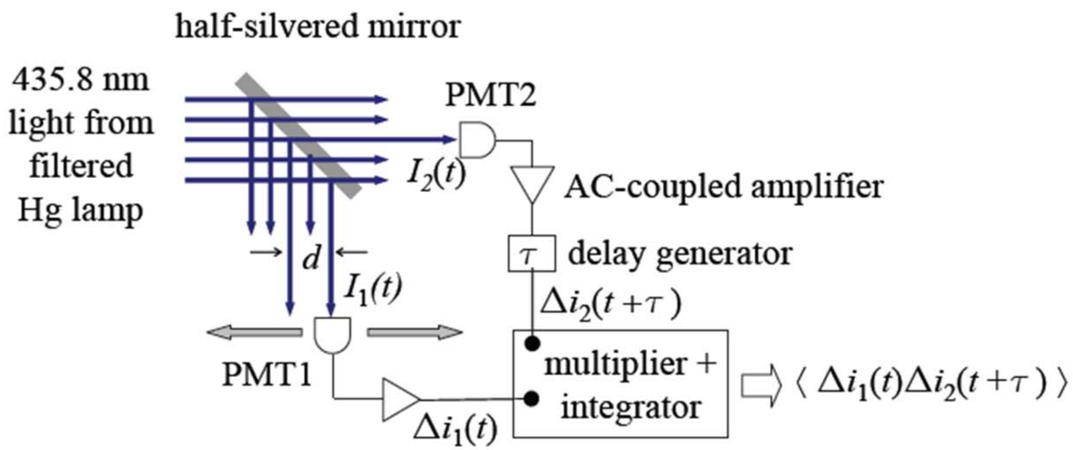


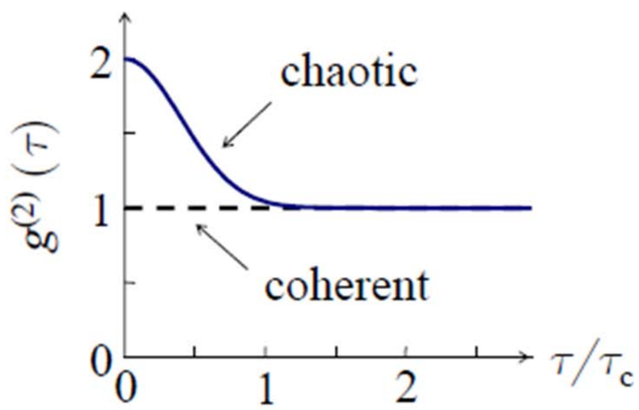


Statistika světla, statistika detekce

Světlo termálních zdrojů …

1960 objev laseru … koherentní světlo





$$g^{(2)}(\tau) = \frac{\langle I(t)I(t+\tau)\rangle}{\langle I(t)\rangle\langle I(t+\tau)\rangle}$$

$$\langle I(t)\rangle = I$$

$$I(t) = I + \Delta I(t) \qquad \langle \Delta I(t)\rangle = 0$$

$$\langle I(t)I(t+\tau)\rangle = \langle (I+\Delta I(t))(I+\Delta I(t+\tau)\rangle = \langle I^2 + I\Delta I(t) + I\Delta I(t+\tau) + \Delta I(t)\Delta I(t+\tau)\rangle$$

$$\gamma(\tau) = 1 + \frac{\langle \Delta I(t)\Delta I(t+\tau)\rangle}{I^2} \qquad \gamma(0) = 1 + \frac{\langle \Delta I(t)^2\rangle}{I^2}$$

Koherentní světlo, fotony ?

Glauber 1963

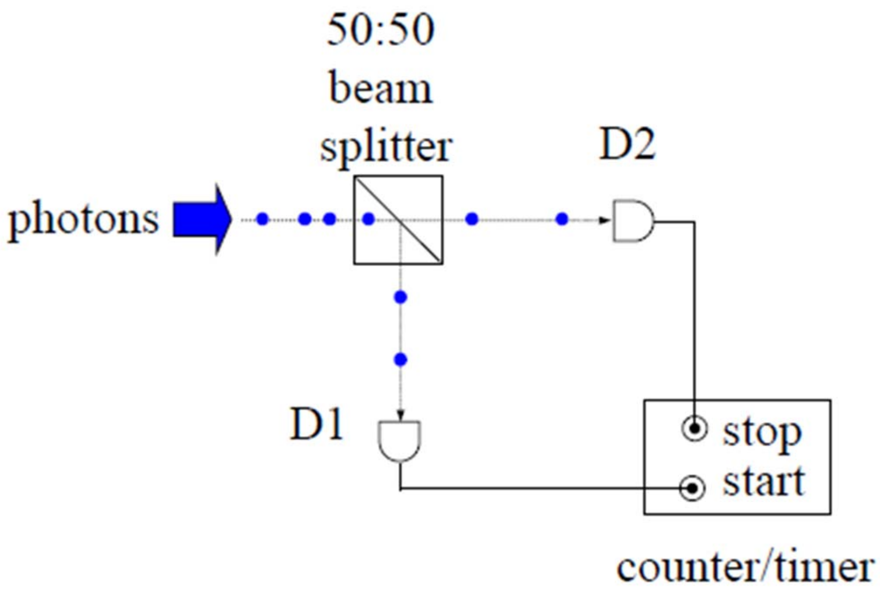
Koherentní stavy světla, kvantová teorie koherence

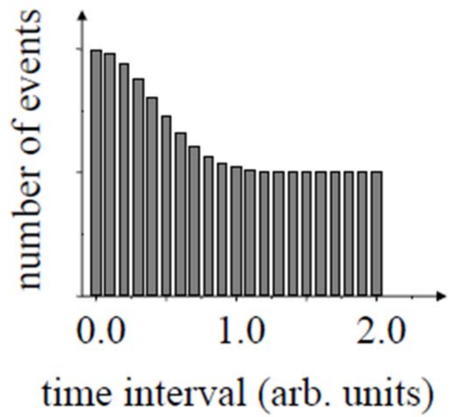
Photo: J.Reed — Photo: Sears.P.Studio — Photo: F.M. Schmidt

Roy J. Glauber — John L. Hall — Theodor W. Hänsch

The Nobel Prize in Physics 2005 was divided, one half awarded to Roy J. Glauber *"for his contribution to the quantum theory of optical coherence"*, the other half jointly to John L. Hall and Theodor W. Hänsch *"for their contributions to the development of laser-based precision spectroscopy, including the optical frequency comb technique"*.

HBT experiment s fotony





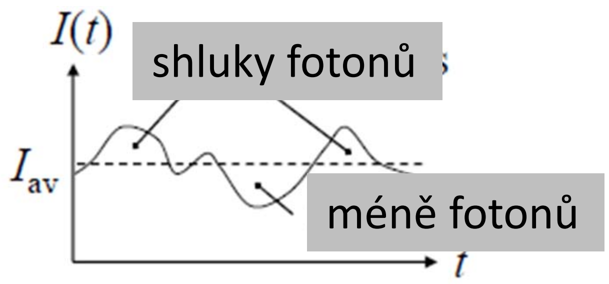
Shluky fotonů: hodně záznamů v okolí τ = 0

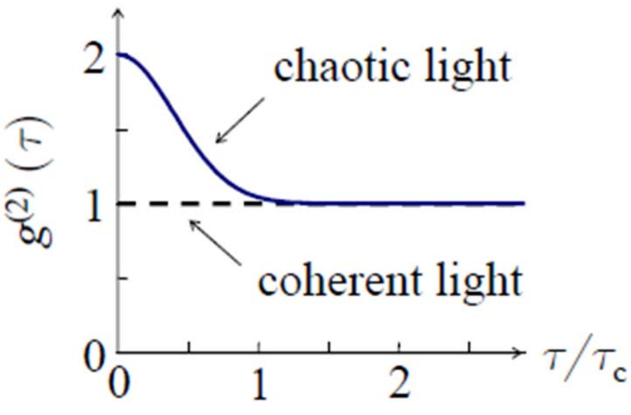
Jednotlivé fotony: žádné záznamy v okolí τ = 0

Pojem shlukování fotonů

Koherentní světlo, žádné fluktuace intenzity ,
náhodné vzdálenosti mezi fotony
(všechny intervaly stejně pravděpodobné) (Poissonova statistika)

Shlukování fotonů, „chaotické světlo“

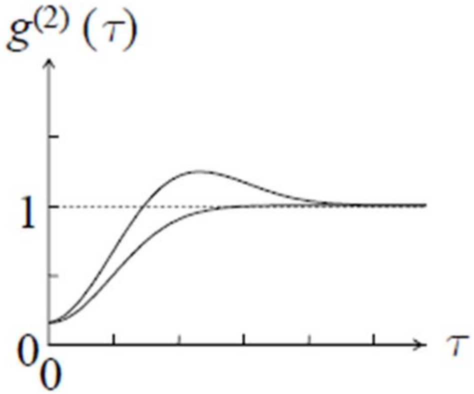




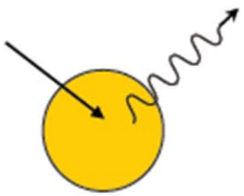
Pojem shlukování fotonů

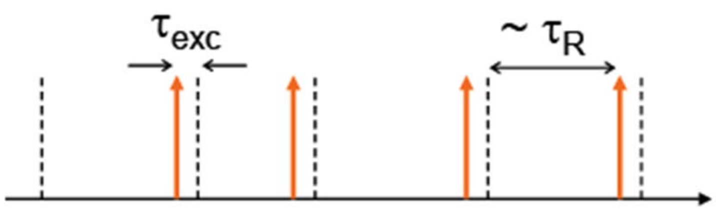
antishlukování fotonů,
pravidelné intervaly

$$g^{(2)}(0) < 1$$



jednofotonové zdroje





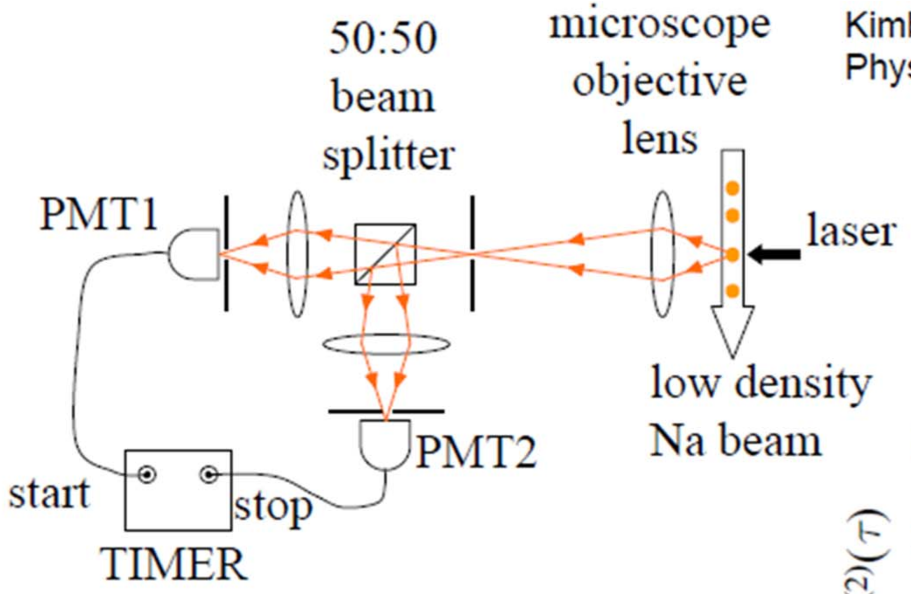
atom,
polovodičový nanokrystal,
barevné luminiscenční centrum v diamantu

ve výbojkách apod. velký počet atomů,
„ztraceno“

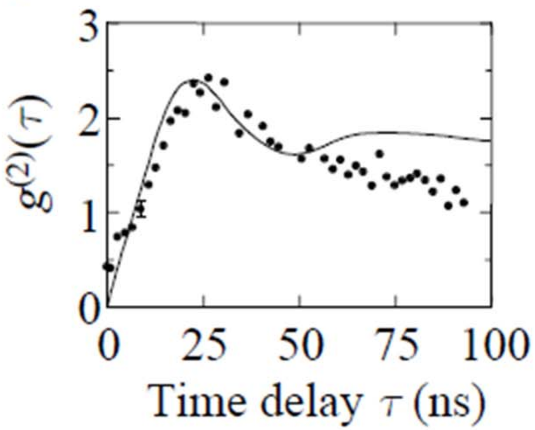
Polovodičová svítící dioda

Yuan et al,
Science 295, 102 (2002)

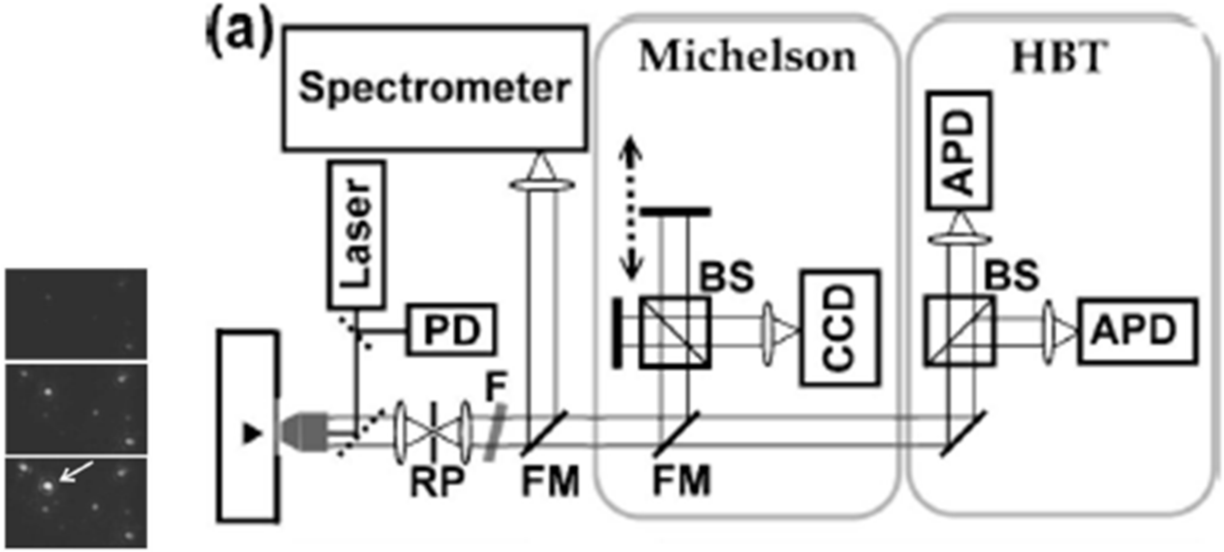
Experimentální pozorování antishlukování



Kimble et al,
Phys. Rev. Lett. 39, 692 (1977)



- $g^{(2)}(0) < 1$
- $g^{(2)}(0)$ not equal to zero due to finite probability of having two atoms in view at a time



V. Zwiller,* T. Aichele, and O. Benson
Nano-Optics, Physics Department, Humboldt University, D-10117 Berlin, Germany

PHYSICAL REVIEW B **69**, 165307 (2004)

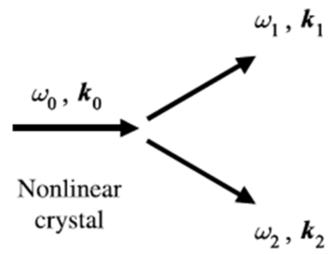
Vlnově-částicový dualismus: Michelsonův interferometr – interference, tj. vlny
HBT měření – částice

„vše s jedním fotonem“

Kvantové jevy v optice

Entanglované stavy (provázané, propletené)

$$|\Psi\rangle = \frac{1}{\sqrt{2}}\left(|\leftrightarrow_1, \updownarrow_2\rangle + e^{i\phi}|\updownarrow_1, \leftrightarrow_2\rangle\right)$$



parametrická generace

Stavy Schrödingerovy kočky

$$|\psi\rangle = N\left(|\alpha\rangle + e^{i\Phi}|-\alpha\rangle\right)$$

Superpozice jednomodových koherentních stavů

$$|\psi\rangle = N\left(|\alpha\rangle + |-\alpha\rangle\right)$$

$$|\psi\rangle = N\left(|\alpha\rangle - |-\alpha\rangle\right)$$

The Nobel Prize in Physics 2012

Serge Haroche, David J. Wineland

The Nobel Prize in Physics 2012

Serge Haroche

David J. Wineland

Photo: © CNRS Photothèque/Christophe Lebedinsky

Serge Haroche

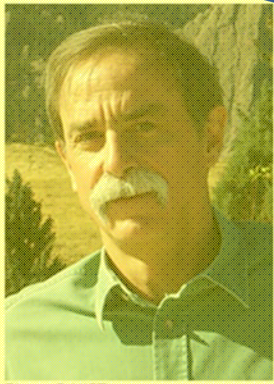


Photo: © NIST

David J. Wineland

The Nobel Prize in Physics 2012 was awarded jointly to Serge Haroche and David J. Wineland *"for ground-breaking experimental methods that enable measuring and manipulation of individual quantum systems"*

Control of individual quantum systems

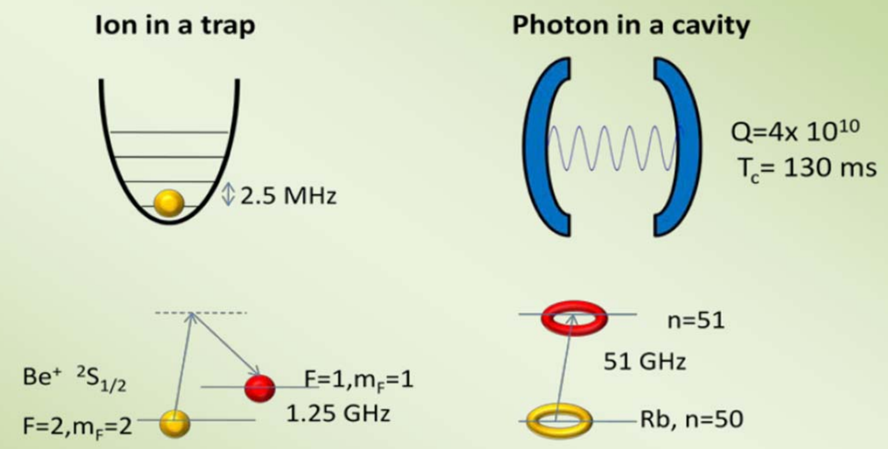
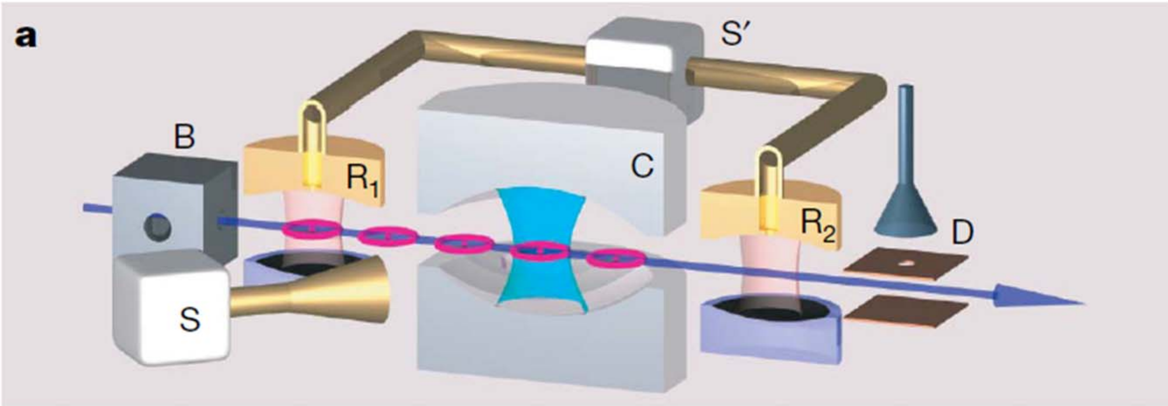
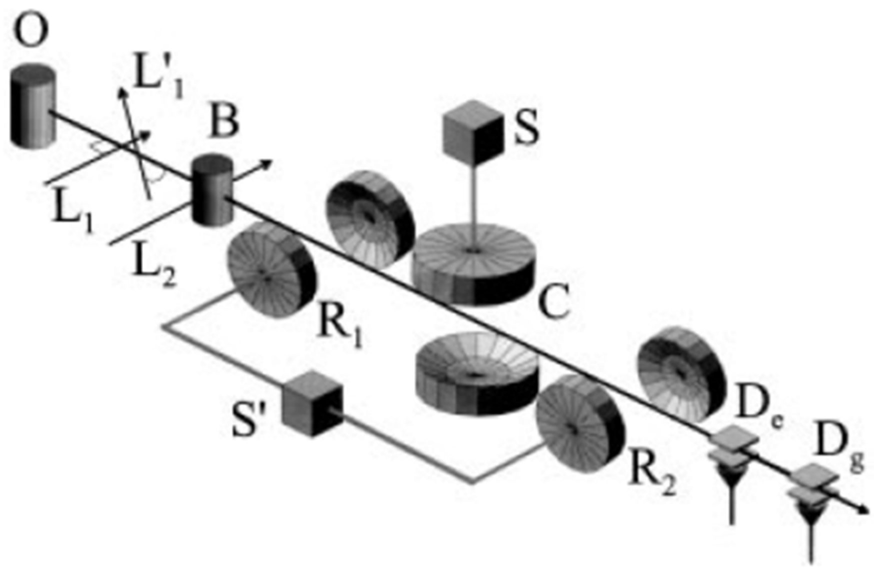


Fig. 1: Illustration of the two types of experiments discussed in this scientific background: On the left, an ion is captured in a harmonic trap. Its quantum state (both its internal state and its motion) is controlled by interaction with laser pulses as exemplified for the case of Be^+. On the right, a photon is (or several photons are) trapped in a high-Q microwave cavity. The field state is measured and controlled by interaction with highly excited Rb atoms.



Atomy Rb , Rydbergovy atomy , n=50,51 , tzv. kruhové stavy.
Optická dutina C schlazená na 1K (supravodivá, vysoká odrazivost), doba života fotonu 130 ms.
R1, R2 sfázované mikrovlnné zdroje
Interakce atomu s polem při průletu dutinou, interakce s polem R2 fázově citlivá.
Ionizační detektor –detekce stavu atomu



VOLUME 77, NUMBER 24 PHYSICAL REVIEW LETTERS 9 DECEMBER 1996

Observing the Progressive Decoherence of the "Meter" in a Quantum Measurement

M. Brune, E. Hagley, J. Dreyer, X. Maître, A. Maali, C. Wunderlich, J. M. Raimond, and S. Haroche

Laboratoire Kastler Brossel, Département de Physique de l'Ecole Normale Supérieure, 24 Rue Lhomond, F-75231 Paris Cedex 05, France*

nature Vol 455|25 September 2008|doi:10.1038/nature07288

LETTERS

Reconstruction of non-classical cavity field states with snapshots of their decoherence

Samuel Deléglise[1], Igor Dotsenko[1,2], Clément Sayrin[1], Julien Bernu[1], Michel Brune[1], Jean-Michel Raimond[1] & Serge Haroche[1,2]

nature Vol 455|25 September 2008|doi:10.1038/nature07288

LETTERS

Reconstruction of non-classical cavity field states with snapshots of their decoherence

Samuel Deléglise[1], Igor Dotsenko[1,2], Clément Sayrin[1], Julien Bernu[1], Michel Brune[1], Jean-Michel Raimond[1] & Serge Haroche[1,2]

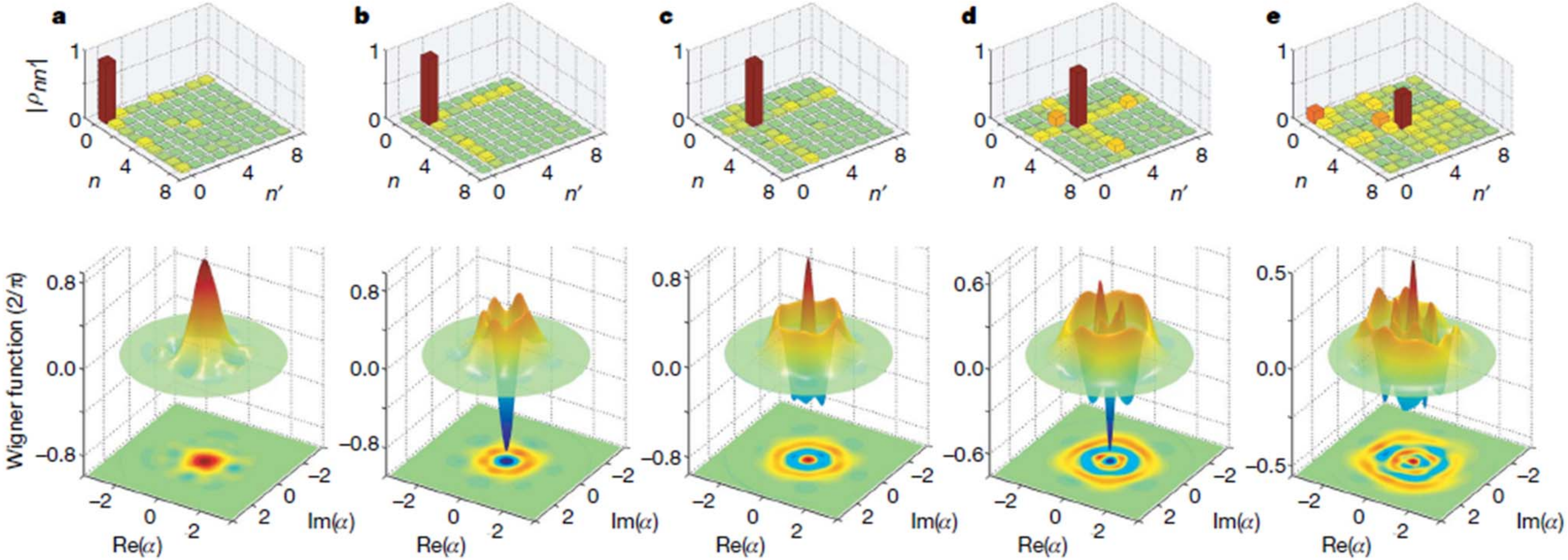


Figure 2 | Reconstructing Fock states. a–e, Reconstructed density matrices (modulus of matrix elements) and Wigner functions (in units of $2/\pi$) of the $n_0 = 0, 1, 2, 3, 4$ Fock states prepared by quantum non-demolition projection of an initial coherent field ($n_m = 1.5$ for $n_0 = 0, 1, 2, 3$; $n_m = 5.5$ for $n_0 = 4$). The Wigner functions are shown as three-dimensional plots and two-dimensional projections. We select a photon number n_0 if, after the detection of ~60 preparation atoms, the measurement has converged to a Fock state having a probability >0.9 for $n_0 = 0, 1, 2, 3$ and >0.8 for $n_0 = 4$. The same detuning ($\delta/2\pi = 120$ kHz) is used for state preparation and reconstruction, corresponding to $\partial\Phi/\partial n \approx \pi/2$ at $n = 3$. Two values of ϕ ($-\Phi(0,\delta) + \pi$ and $-\Phi(0,\delta) + \pi/2$) are used for state preparation and reconstruction, which is made in a nine-dimensional Hilbert space. We sample ~400 points in phase space and, for each point, average between about 50 (for $n_0 = 3$) and 500 ($n_0 = 0, 1$) realizations, with ~10 atoms in each realization. In addition to the main peak in the density matrices, for $n_0 > 1$ we observe a small diagonal peak at $n = n_0 - 1$ due to cavity damping during reconstruction. A peak at $n = 0$ also appears in the $n_0 = 4$ density matrix, because of imperfections in the state preparation process that selects the photon number modulo four (as $\Phi(n+4,\delta) \approx \Phi(n,\delta) + 2\pi$). The off-diagonal elements in the density matrices and the corresponding fluctuations in the angular distributions of the Wigner functions mainly reflect statistical noise (fewer atoms detected for reconstructing $n_0 = 2, 3, 4$ than for $n_0 = 0, 1$). The fidelities, $F = \langle n_0|\rho|n_0\rangle$, of the reconstructed states are 0.89, 0.98, 0.92, 0.82, 0.51 for $n_0 = 0, 1, 2, 3, 4$, respectively.

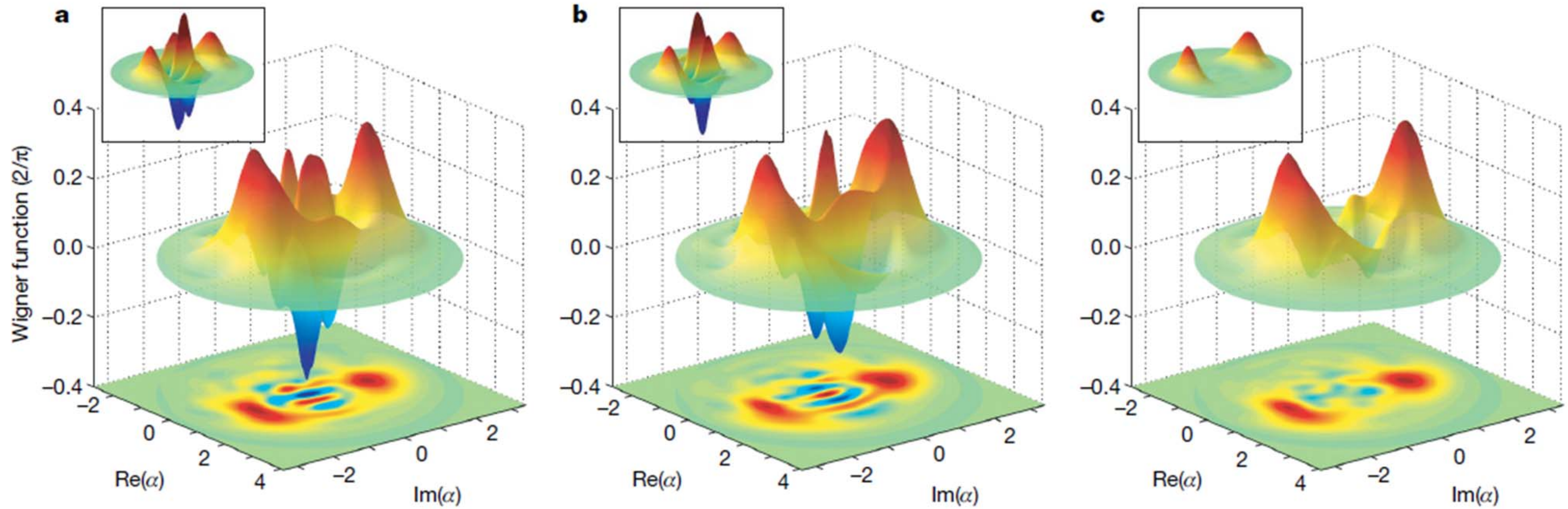


Figure 3 | Reconstructing Schrödinger cat states. a, b, The Wigner functions (in units of $2/\pi$) of even (**a**) and odd (**b**) Schrödinger cat states with $n_m = 3.5$ and $\chi = 0.37\pi$ are reconstructed, following state preparation. The same detuning ($\delta/2\pi = 51$ kHz) and interferometer phase ($\phi = -\Phi(0, \delta) + \pi$) are used for state preparation and reconstruction. The number of sampling points is ~500, with ~2,000 atoms detected at each point, in 400 realizations. The dimension of the Hilbert space used for reconstruction is 11. The small insets present for comparison the theoretical Wigner functions computed in the case of ideal preparation and detection of the atomic state superpositions. Decoherence during state preparation is taken into account. The maximum theoretical values of the classical components and interference fringes are close to 0.5 and 1, respectively. In the reconstructed states, the quantum interference is smaller, mainly owing to imperfections of the Ramsey interferometer that affect the preparation of the Schrödinger cat state (but not its reconstruction). **c**, Reconstructed Wigner function of the field prepared in C when the state of the preparation atom is not read-out (statistical mixture of two classical fields). Inset, corresponding theoretical Wigner function.

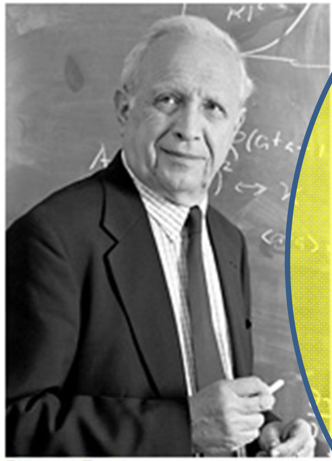


Photo: J.Reed

Roy J. Glauber

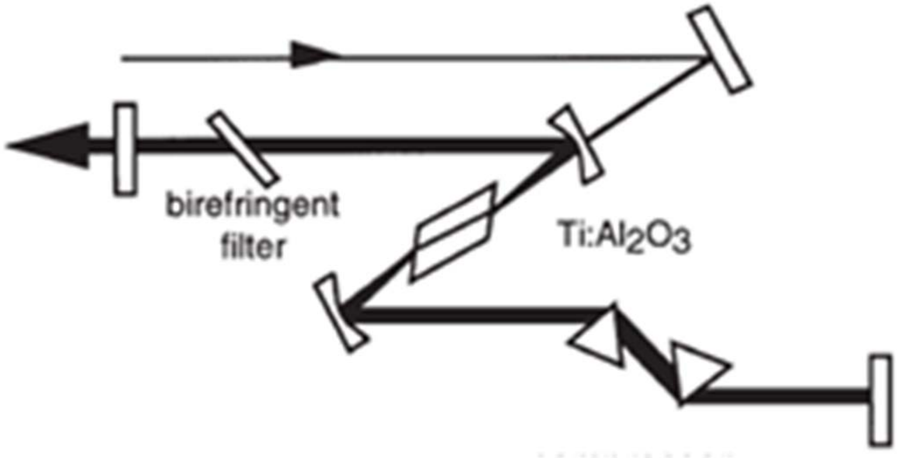
Photo: Sears.P.Studio

John L. Hall

Photo: F.M. Schmidt

Theodor W. Hänsch

The Nobel Prize in Physics 2005 was divided, one half awarded to Roy J. Glauber *"for his contribution to the quantum theory of optical coherence"*, the other half jointly to John L. Hall and Theodor W. Hänsch *"for their contributions to the development of laser-based precision spectroscopy, including the optical frequency comb technique"*.

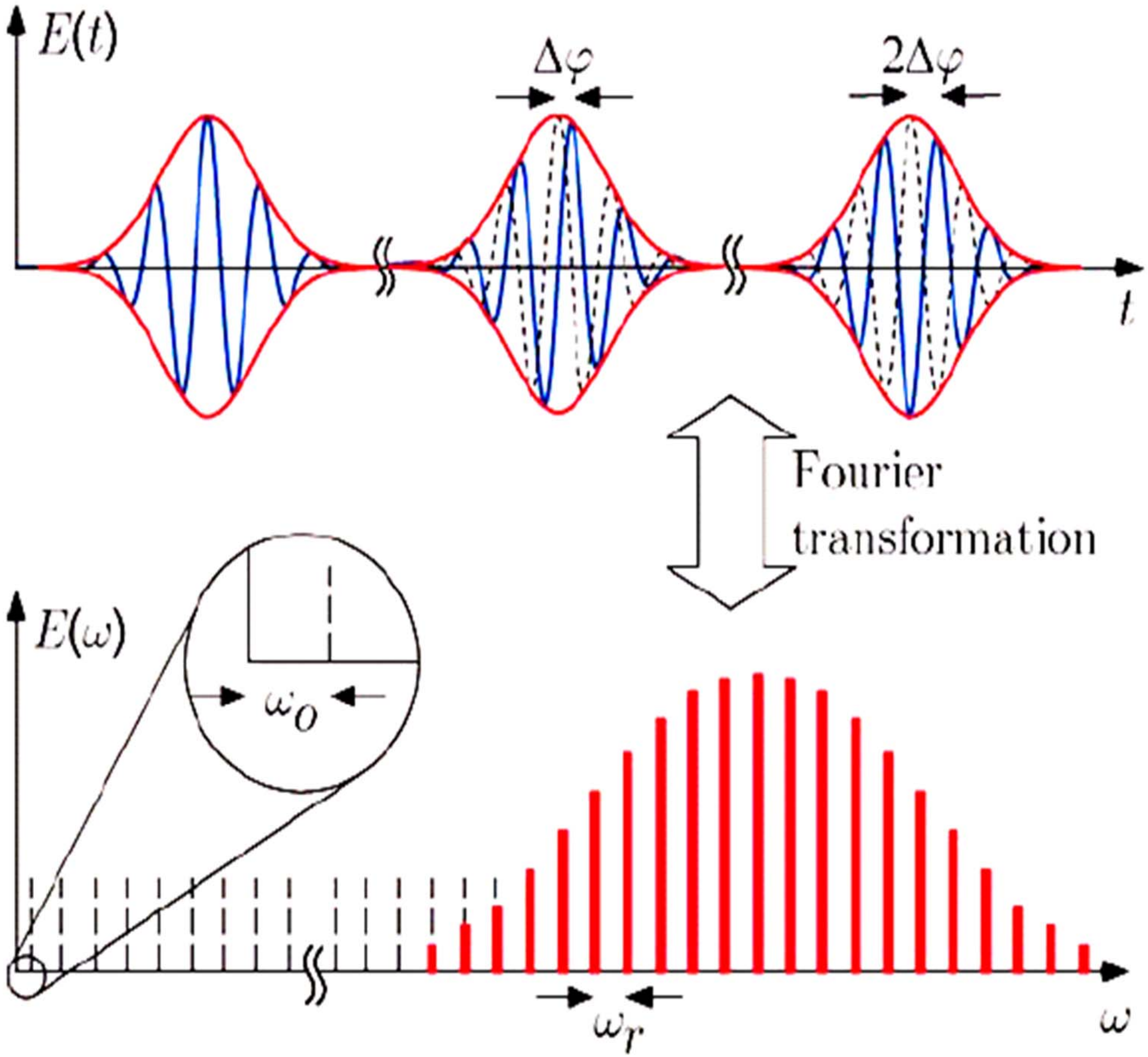


Femtosekundový laser – základní schéma

$$\cos(\omega_1 t) + \cos(\omega_2 t) = 2\cos\left(\frac{\omega_1 + \omega_2}{2} t\right)\cos\left(\frac{\omega_1 - \omega_2}{2} t\right)$$

$$\omega_1 = \omega_2 + \Delta\omega \qquad \cos(\omega_1 t) + \cos(\omega_2 t) \approx 2\cos(\omega_1 t)\cos\left(\frac{\Delta\omega}{2} t\right)$$

zázněje, porovnání frekvencí



$E(t)$
$\Delta\varphi$
$2\Delta\varphi$
t
Fourier transformation
$E(\omega)$
ω_0
ω_r
ω

$$E(t) = \mathrm{Re}\left(A(t) \cdot e^{-i\,2\pi\, f_c\, t}\right)$$

$$A(t) = A(t+T) \qquad A(t) = \sum_k A_k \cdot e^{-i\;2\pi\, k\, f_r\, t}$$ Fourierův rozvoj

$$E(t) = \mathrm{Re}\left(\sum_k A_k \cdot e^{-i\;2\pi\,(f_c + k\, f_r)\,t}\right)$$

$$f_c = m f_r + f_o$$ Najdeme číslo m, aby f0 bylo co nejmenší

$$n = m + k$$ Označíme

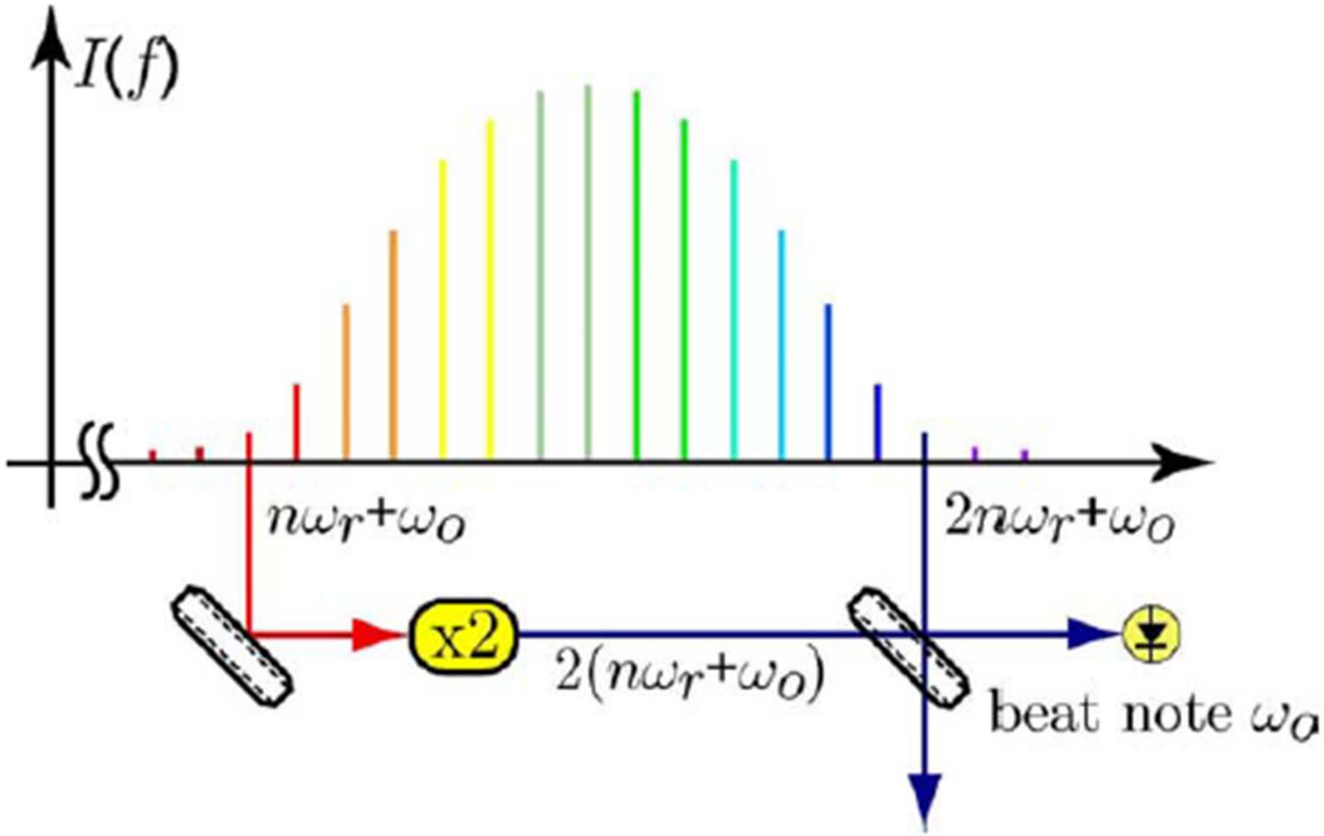
$$E(t) = \mathrm{Re}\left(\sum_n A_n \cdot e^{-i\;2\pi\,(f_o + n\, f_r)\,t}\right)$$

$$f_n = f_o + n f_r$$ Frekvence zubů

f_r lze snadno měřit, nastavuje se délkou rezonátoru

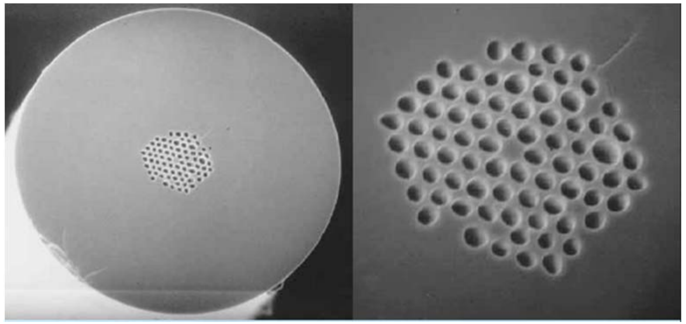
typicky f_r= 50MHz..1 GHz
n= $1x10^6$

f_o složitější, nastavuje se „disperzí“ v rezonátoru, např. klín, …



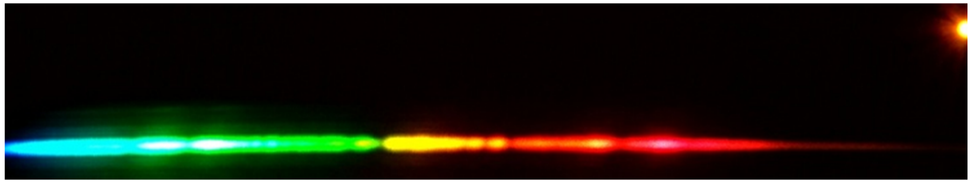
$$2 \cdot f_n - f_{2n} = 2\left(nf_r + f_o\right) - \left(2nf_r + f_o\right) = 2nf_r + 2f_o - 2nf_r - f_o = f_o$$

$$f_n = f_o + nf_r$$



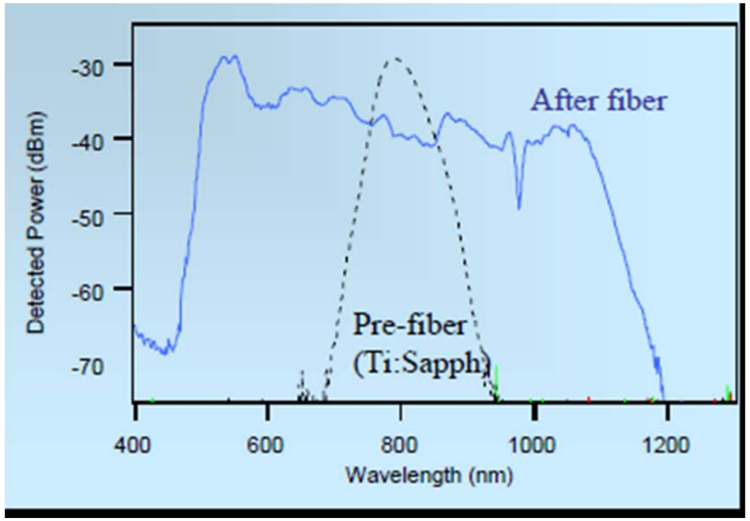
Vysoké optické nelinearity

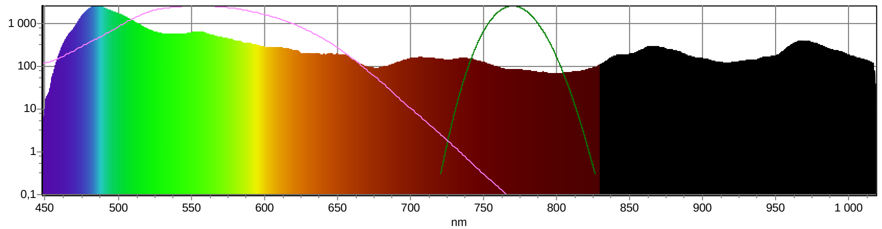
Generace femtosekundového kontinua



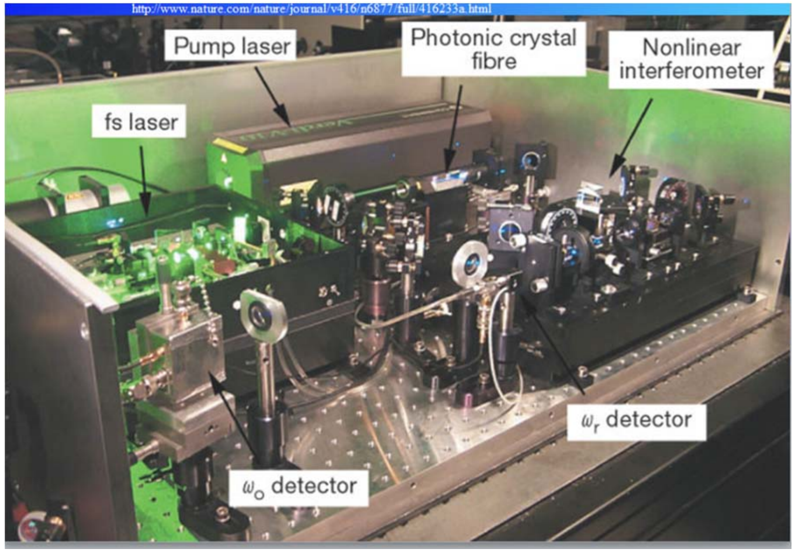
Fotonická vlákna

1999



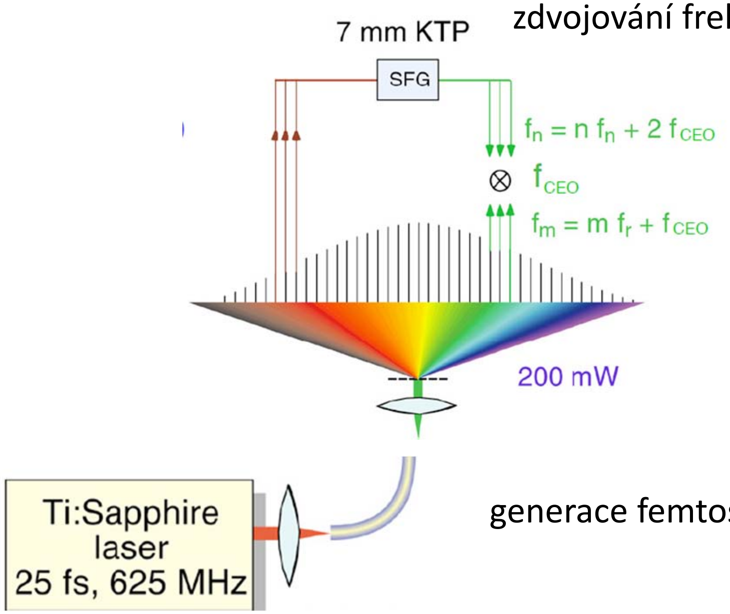


Zdvojování frekvence v nelineárním krystalu



MPQ- MenloSystems

zdvojování frekvence v nelineárním krystalu



generace femtosekundového kontinua

Přesnost měření základní frekvence a 2. harmonické 2x 10^{-20}

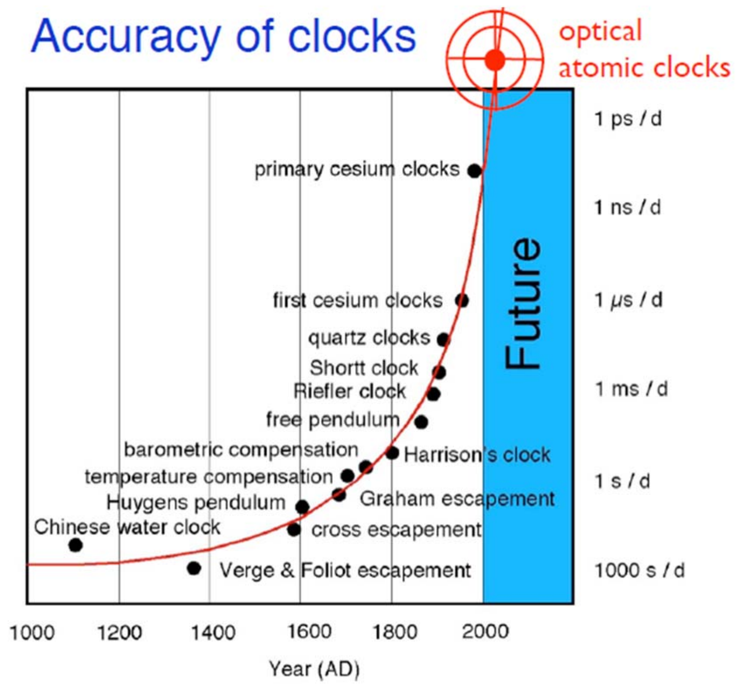
Porovnání 2 hřebenů 10^{-20} relativní přesnost

Přesnost optických hodin lepší než atomových, během sekund …

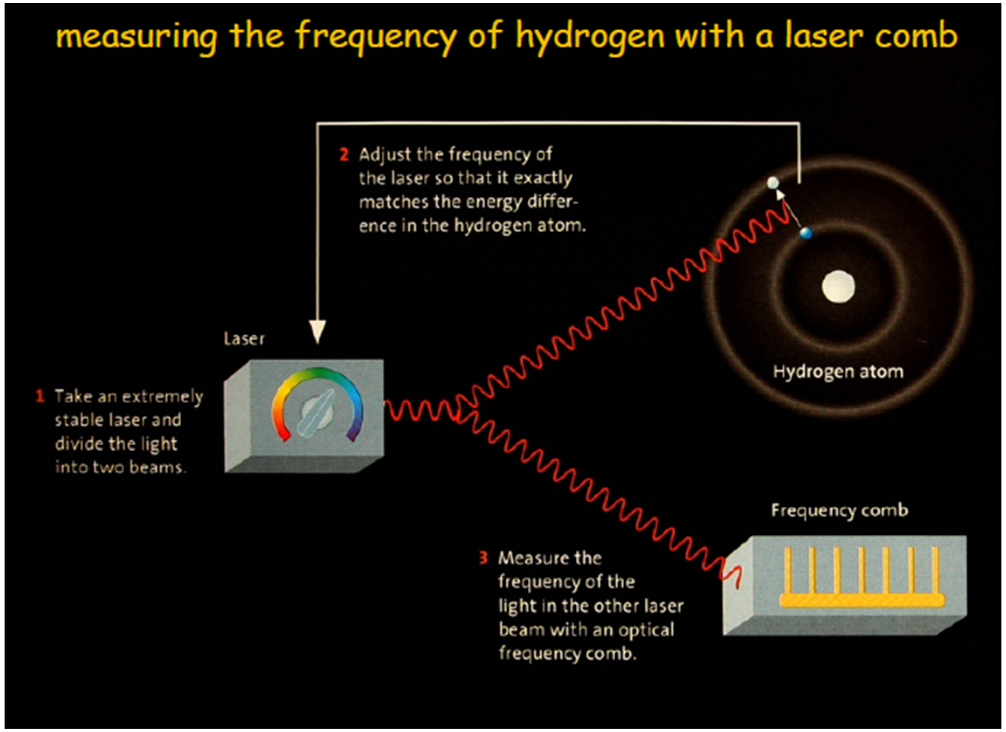
Přesnost optických hodin v současnosti cca 1 s / dobu života Země

Synchronizace 2 optických hodin na 1000 km optickými vlákny

K. Predehl, G. Grosche, S.M.F. Raupach, S. Droste, O. Terra, J. Alnis, Th. Legero, T.W. Hänsch, Th. Udem, R. Holzwarth, and H. Schnatz
A 920 km Optical Fiber Link for Frequency Metrology at the 19th Decimal Place., *Science, 27 April 2012*



T. Hansch, Nobel Lecture



T. Hansch, Nobel Lecture

Hydrogen 1S-2S frequency

(F=1 to F'=1 hyperfine component)

Feb. 2003: f(1S-2S) = (2 466 061 102 474 851 ± 34) Hz
relative uncertainty: 1.4×10^{-14}

June 1999: f(1S-2S) = (2 466 061 102 474 870 ± 46) Hz
relative uncertainty: 1.9×10^{-14}

A difference of (-29 ± 57) Hz in 44 months equals a relative drift of the 1S-2S transition frequency of

$(3.2 \pm 6.3) \times 10^{-15}$ per year

RL 102, 213002 (2009) PHYSICAL REVIEW LETTERS week ending 29 MAY 2009

Measurement of the 2S Hyperfine Interval in Atomic Hydrogen

N. Kolachevsky,* A. Matveev,* J. Alnis, C. G. Parthey, S. G. Karshenboim,† and T. W. Hänsch
Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany
(Received 3 February 2009; published 28 May 2009)

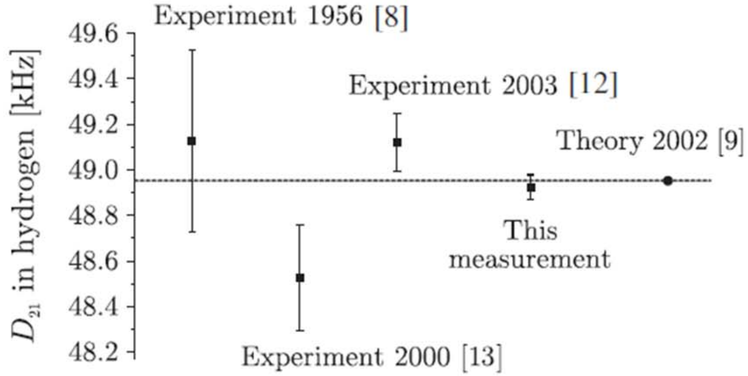


FIG. 4. Experimental and theoretical values for the $D_{21} = 8f_{\mathrm{HFS}}(2S) - f_{\mathrm{HFS}}(1S)$ difference in atomic hydrogen.

Photo: U. Montan

Charles Kuen Kao

Photo: U. Montan

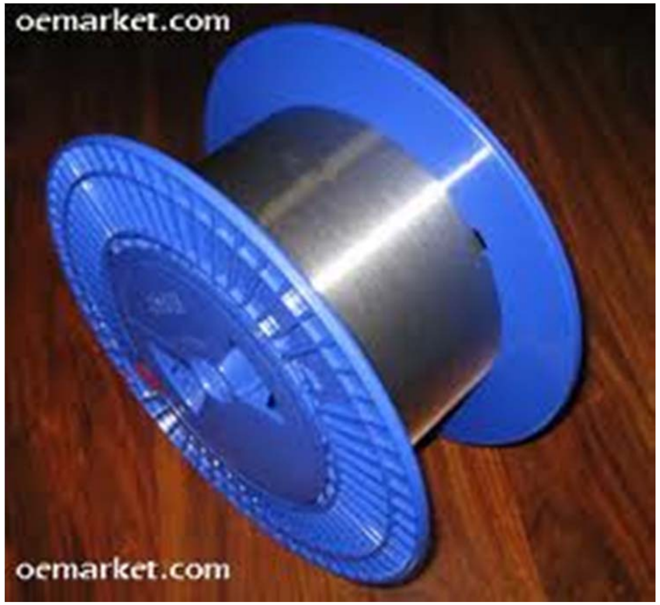
Willard S. Boyle

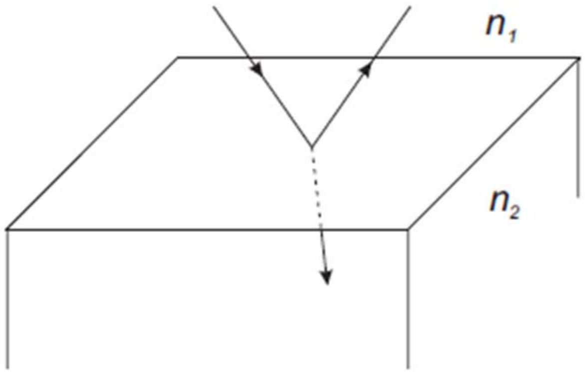
Photo: U. Montan

George E. Smith

The Nobel Prize in Physics 2009 was divided, one half awarded to Charles Kuen Kao *"for groundbreaking achievements concerning the transmission of light in fibers for optical communication"*, the other half jointly to Willard S. Boyle and George E. Smith *"for the invention of an imaging semiconductor circuit – the CCD sensor"*.

Optická vlákna





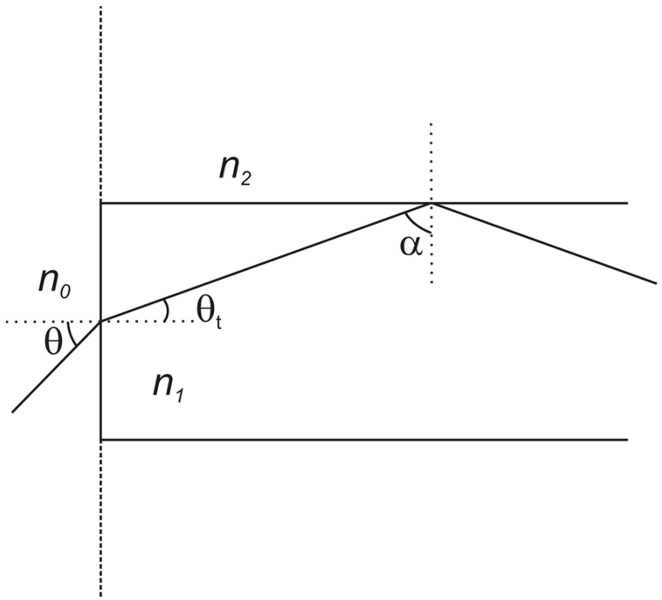
$$n_1 \sin\theta = n_2 \sin\theta_t$$

pro $n_2 < n_1$ $\theta_t > \theta$

kritický úhel dopadu $\theta = \theta_c$

$$n_1 \sin\theta_c = n_2 \sin 90^\circ = n_2$$

úplný odraz



$$\sin \alpha_c = \frac{n_2}{n_1}$$

$$\theta_t + \alpha = \frac{\pi}{2}$$

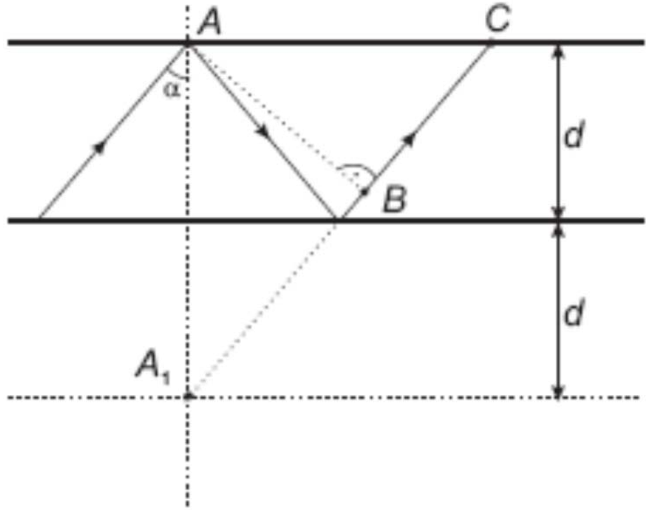
$$n_0 \sin \theta = n_1 \sin \theta_t$$

$$n_0^2 \sin^2 \theta_{\max} = n_1^2 - n_2^2$$

$$NA = n_0 \sin \theta_{\max} = \sqrt{n_1^2 - n_2^2}$$

křemenné vlákno se skokovou změnou indexu lomu ($n1$ = 1,53, a $n2$ =1,51)
NA=0,247 a pro n_0 = 1,0 vychází akceptační úhel 14º

Numerická apertura



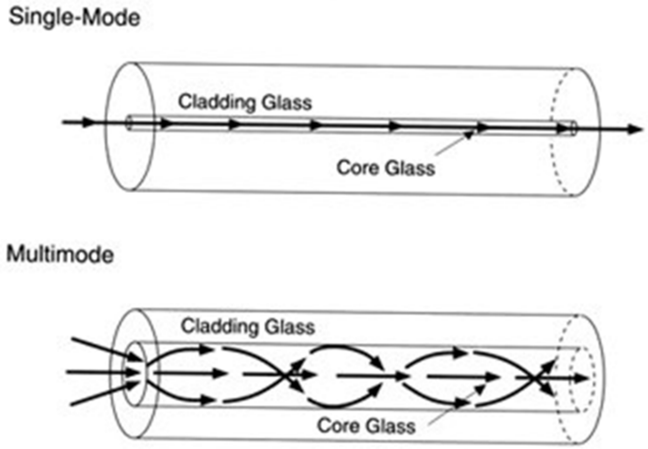
Obr. 17.2 Planární vlnovod – k výkladu vedených modů

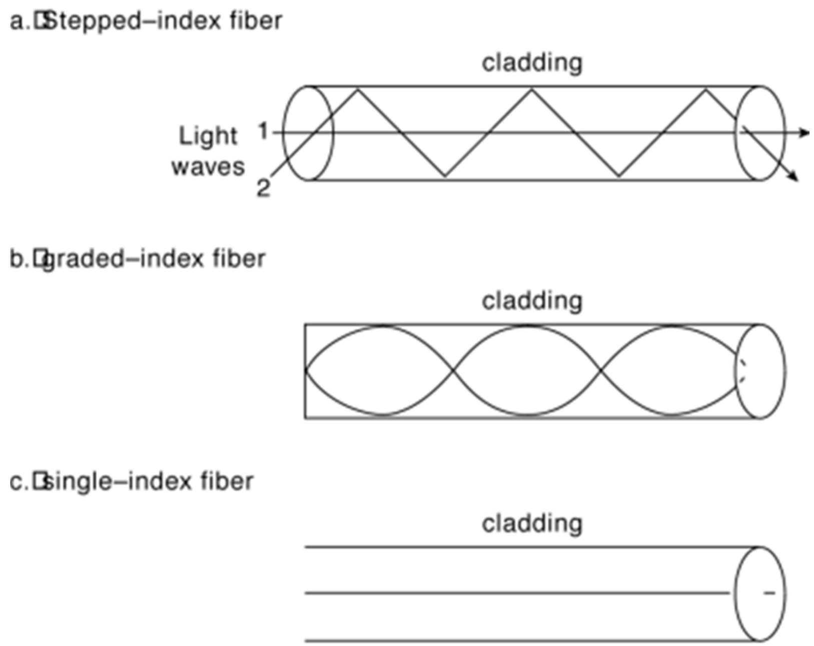
$$A_1B = 2d\cos\alpha$$

$$2n_1k_0d\cos\alpha + \Delta\varphi = 2m\pi \qquad m = 0,1,\dots,M$$

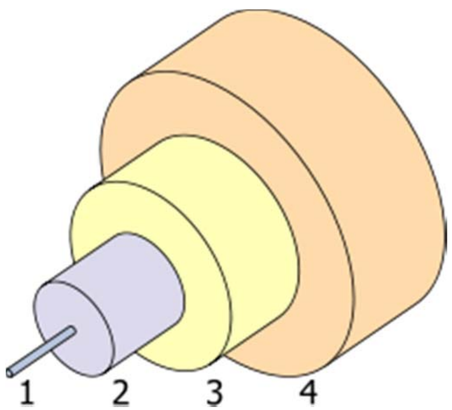
$$\Delta\varphi \approx 0 \qquad 2n_1k_0d\cos\alpha_c \approx 2M\pi \qquad M \approx \left\{\frac{2d}{\lambda_0}NA\right\}_{CELÁ\ ČÁST}$$

Existence módů v optickém vlnovodu





Jednomodové vlákno



1.- Core 8-10 µm
2.- Cladding 125 µm
3.- Buffer 250 µm
4.- Jacket 400 µm

Útlum vlákna

$$ÚTLUM = 10\log_{10}\left(\frac{P_1}{P_2}\right)$$

$$\alpha[\mathrm{dB/km}] = \frac{10}{L[\mathrm{km}]}\log\left(\frac{P_{\mathrm{in}}}{P_{\mathrm{out}}}\right)$$

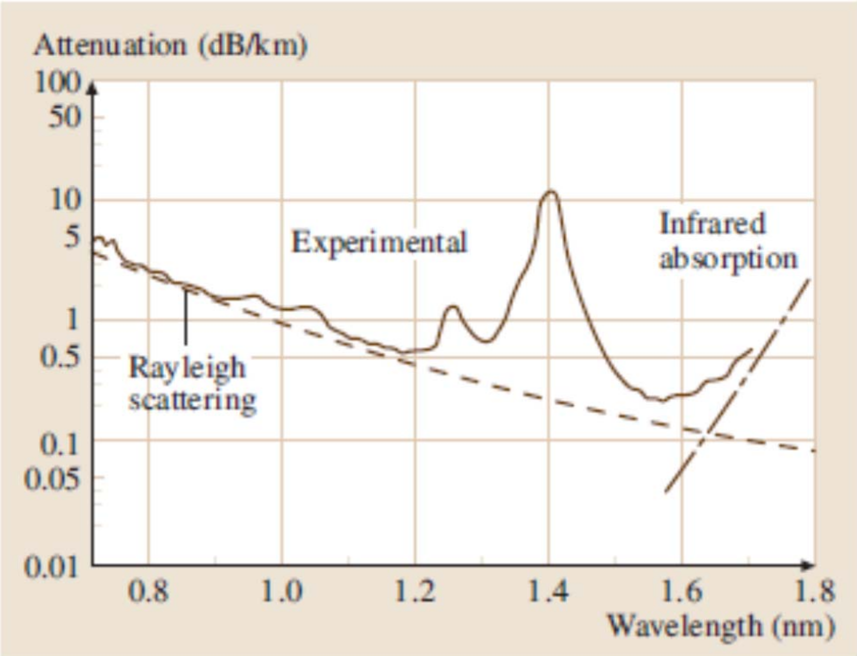


Fig. 8.69 Attenuation spectrum of a typical silica optical fiber (after [8.231])

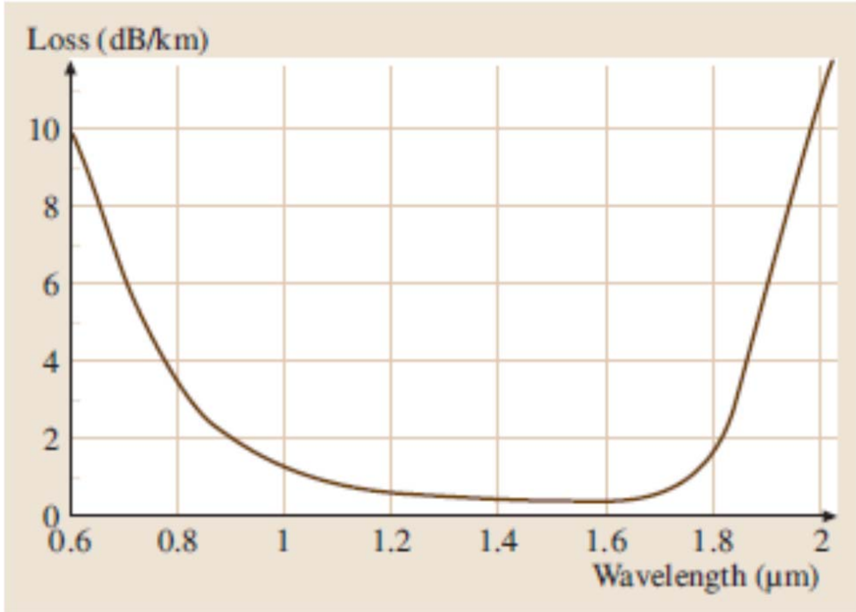
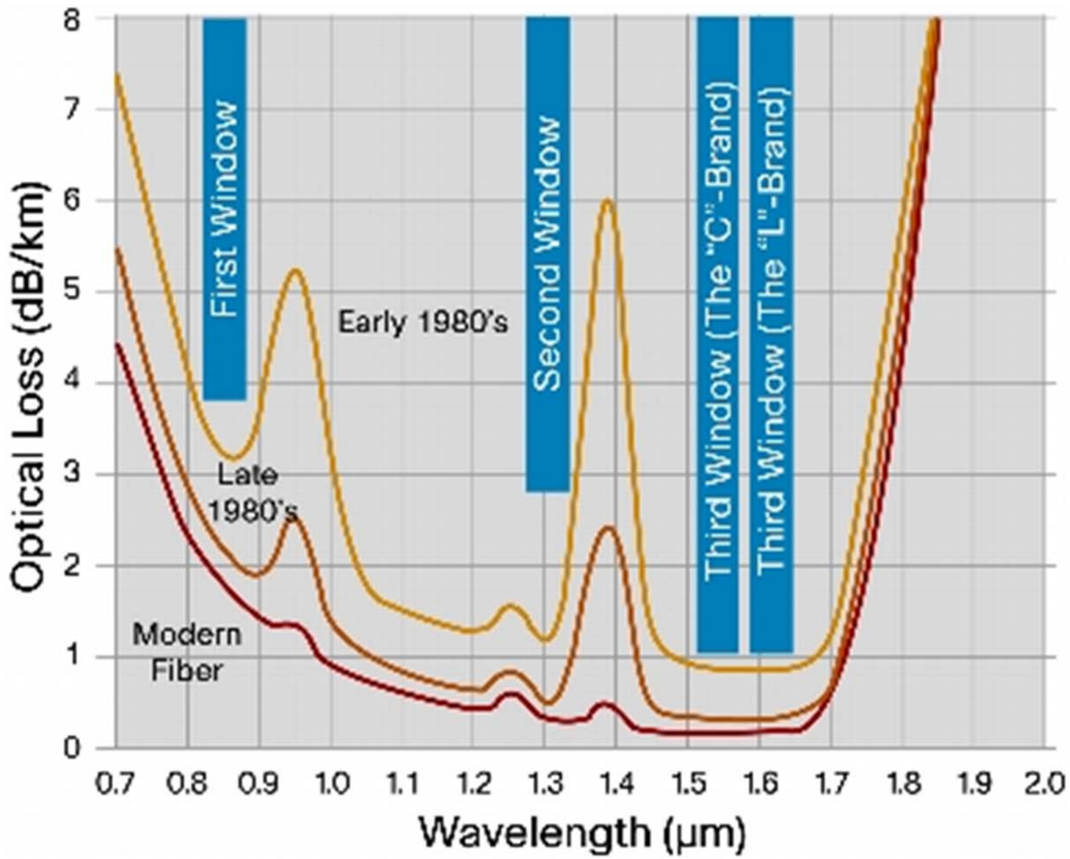


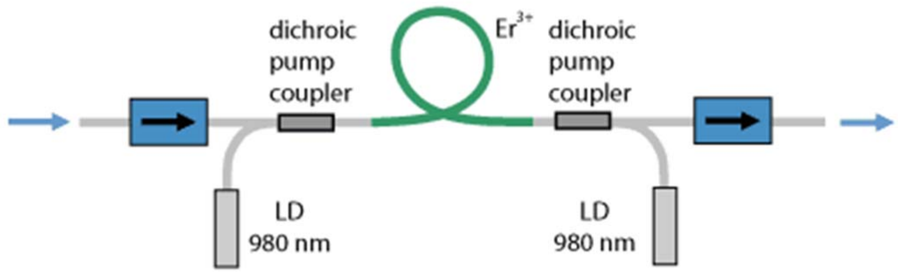
Fig. 8.70 Loss spectrum of an optical fiber with ultimately low water content. Note that the low-loss window extends from 1250 nm to 1650 nm (≈ 50 THz) and such fibers are now available commercially (after [8.232])

0,17–0,25 dB/km pro vlnovou delku 1,55 µm

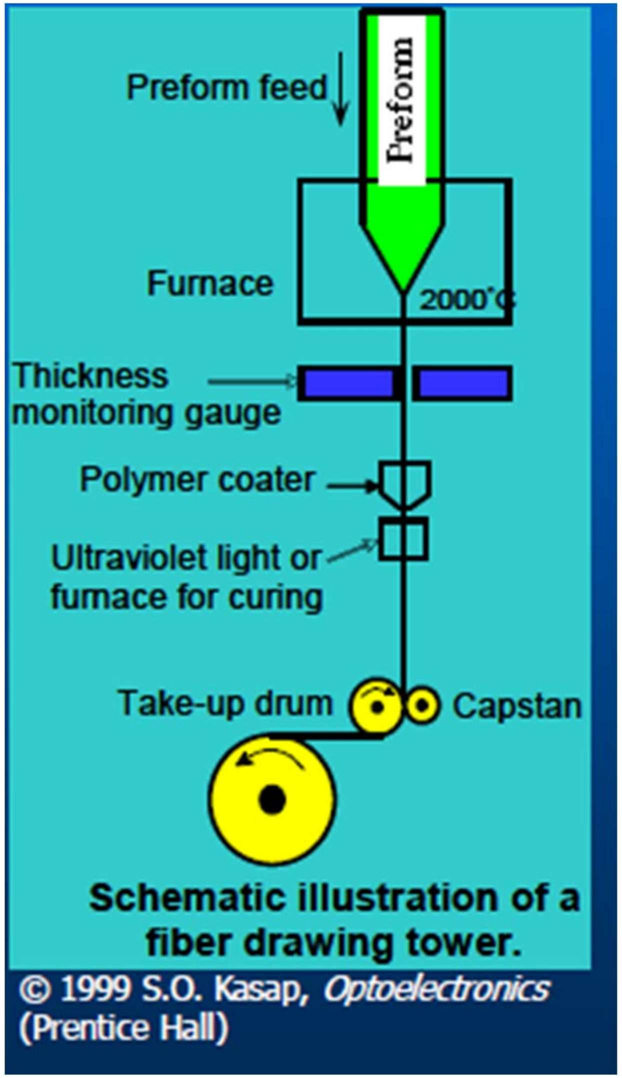
0,35–0,6 dB/km pro vlnovou delku 1,3 µm



útlum



zesilovač



Tažení vlákna

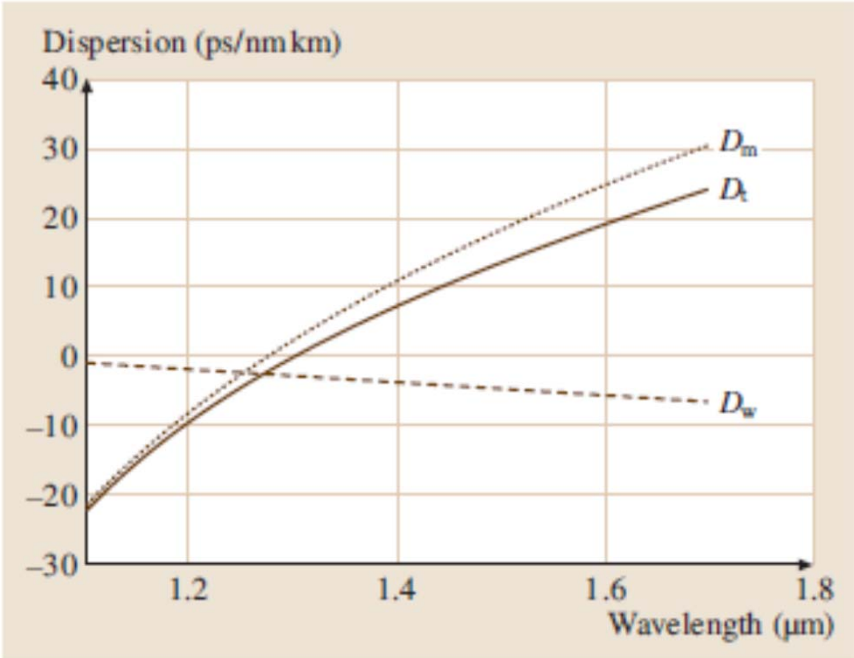
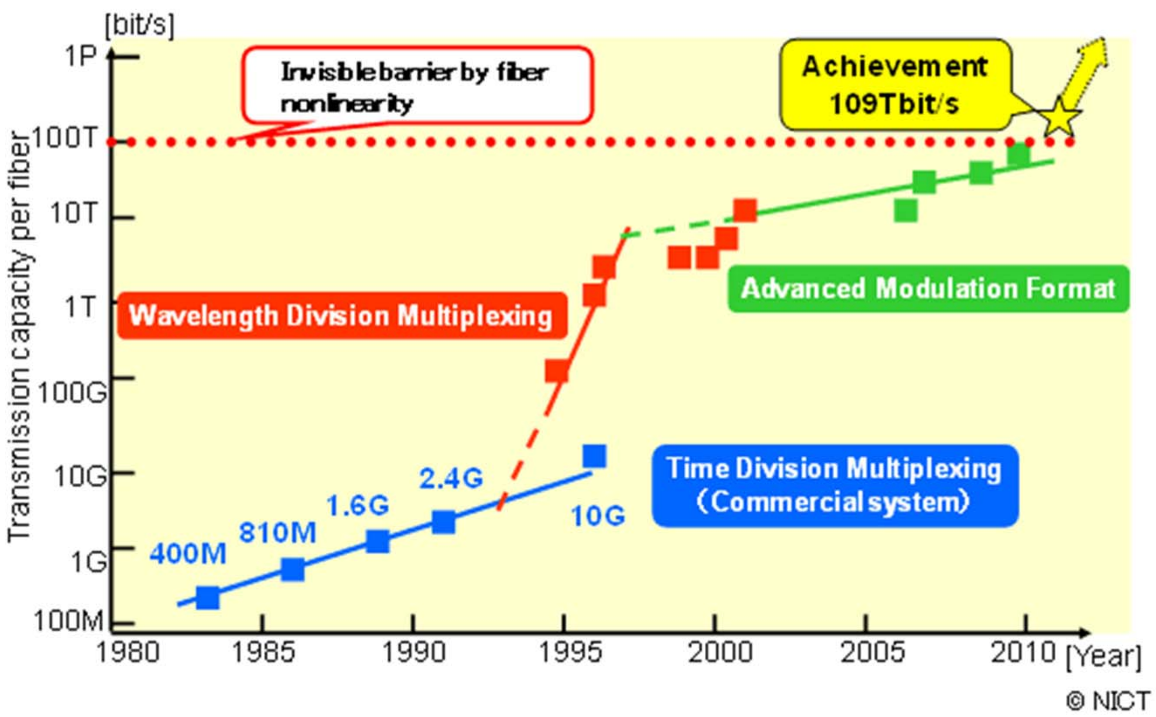
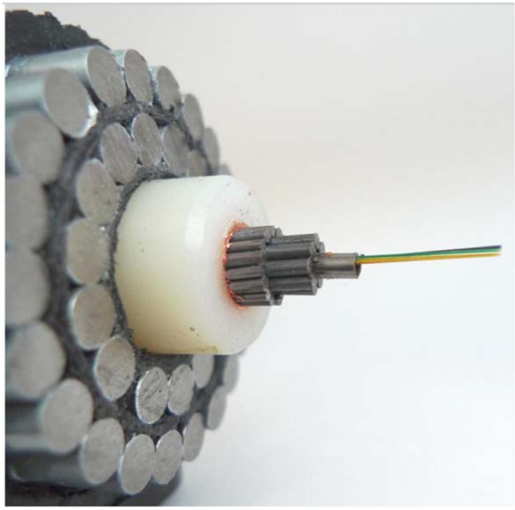


Fig. 8.74 Variation of material, waveguide and total dispersion with wavelength for a standard single-mode fiber

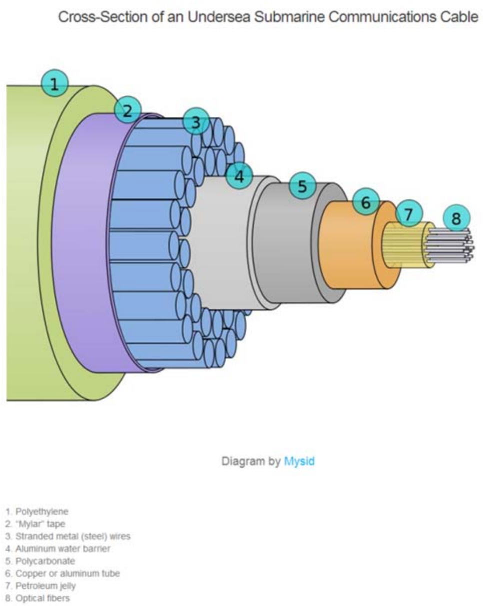
Disperze – rozšiřování pulsů: materiálová
módová
vlnovodná

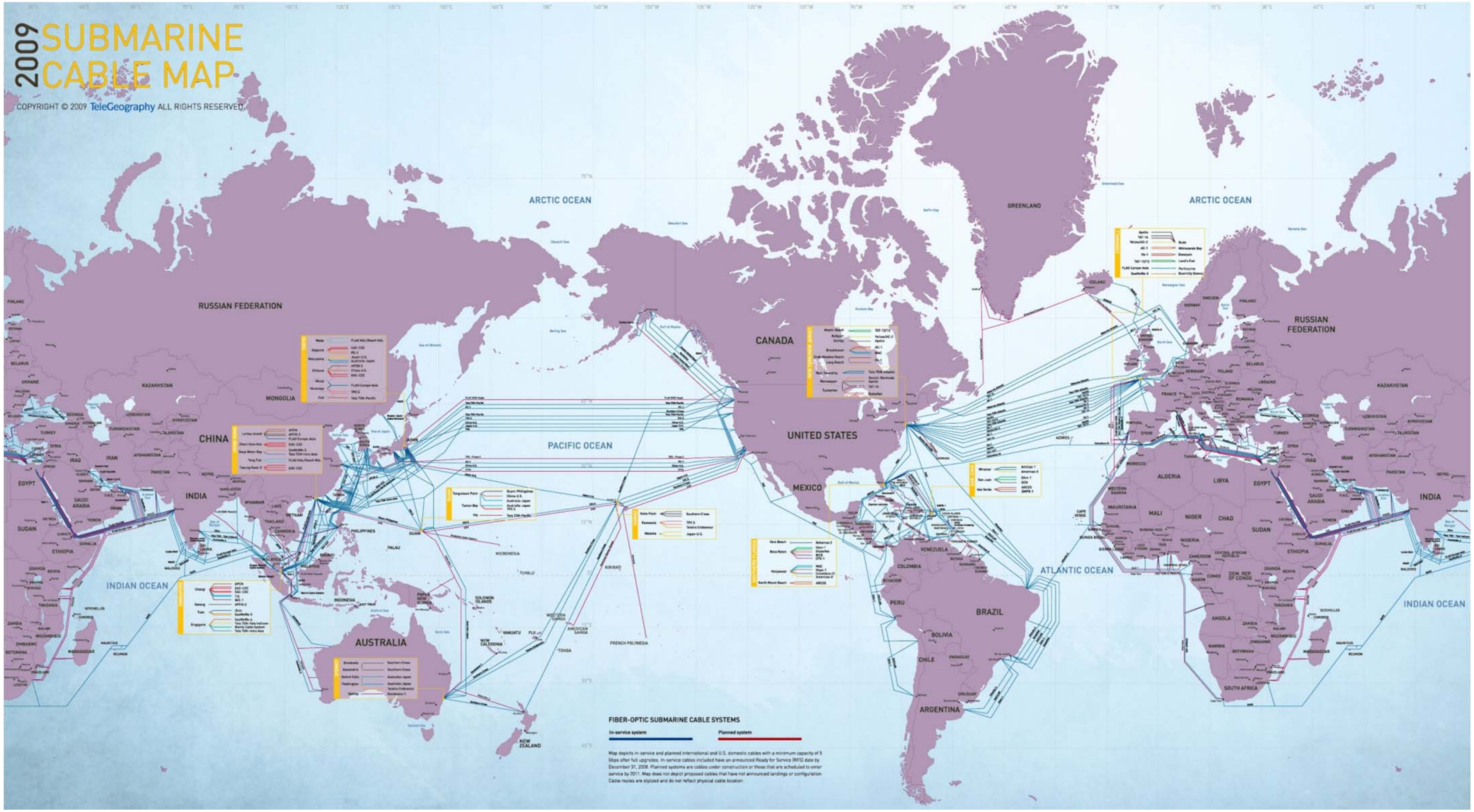


Přenosová kapacita

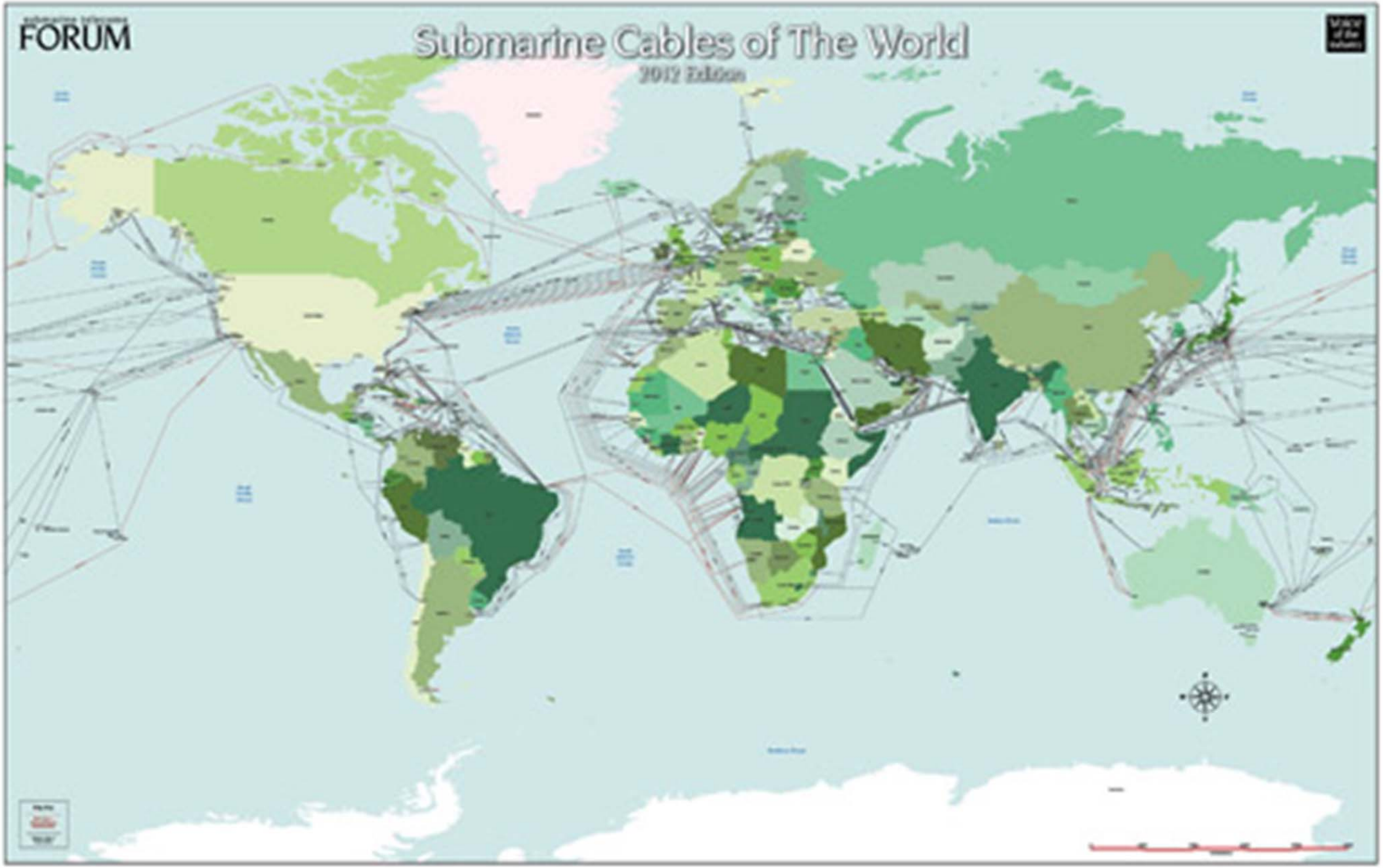


diameter of 69 millimeter (2.7 inches)





2009 SUBMARINE CABLE MAP
COPYRIGHT © 2009 TeleGeography ALL RIGHTS RESERVED
ARCTIC OCEAN
PACIFIC OCEAN
ATLANTIC OCEAN
INDIAN OCEAN
RUSSIAN FEDERATION
CHINA
INDIA
MONGOLIA
KAZAKHSTAN
AUSTRALIA
NEW ZEALAND
CANADA
UNITED STATES
MEXICO
GREENLAND
BRAZIL
ARGENTINA
PERU
BOLIVIA
CHILE
COLOMBIA
VENEZUELA
ALGERIA
LIBYA
EGYPT
MALI
NIGER
CHAD
SUDAN
ETHIOPIA
SAUDI ARABIA
IRAN
SOUTH AFRICA
ANGOLA
DEM. REP. OF CONGO
FRENCH POLYNESIA
FIBER-OPTIC SUBMARINE CABLE SYSTEMS
In-service system
Planned system
Map depicts in-service and planned international and U.S. domestic cables with a minimum capacity of 5 Gbps after full upgrades. In-service cables included have an announced Ready for Service (RFS) date by December 31, 2008. Planned systems are cables under construction or those that are scheduled to enter service by 2011. Map does not depict proposed cables that have not announced landings or configuration. Cable routes are stylized and do not reflect physical cable location.


submarine telecoms
FORUM
Submarine Cables of The World
2012 Edition

Význam optických vláken zřejmý

Photo: U. Montan

Charles Kuen Kao

Photo: U. Montan

Willard S. Boyle

Photo: U. Montan

George E. Smith

The Nobel Prize in Physics 2009 was divided, one half awarded to Charles Kuen Kao *"for groundbreaking achievements concerning the transmission of light in fibers for optical communication"*, the other half jointly to Willard S. Boyle and George E. Smith *"for the invention of an imaging semiconductor circuit – the CCD sensor"*.

Dr.Willard Boyle (vlevo) a Dr. George Smith (vpravo)

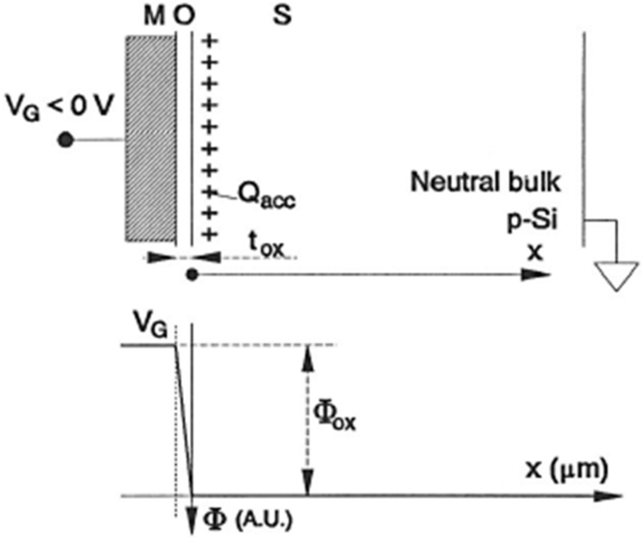
Detekce světla

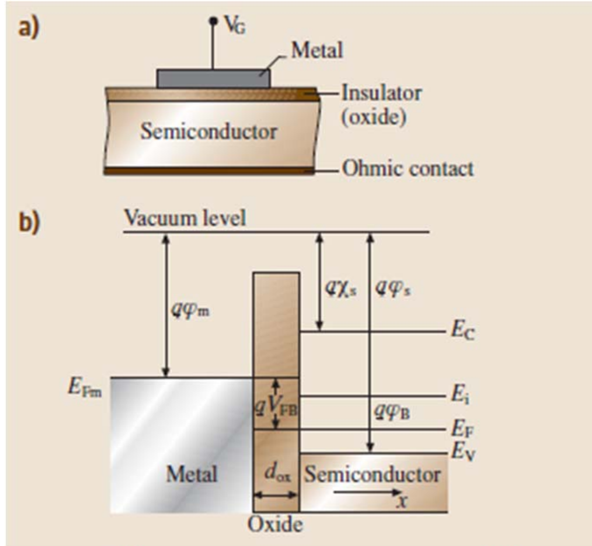
Interakce světla s látkou

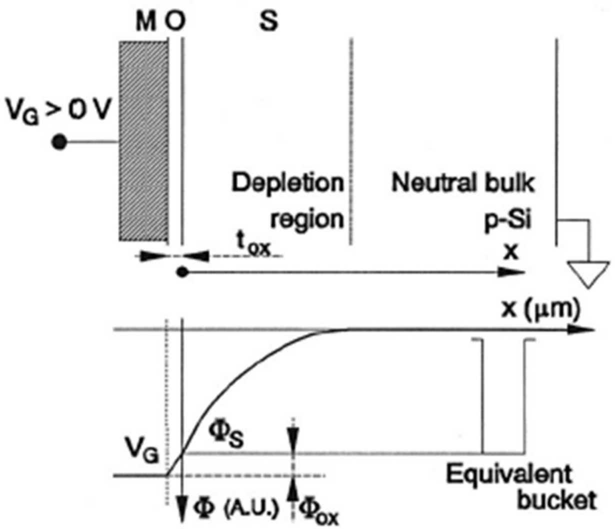
Plošné detektory: fotografický film/deska
diodové pole (polovodičové diody)
CCD
CMOS

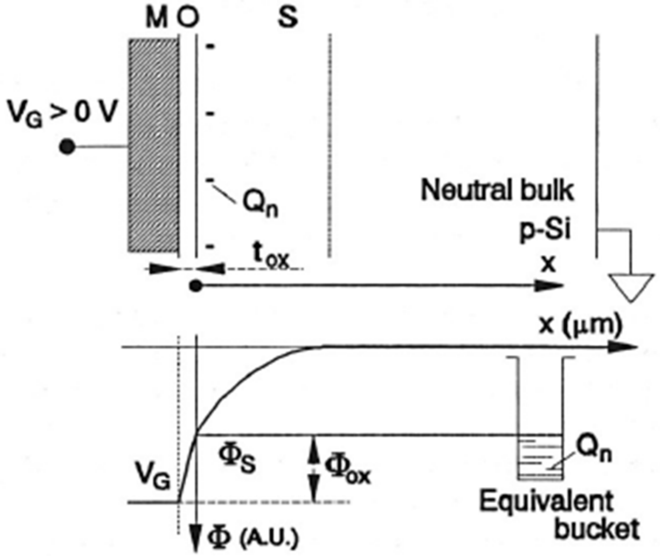
Detektory s přenosem náboje

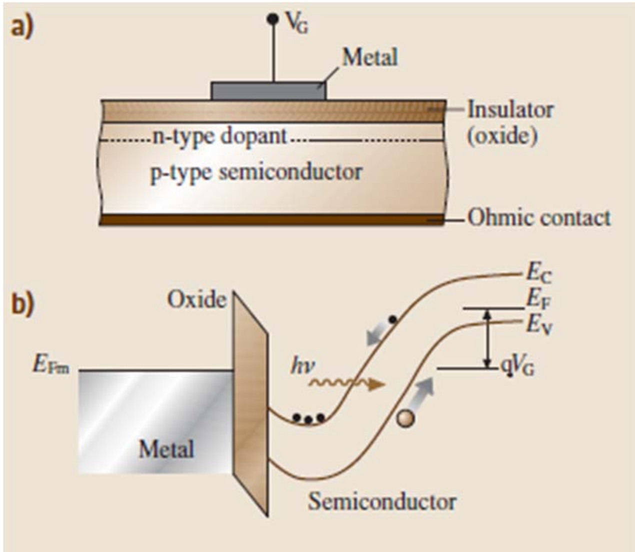
CCD – charge coupled device


M O
S
V_G < 0 V
Q_acc
t_ox
Neutral bulk
p-Si
x
V_G
Φ_ox
x (μm)
Φ (A.U.)

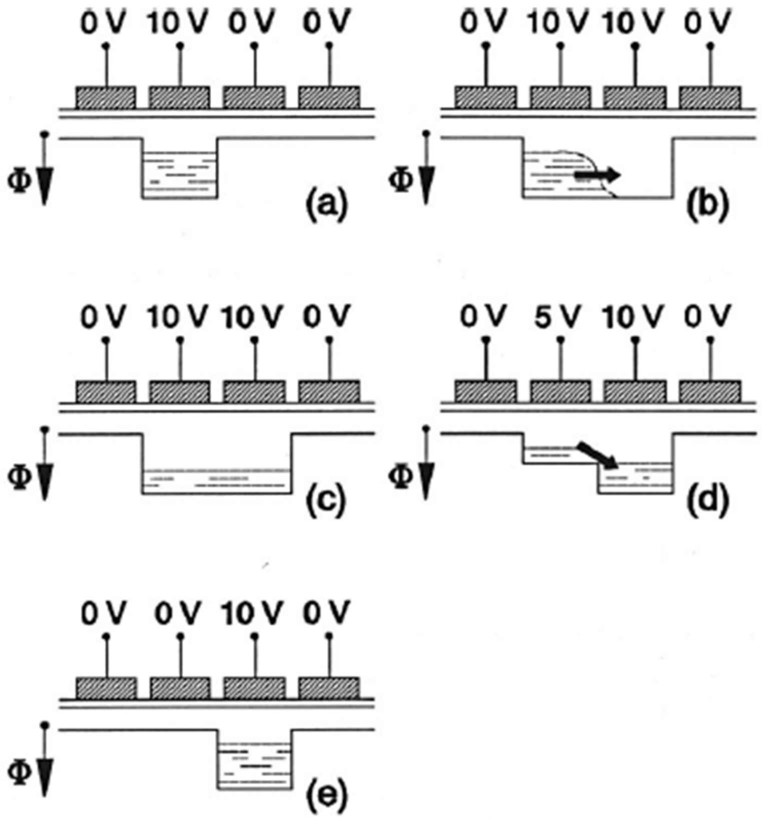

a)
V_G
Metal
Insulator
(oxide)
Semiconductor
Ohmic contact
b)
Vacuum level
qφ_m
qχ_s
qφ_s
E_C
E_Fm
qV_FB
E_i
qφ_B
E_F
E_V
Metal
d_ox
Semiconductor
x
Oxide


M O
S
V_G > 0 V
Depletion
region
Neutral bulk
p-Si
t_ox
x
x (μm)
Φ_S
V_G
Equivalent
bucket
Φ (A.U.)
Φ_ox

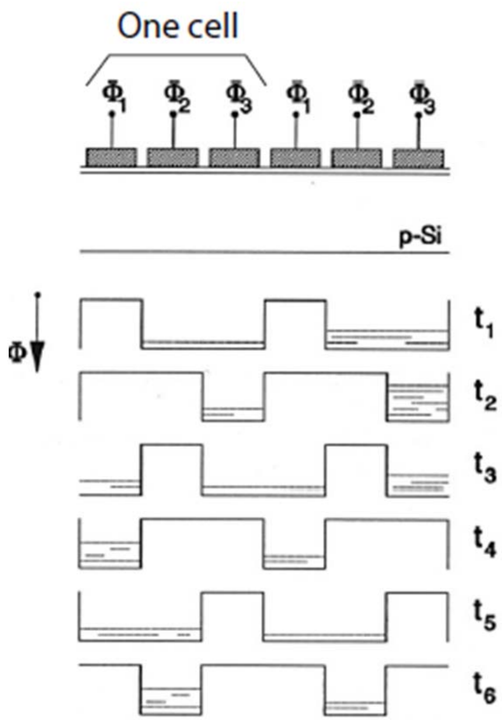

M O
S
V_G > 0 V
Q_n
t_ox
Neutral bulk
p-Si
x
x (μm)
Φ_S
Φ_ox
Q_n
V_G
Equivalent
bucket
Φ (A.U.)

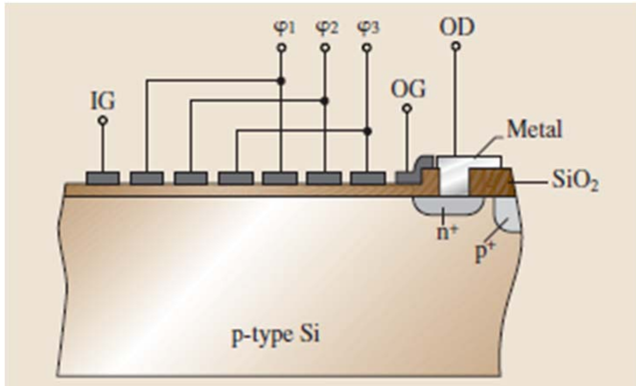


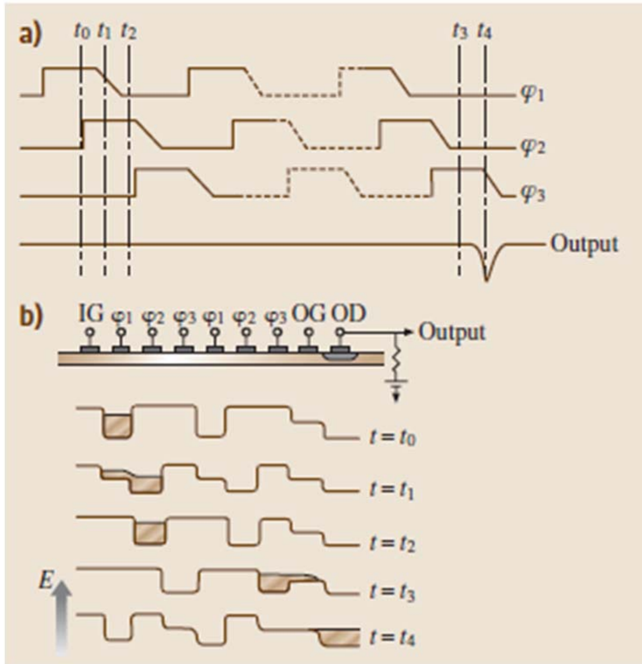
a)
VG
Metal
Insulator
(oxide)
n-type dopant
p-type semiconductor
Ohmic contact
b)
Oxide
EC
EF
EV
EFm
hν
qVG
Metal
Semiconductor

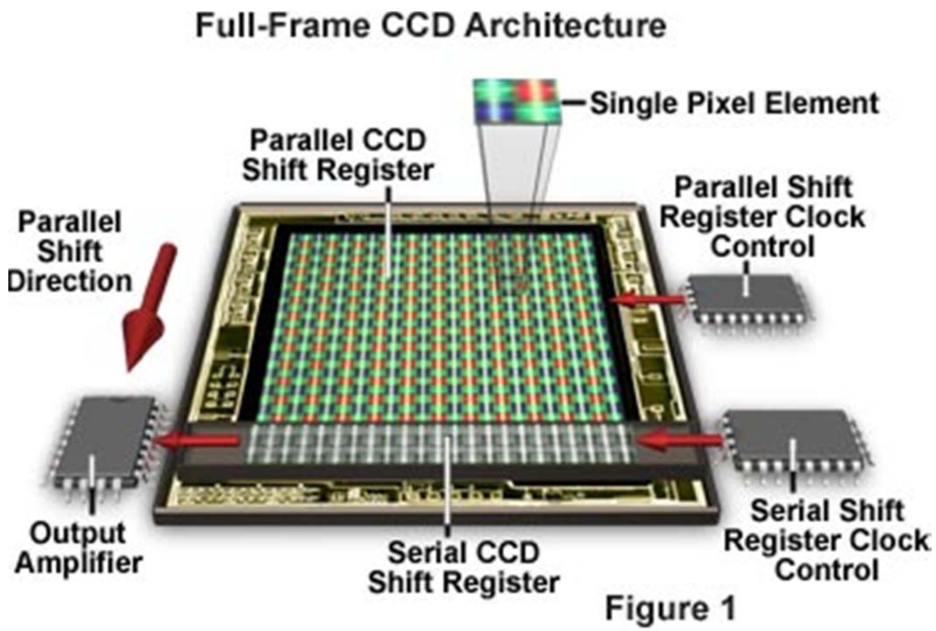

0 V
10 V
0 V
0 V
Φ
(a)
0 V
10 V
10 V
0 V
Φ
(b)
0 V
10 V
10 V
0 V
Φ
(c)
0 V
5 V
10 V
0 V
Φ
(d)
0 V
0 V
10 V
0 V
Φ
(e)

trojfázový cyklus



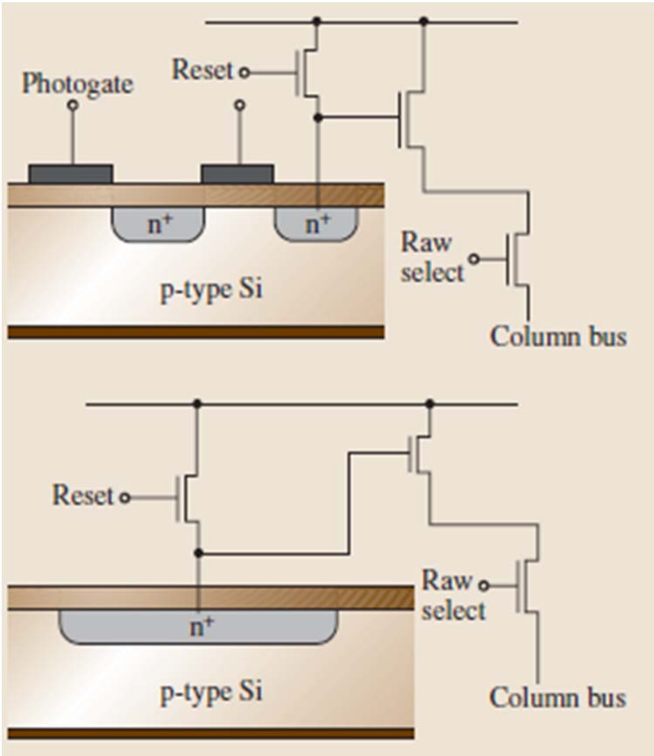


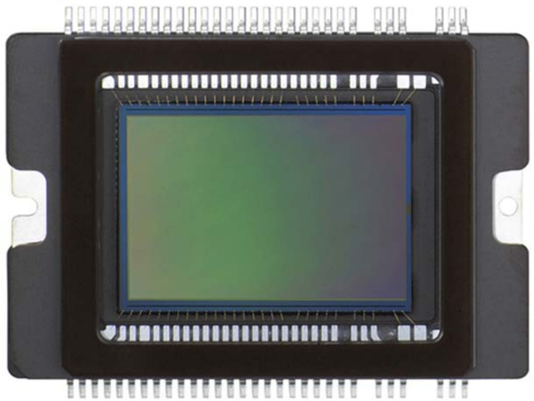




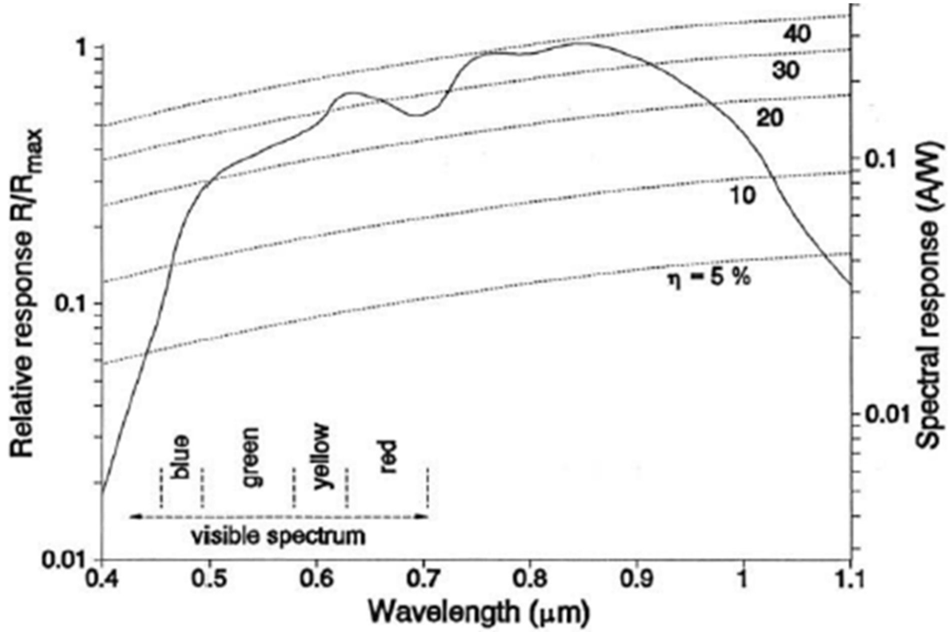
Typický rozměr pixelu 4 mikrometry

CMOS detektor - alternativa

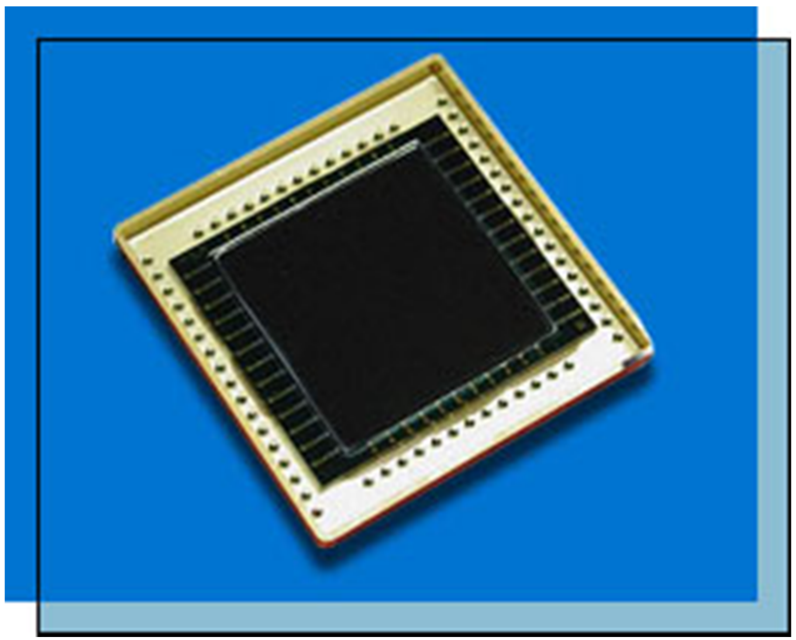




Complementary Metal–Oxide–Semiconductor

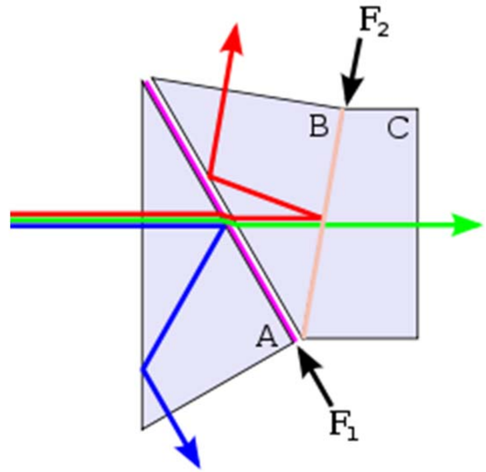


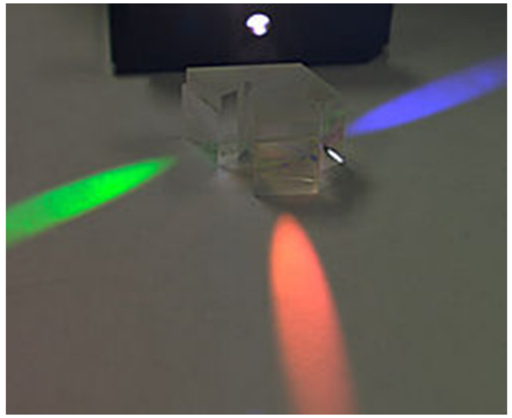
Relative response R/R_max
Spectral response (A/W)
Wavelength (µm)
40
30
20
10
η = 5 %
blue
green
yellow
red
visible spectrum
1
0.1
0.01
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1



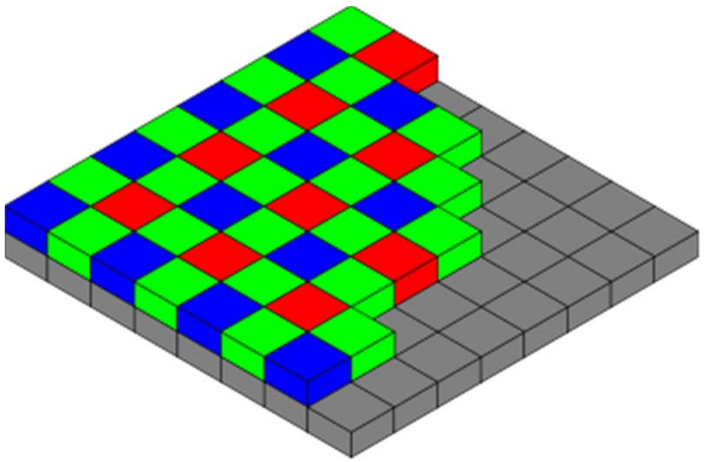
Barevné CCD

3 CCD

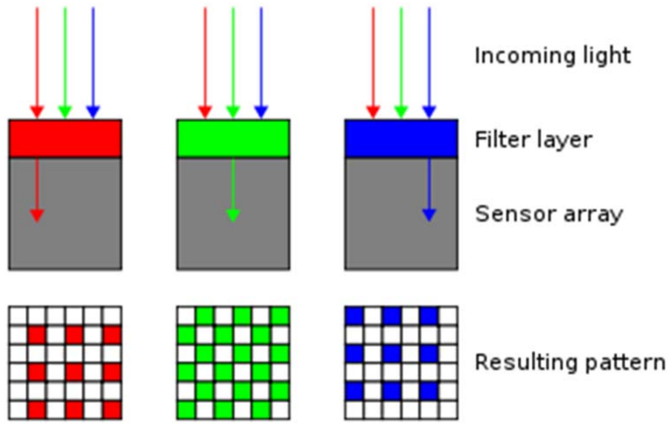




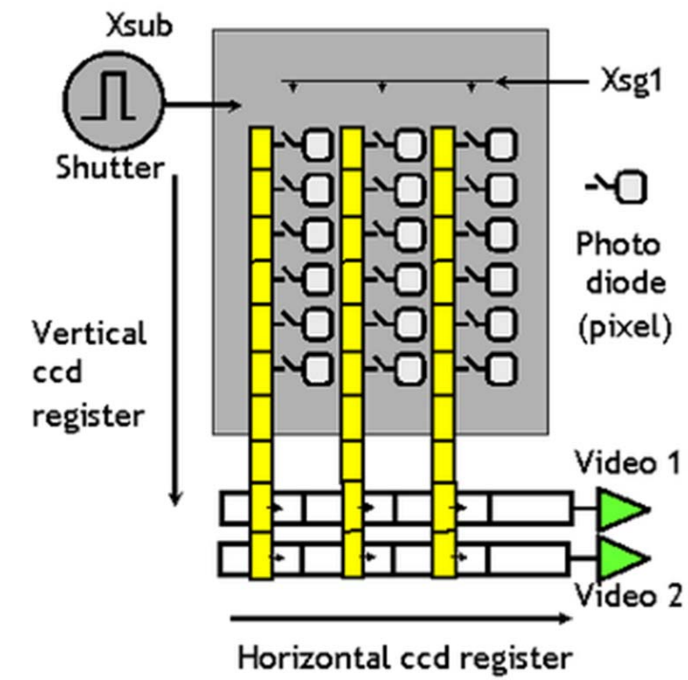
Philips

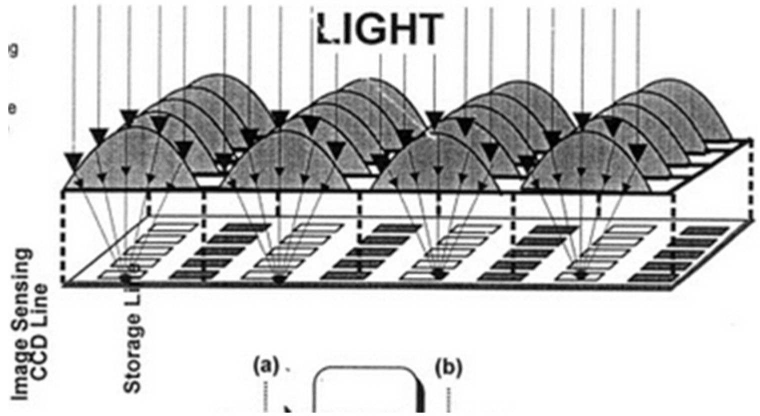


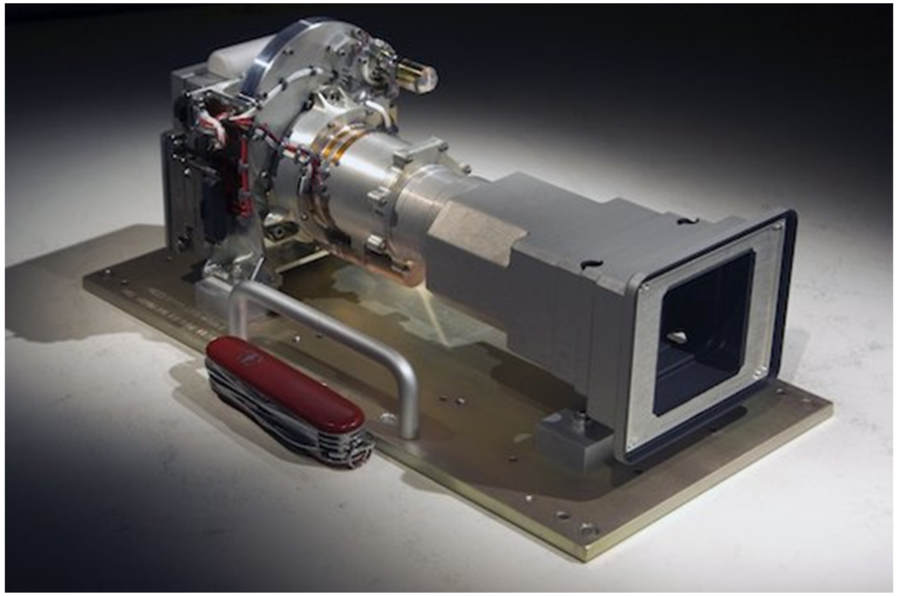
Bryce Bayer,, KODAK



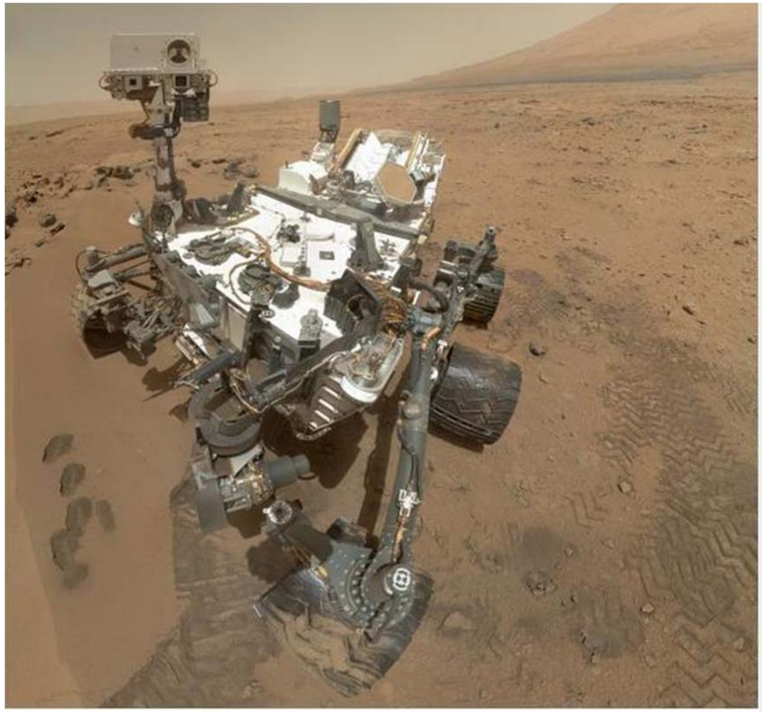
Interline Transfer CCD - Progressive Scan







2 Mega pixely, jedna z kamer – Curiosity, Mars



NASA/JPL-Caltech/Malin Space Science Systems

Curiosity's high-res self-portrait

Materiály publikované na http://www.nobelprize.org/nobel_prizes/

M. Fox: Quantum Optics, Oxford University Press, Oxford, 2006

Časopisecká literatura

Materiály publikované na http://www.nasa.gov

P. Malý: Optika, Karolinum, Praha, 2008