50 ans de fibres optiques: “vers le haut debit et au delà”

Maxime Cavillon
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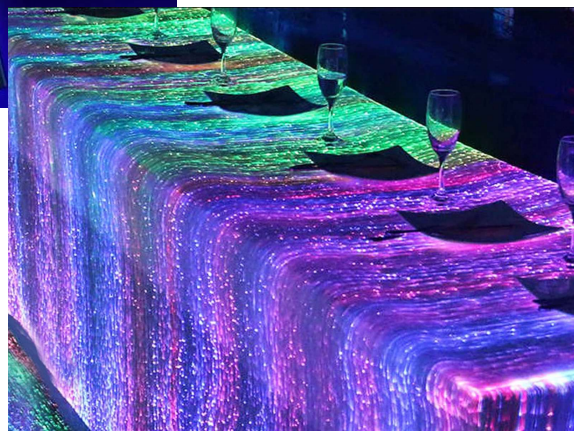
Le verre: d’hier à demain

Quand on pense fibre… google nous donne les tendances



Design, déco…

Internet, cables…

« Passez à la vitesse de la fibre »

« La fibre et plus vite que ça »

free

« Ici dans ce quartier vivez la puissance de la fibre à 1 Gb/s »

« N'attendez pas demain pour adopter la technologie de demain »

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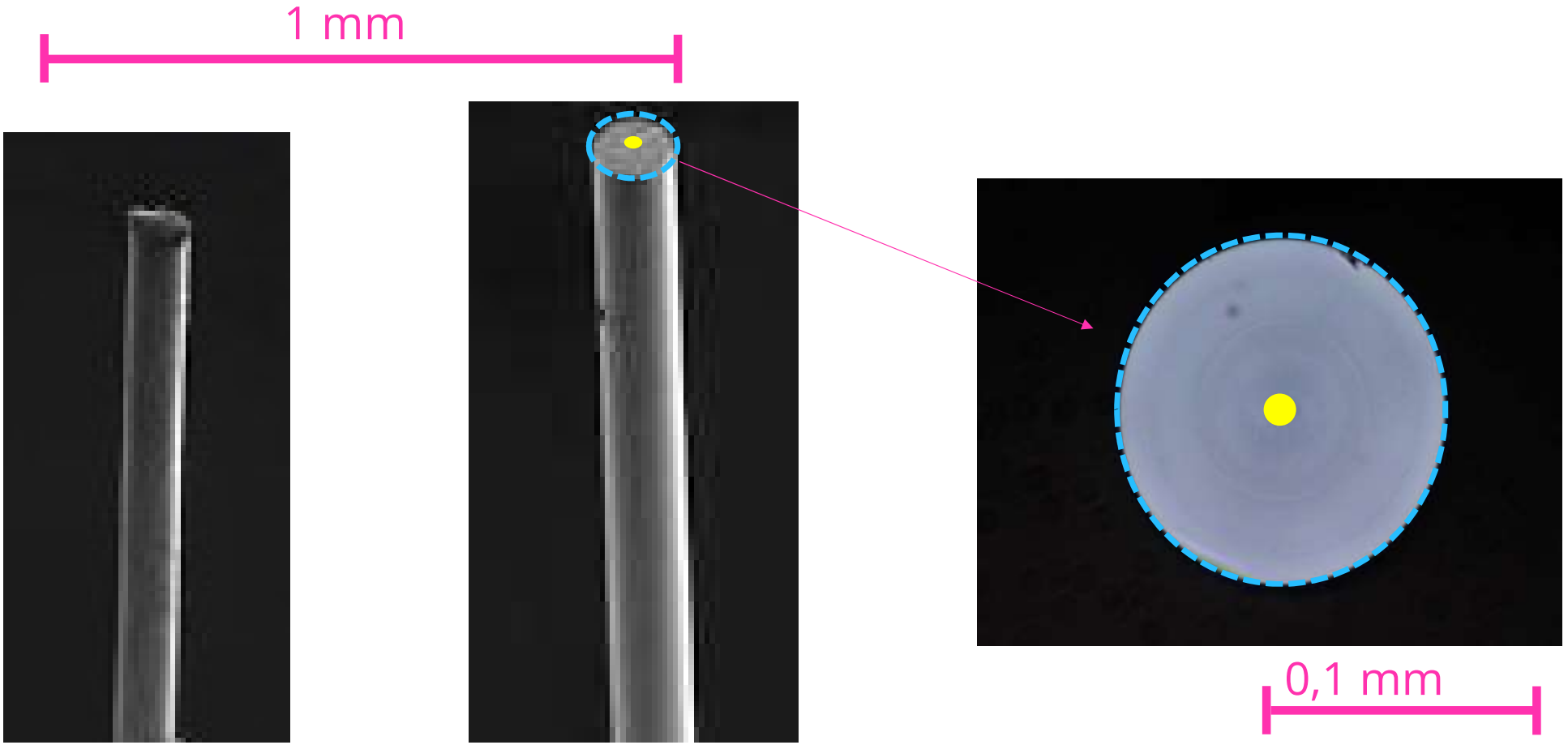


Cheveux

Fibre optique

Origines et principes de la fibre optique

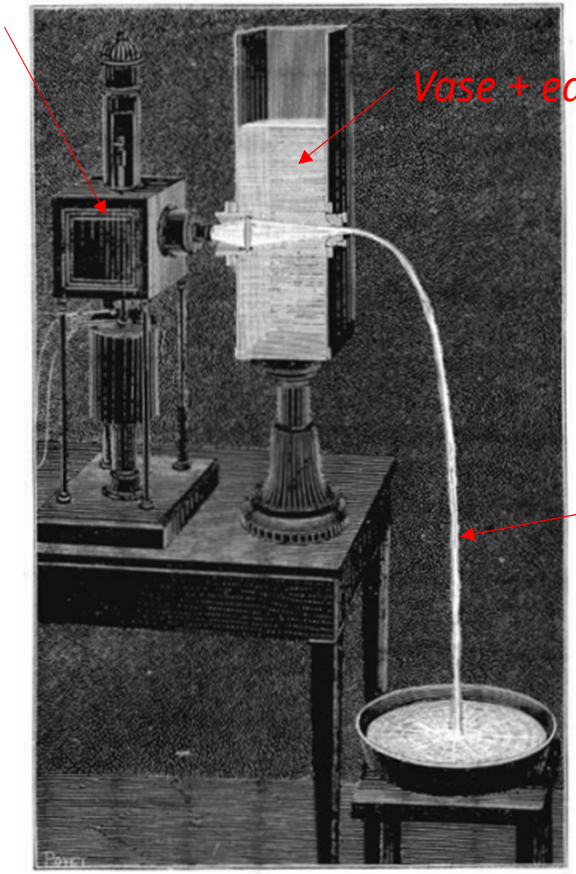
La fibre télécom: alignement de planètes et formidable succès

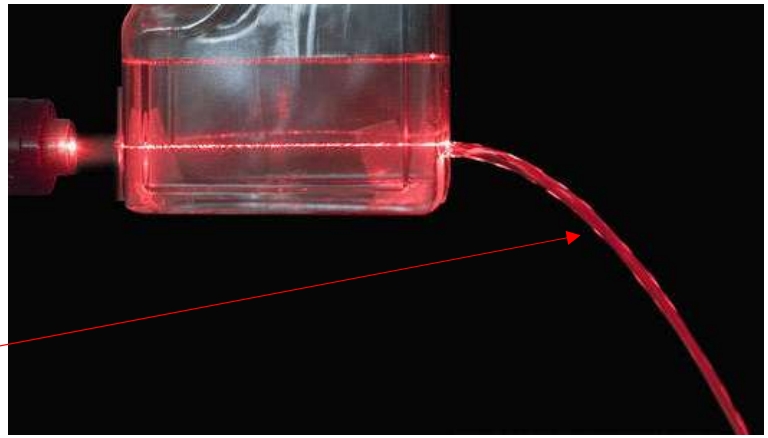
Le télécom? Mais les autres alors?

Les origines du guidage de la lumière

Jean-Daniel Colladon
(1802 – 1893)

Fontaines lumineuses (1841)





Les origines du guidage de la lumière

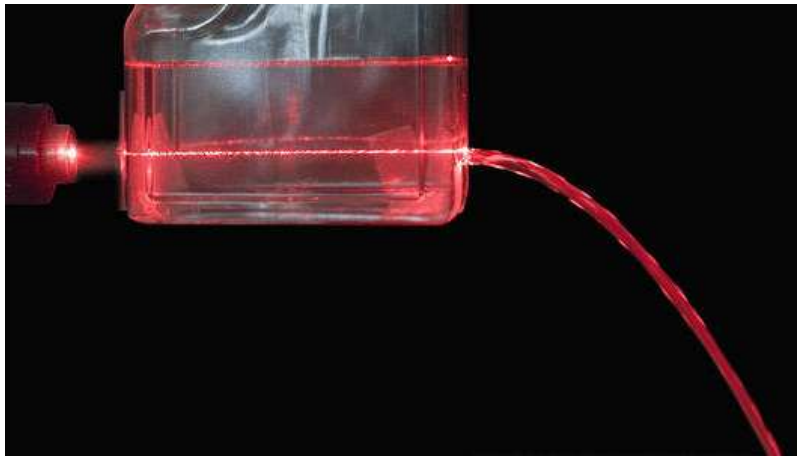
Exposition universelle (1889)

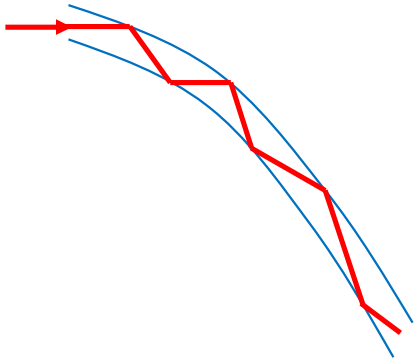
Jacques Babinet
(1794 - 1872)

Pour lui:
- Déjà vu d'après lui – s'explique bien
- Utile pour acheminer la lumière (aspect pratique)

Mais aussi…
Opera de Paris (1849)
International Health exhibition (Londres, 1884)
Royal Jubilee Exhibition (Manchester, 1887)

La propagation de la lumière





S'explique par le phénomène de réfraction

~ 1625 : Formule de Snell-Descartes

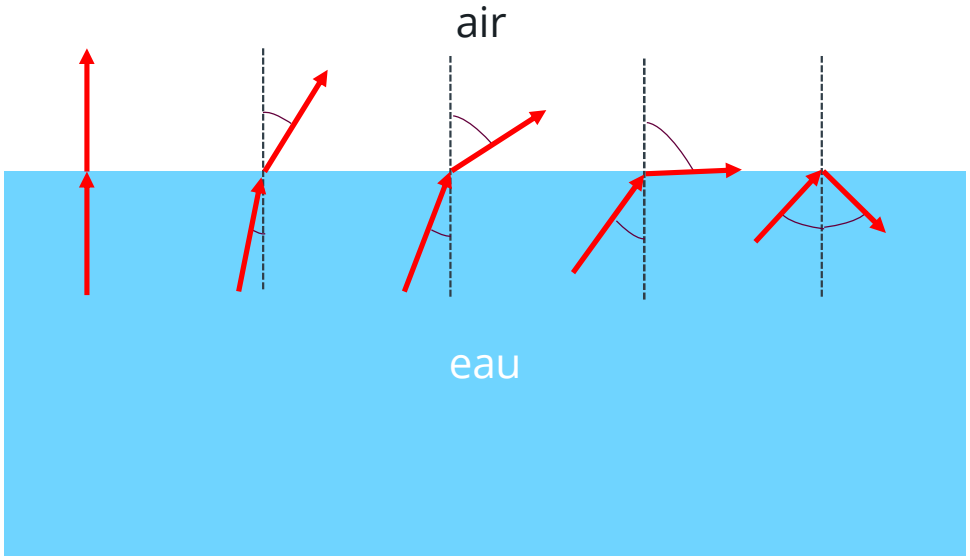
La lumière se propage en ligne droite (rayon)

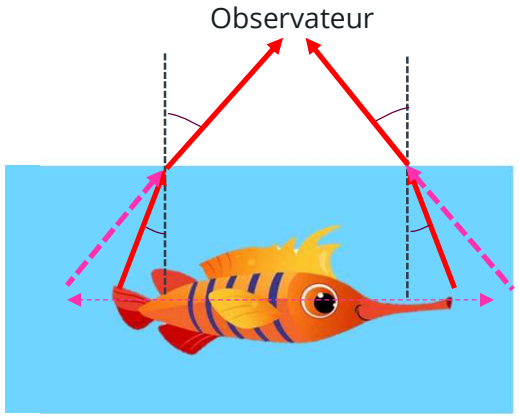
Lorsque la lumière passe d'un milieu à l'autre

(eau ↔ air), elle est déviée

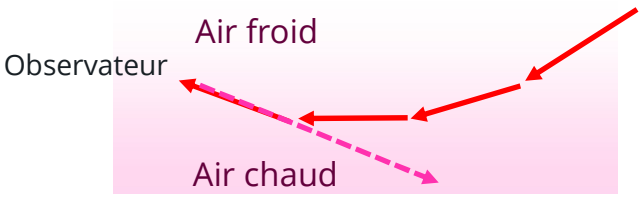
Formule de Snell-Descartes

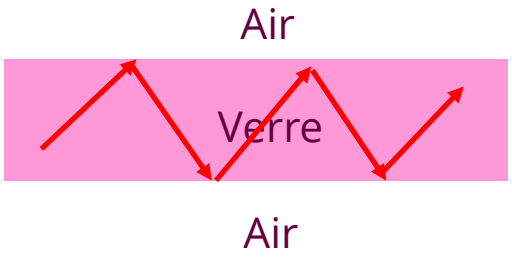
$n_{eau}\sin(i_{eau}) = n(_{air})\sin(i_{air})$





« Pécheur marseillais »



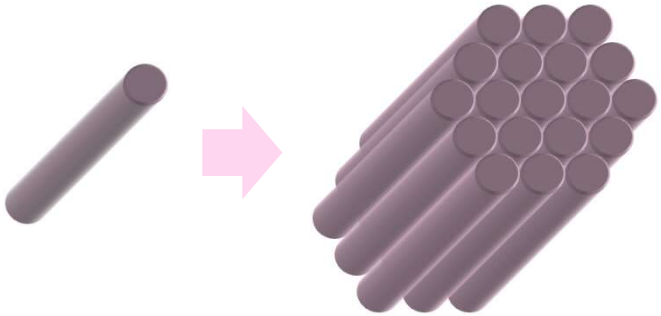


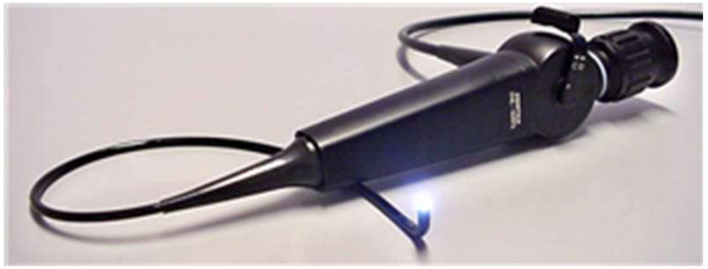
« Fibres optiques »

Les premières fibres optiques

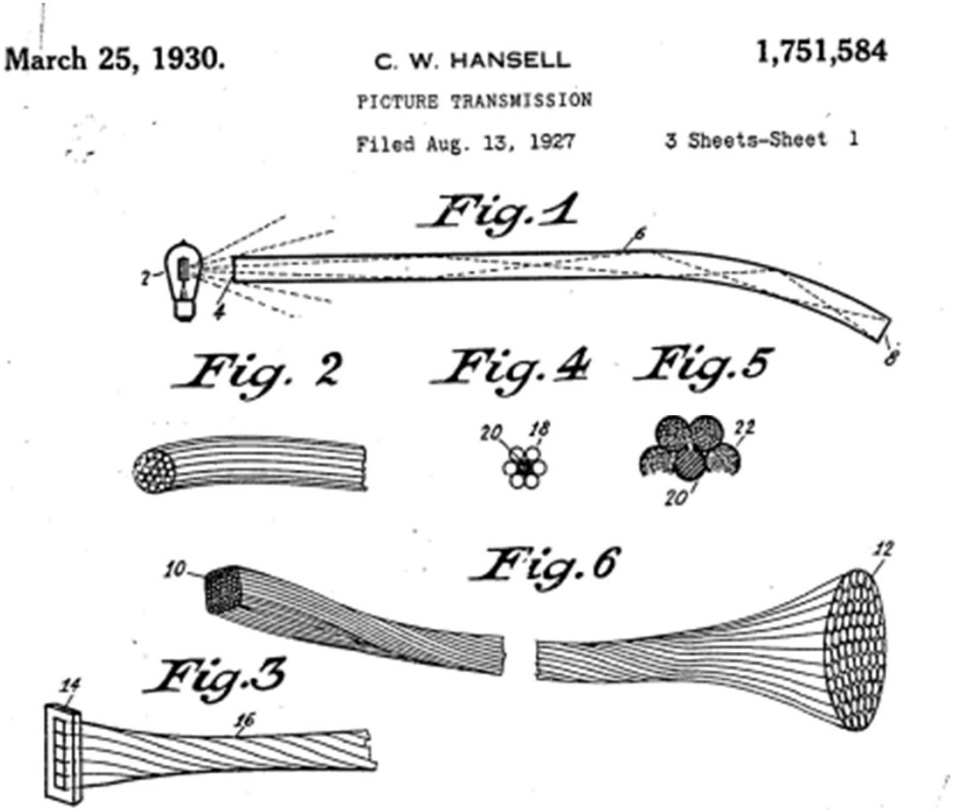
1 pixel

1 image





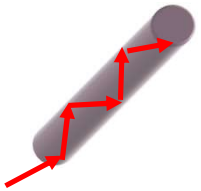
Principe du fibroscope

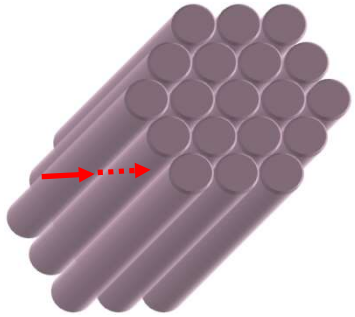


Prototype : H. Lamm (1930)

Les premières fibres optiques

Le problème…





…La solution

1955 : L.E. Curtiss (stage de License) avec B. Hirschowitz & C. W. Peters

1957 (accepté en 1971!) : « Glass fiber optical devices », L.E. Curtiss

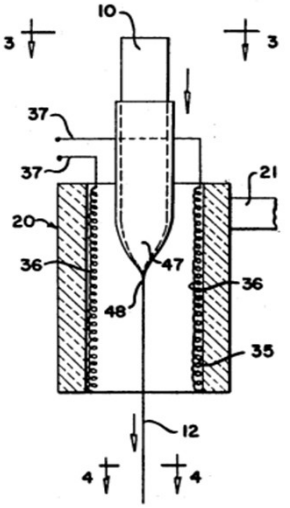
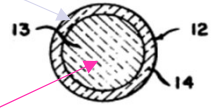


FIG. 2

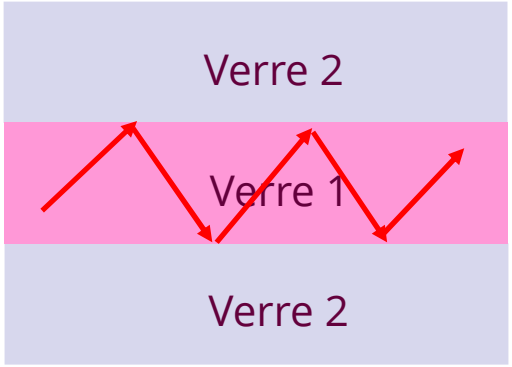
Gaine



Cœur

FIG. 4

INVENTOR.
LAWRENCE E. CURTISS
BY
Cullen & Canton
ATTORNEYS



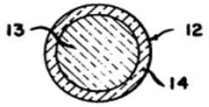
L'essor des fibres optiques...

...The Force Awakens

« Optical fibers »
Web of Science
148 000 articles scientifiques

(3) Trop de pertes (même pas la faute du verre!)
C. K. Kao, 1966

Curtiss (1957)



(2) Invention laser
(Maiman, 1960)

(1) Téléphone (Bell/Meucci, 1880) + plein essor des radiocommunications (début du 20ème siècle)

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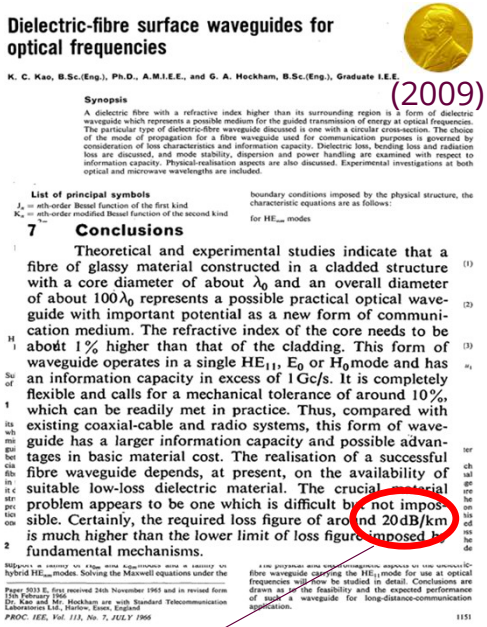
Vers les fibres « transparentes »



Dielectric-fibre surface waveguides for optical frequencies

K. C. Kao, B.Sc.(Eng.), Ph.D., A.M.I.E.E., and G. A. Hockham, B.Sc.(Eng.), Graduate I.E.E.

Synopsis

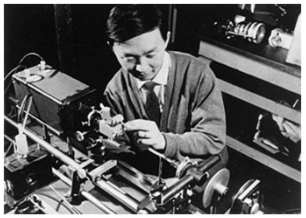
A dielectric fibre with a refractive index higher than its surrounding region is a form of dielectric waveguide which represents a possible medium for the guided transmission of energy at optical frequencies. The particular type of dielectric-fibre waveguide discussed is one with a circular cross-section. The choice of the mode of propagation for a fibre waveguide used for communication purposes is governed by consideration of loss characteristics and information capacity. Dielectric loss, bending loss and radiation loss are discussed, and mode stability, dispersion and power handling are examined with respect to information capacity. Physical-realisation aspects are also discussed. Experimental investigations at both optical and microwave wavelengths are included.

List of principal symbols

7 Conclusions

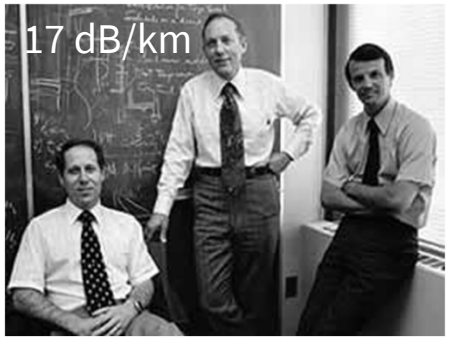
Theoretical and experimental studies indicate that a fibre of glassy material constructed in a cladded structure with a core diameter of about λ_0 and an overall diameter of about $100\lambda_0$ represents a possible practical optical waveguide with important potential as a new form of communication medium. The refractive index of the core needs to be about 1% higher than that of the cladding. This form of waveguide operates in a single HE_{11}, E_0 or H_0 mode and has an information capacity in excess of 1 Gc/s. It is completely flexible and calls for a mechanical tolerance of around 10%, which can be readily met in practice. Thus, compared with existing coaxial-cable and radio systems, this form of waveguide has a larger information capacity and possible advantages in basic material cost. The realisation of a successful fibre waveguide depends, at present, on the availability of suitable low-loss dielectric material. The crucial material problem appears to be one which is difficult but not impossible. Certainly, the required loss figure of around 20 dB/km is much higher than the lower limit of loss figure imposed by fundamental mechanisms.

(2009)



C. K. Kao
(1933 - 2018)

(Corning, J.F. Hyde
(US patent 2,272,342, **1942**, CVD)
$SiCl_4 + O_2 \rightarrow SiO_2 + Cl_2$



D. B. Keck, R. D. Maurer and P. C. Schultz
Corning Glass Works - USA

1% de lumière résiduelle après 1 km

diode laser à émission continue à température ambiante (Z. Alferov, Prix Nobel en 2000!)

~ 50 ans!

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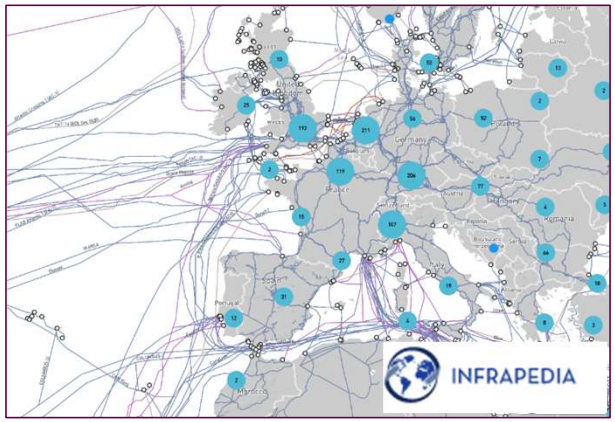
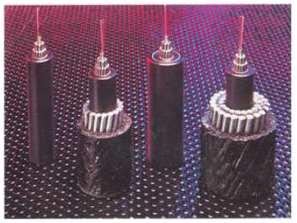
La diminution des pertes… et la fibre tisse sa toile!



440 cables sous marin dans le monde
>500 millions km/an (70 m / personne / an)
Soit 1300 allers-retours terre / lune



Aujourd'hui: 0,16 dB/km
(1% après ~125 km)

Dunan (Google)
(USA – France)
$260 millions
1200 film Blu-ray par seconde

TAT-8 (1er câble transocéanique)
(New Jersey – Angleterre – France)
$335 millions
1 film Blu-ray par minute

x 50 000 – x 100 000

17 dB/km
(1% après ~1,2 km)

0,2 dB/km
(1% après ~100 km)

articles scientifiques publiés par an

0
2k
4k
6k
8k
10k

1950
1960
1970
1980
1990
2000
2010
2020

Années

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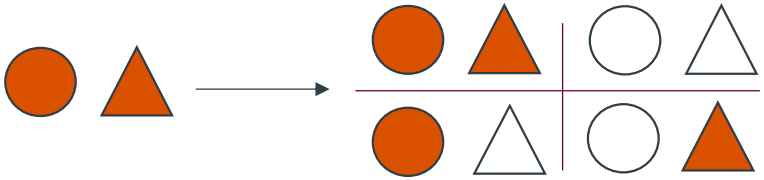
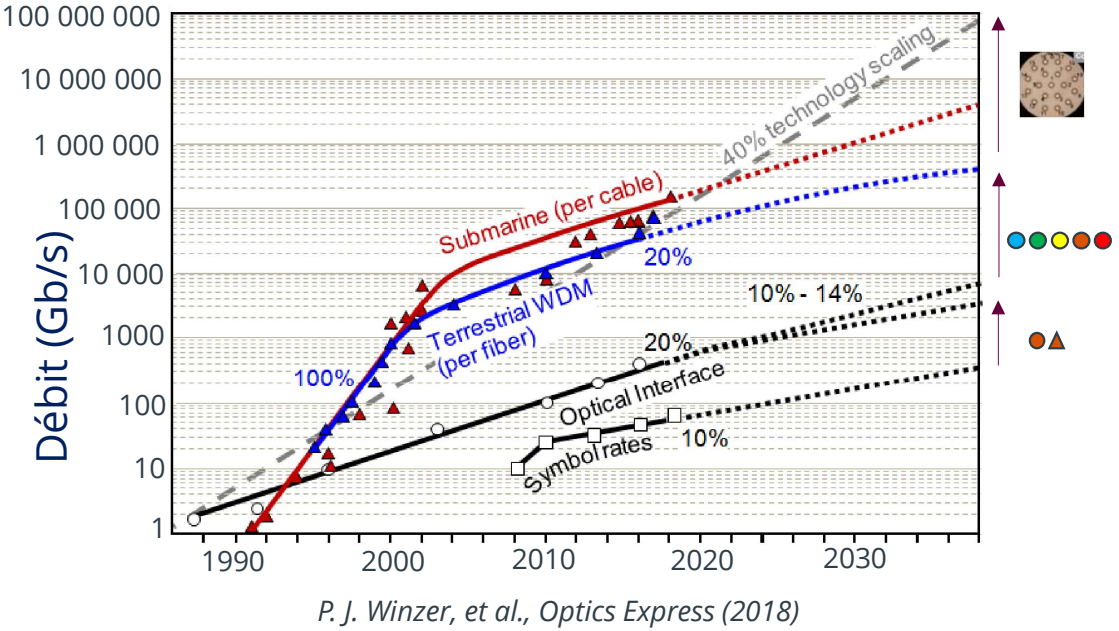
Augmentation du débit… solutions et perspectives

- Modulation du signal (*amplitude, phase, polarisation*)
Mettre plus d'information

1er cas

2eme cas





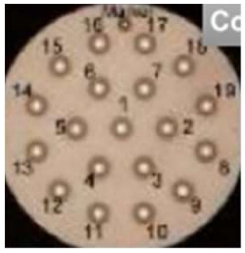
P. J. Winzer, et al., Optics Express (2018)

- Multiplexage en longueur d'onde

1er cas

2eme cas

- Multiplexage spatial



Multi-coeurs
ou
« Multi-modes »

I. Cristiani, Roadmap on multimode photonics, Journal of Optics (2022)

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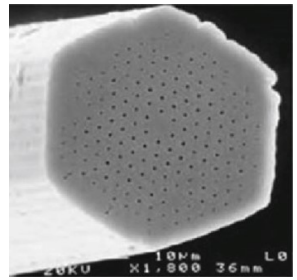
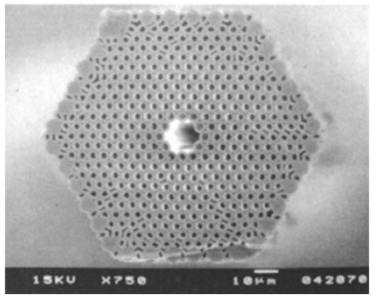
Il n’y a pas que les télécoms dans la vie!

- Fibres lasers hautes puissances
- Trading haute fréquence
- Capteurs
- Etc…

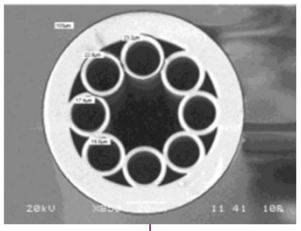


1ère fibre à cristal photonique
P.J. Russell, 1996



1ère fibre à cœur creux
R.F. Cregan, 1999

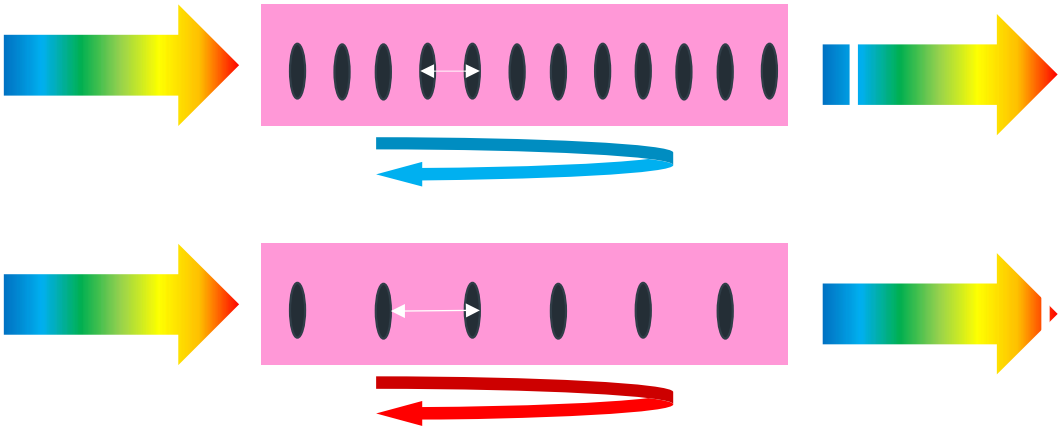
1ère fibres tubulaires anti-résonantes
A. D. Pryamikov, 2010



P. Russell, Photonic Crystal Fibers: A Historical Account (IEEE Leos Newsletter)

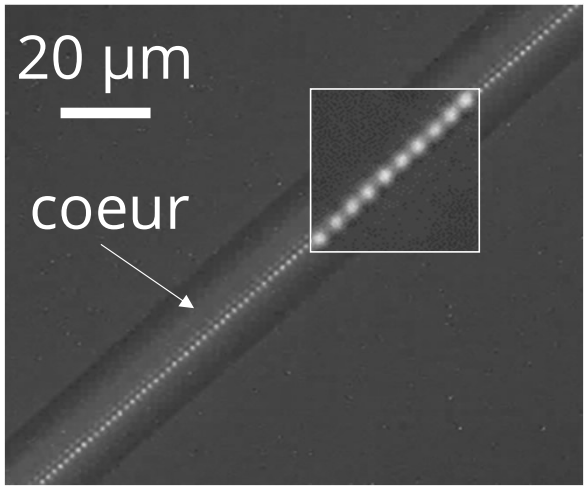
Il n’y a pas que les télécoms dans la vie!

Principe du capteur de température

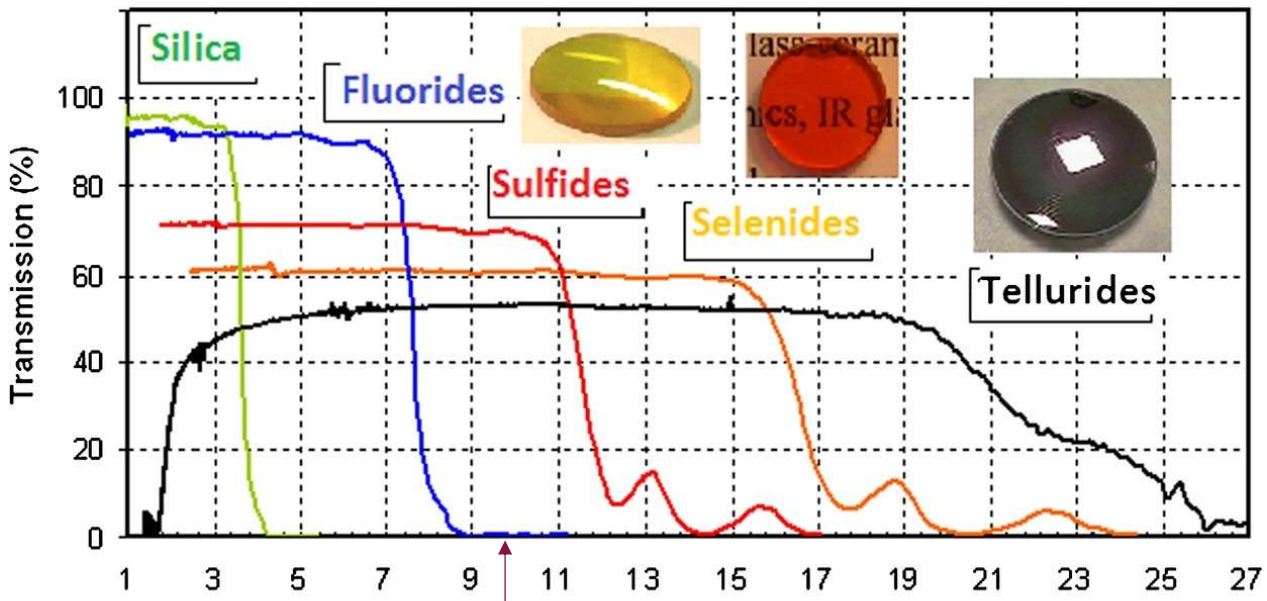


Température « froide »

Température « chaude »



Ca marche aussi pour la pression, déformation, élongation etc.



rayonnement thermique à température ambiante

Fibres en plastique

L. Calvez, Comptes Rendus Physique (2017)

“vers le haut debit et au delà… !”