INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
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H4.SMR. 405/13

SECOND WORKSHOP ON TELEMATICS

6 - 24 November 1989

Materials and Technologies for Optical Fibres

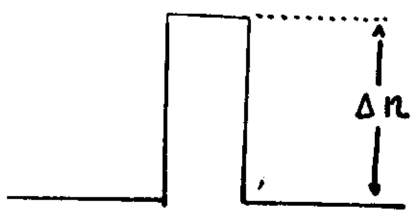
E. MODONE
CSELT, Torino, Italy

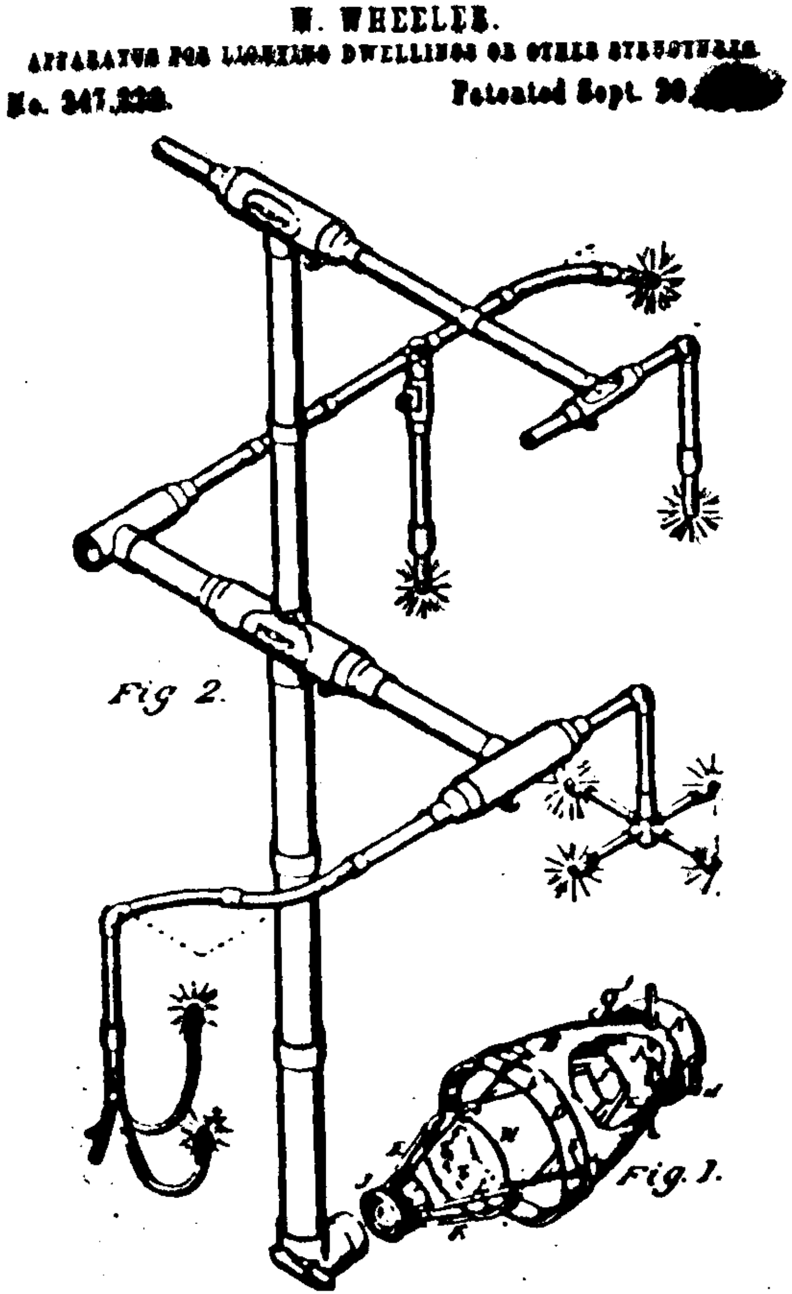
What is an optical fibre?

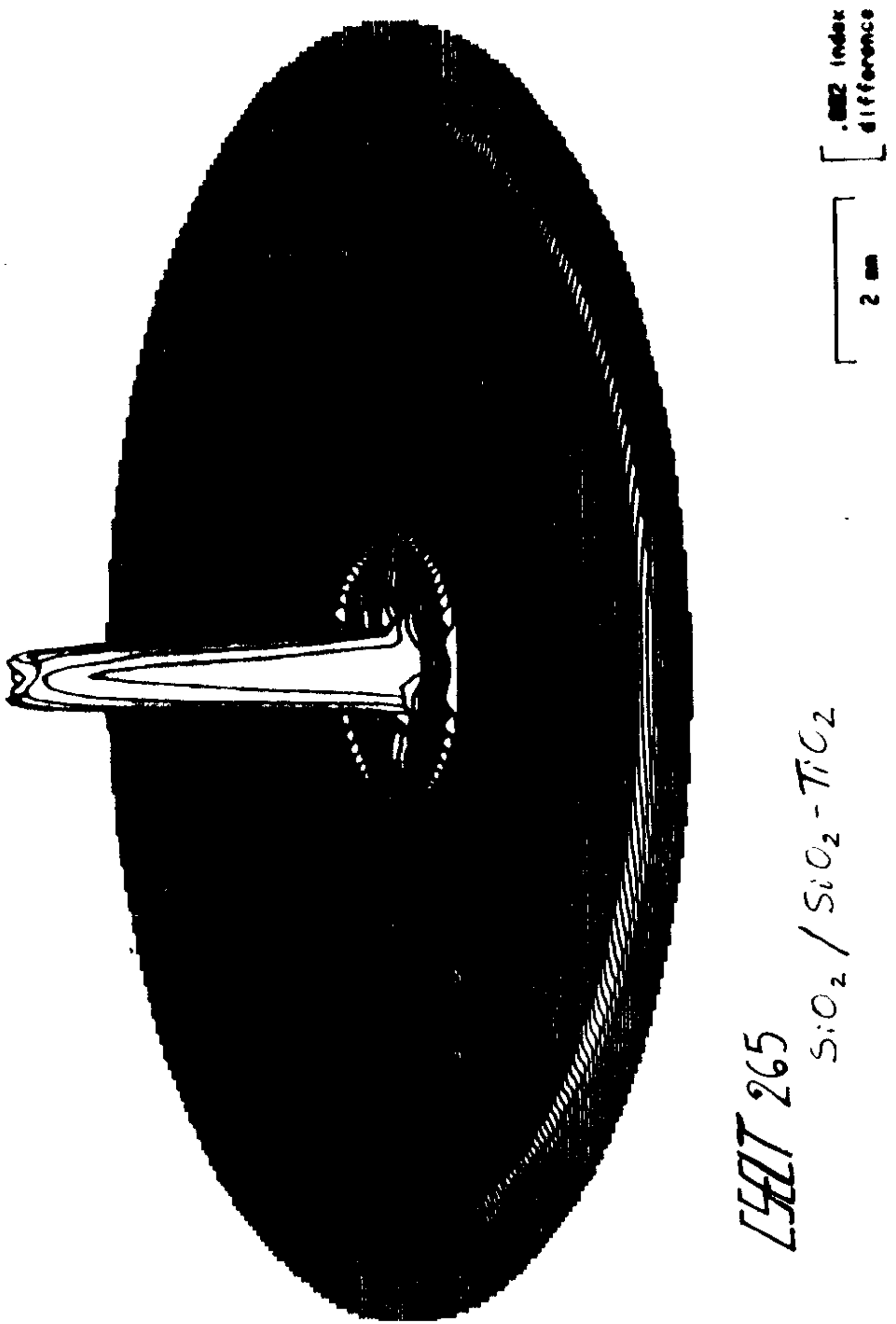
Optical fibre is dielectric waveguide structure that is used to confine and guide the light.

How can it guide the light?

Essentially, it is due to the small refractive index difference between the inner dielectric material called "core" and the outer dielectric material called "cladding".

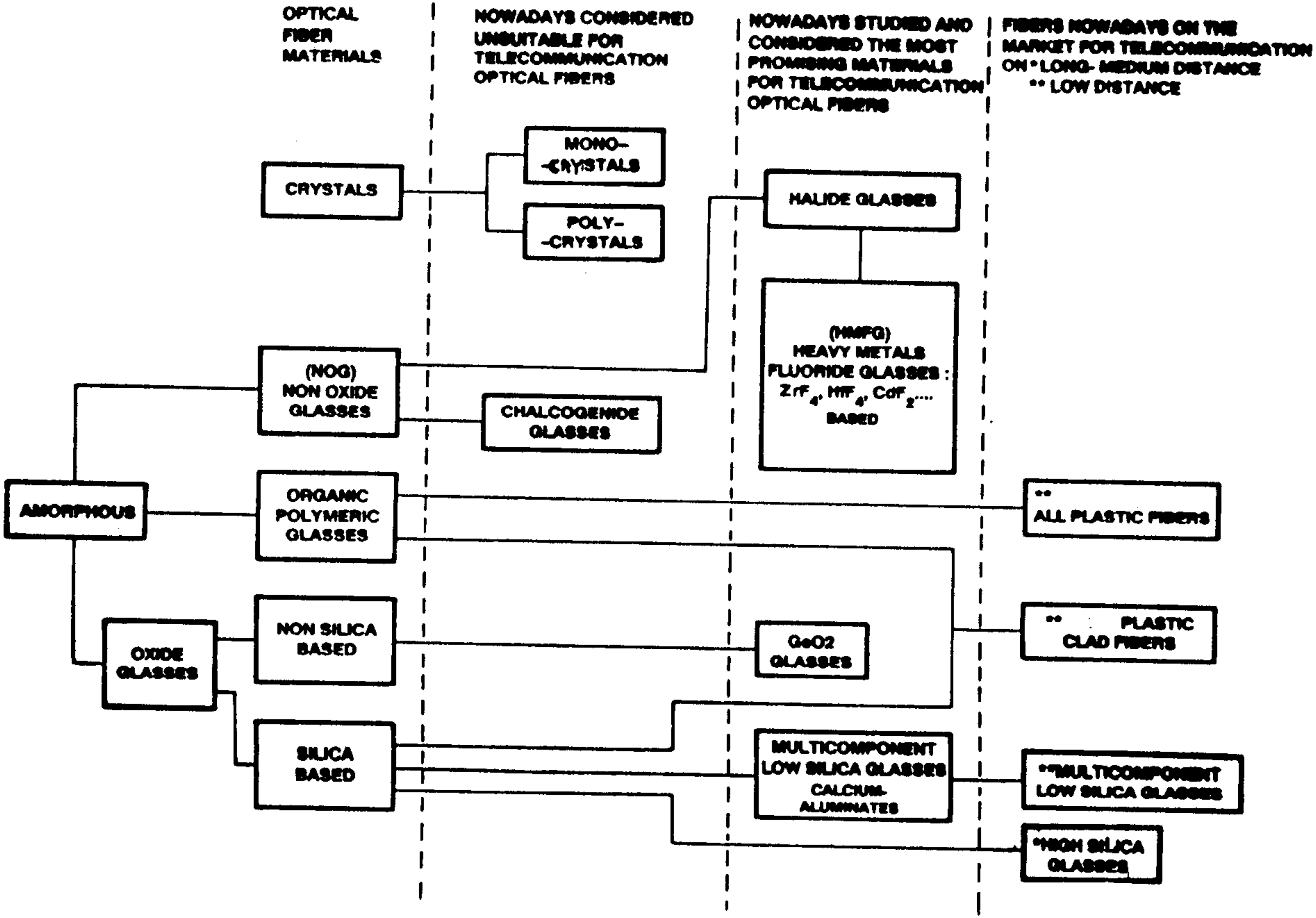






Main properties required of materials for telecommunication optical fibres:

- excellent transparency in the spectral region used.
- resistence to chemical attack.
- good stability.
- good mechanical properties.
- low cost.
- good adaptability to industrial processes.

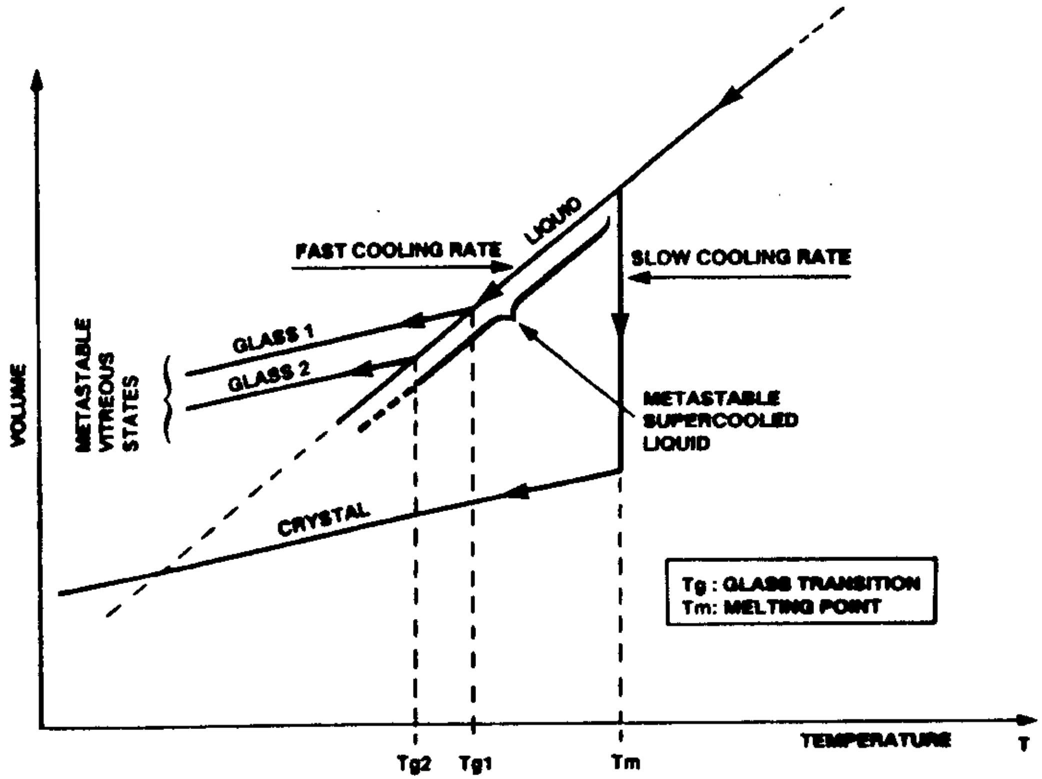

OPTICAL FIBER MATERIALS
NOWADAYS CONSIDERED UNSUITABLE FOR TELECOMMUNICATION OPTICAL FIBERS
NOWADAYS STUDIED AND CONSIDERED THE MOST PROMISING MATERIALS FOR TELECOMMUNICATION OPTICAL FIBERS
FIBERS NOWADAYS ON THE MARKET FOR TELECOMMUNICATION ON * LONG- MEDIUM DISTANCE
** LOW DISTANCE
CRYSTALS
MONO- -CRYSTALS
POLY- -CRYSTALS
HALIDE GLASSES
(HMFG) HEAVY METALS FLUORIDE GLASSES : ZrF_4, HfF_4, CdF_2.... BASED
(NOG) NON OXIDE GLASSES
CHALCOGENIDE GLASSES
AMORPHOUS
ORGANIC POLYMERIC GLASSES
** ALL PLASTIC FIBERS
OXIDE GLASSES
NON SILICA BASED
GeO2 GLASSES
** PLASTIC CLAD FIBERS
SILICA BASED
MULTICOMPONENT LOW SILICA GLASSES CALCIUM-ALUMINATES
**MULTICOMPONENT LOW SILICA GLASSES
*HIGH SILICA GLASSES

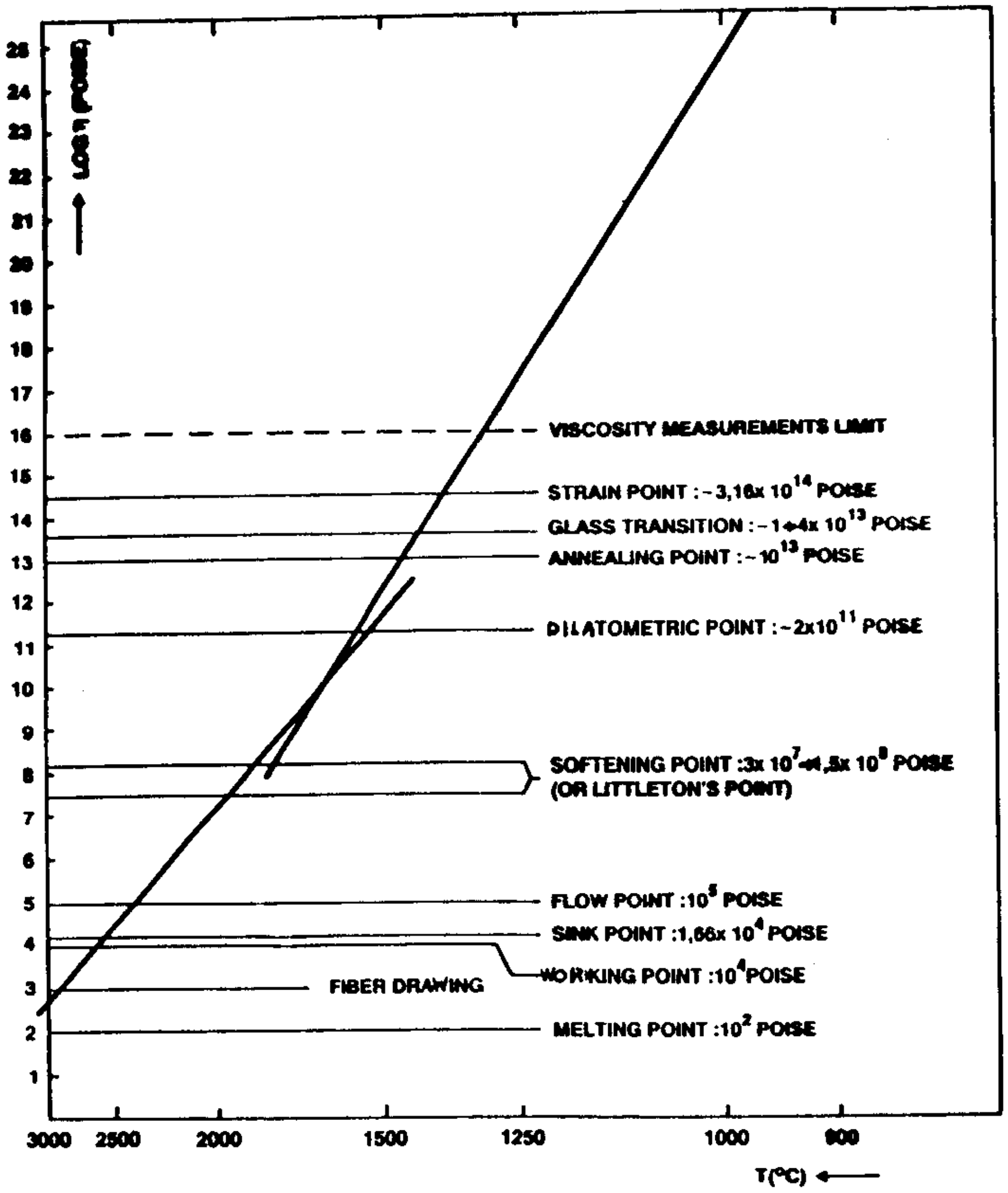
Glass Science

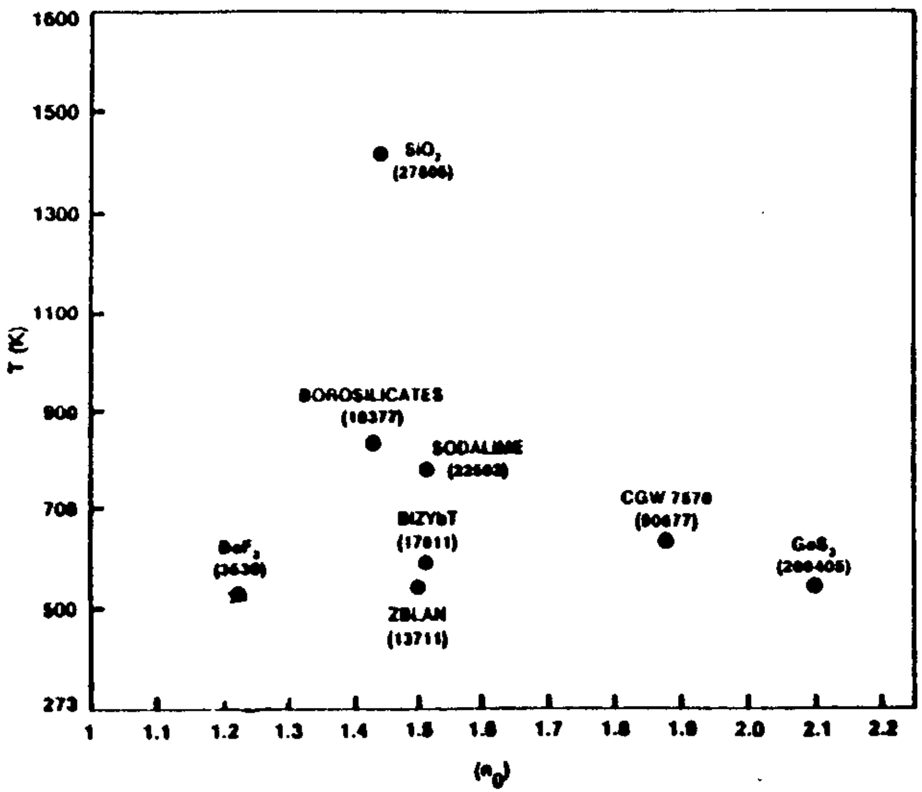
ROBERT H. DOREMUS
Rensselaer Polytechnic Institute

Glass is an amorphous solid. A material is amorphous when it has no long-range order, that is, when there is no regularity in the arrangement of its molecular constituents on a scale larger than a few times the size of these groups. 1

Many earlier writers insist on this criterion: "A glass ... is a material, formed by cooling from the normal liquid state, which has shown no discontinuous change ... at any temperature, but has become more or less rigid through a progressive increase in its viscosity," according to Jones (Ref. 1, p. 1), or, more succinctly, "glass is an inorganic product of fusion which has been cooled to a rigid condition without crystallization" as taken from the *ASTM Standards for Glass*. The difficulty with this view is that glasses can be prepared without cooling from the liquid state. Glass coatings are deposited from the vapor or liquid solution, sometimes with chemical reactions.




LOG η (POISE)
VISCOSITY MEASUREMENTS LIMIT
STRAIN POINT : ~3,16x 10^14 POISE
GLASS TRANSITION : ~1÷4x 10^13 POISE
ANNEALING POINT : ~10^13 POISE
DILATOMETRIC POINT : ~2x10^11 POISE
SOFTENING POINT :3x 10^7÷4,5x 10^8 POISE
(OR LITTLETON'S POINT)
FLOW POINT :10^5 POISE
SINK POINT :1,66x 10^4 POISE
WORKING POINT :10^4 POISE
FIBER DRAWING
MELTING POINT :10^2 POISE
3000 2500 2000 1500 1250 1000 900
T(°C)


T (K)
1600
1500
1300
1100
900
700
500
273
SiO₂
BOROSILICATES
SODALIME
CGW 7570
(90677)
BIZYbT
(17011)
ZBLAN
(13711)
BeF₂
GeS₂
1 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2.0 2.1 2.2
(n_D)

In conclusion, glass is the result of:

chemical compositions

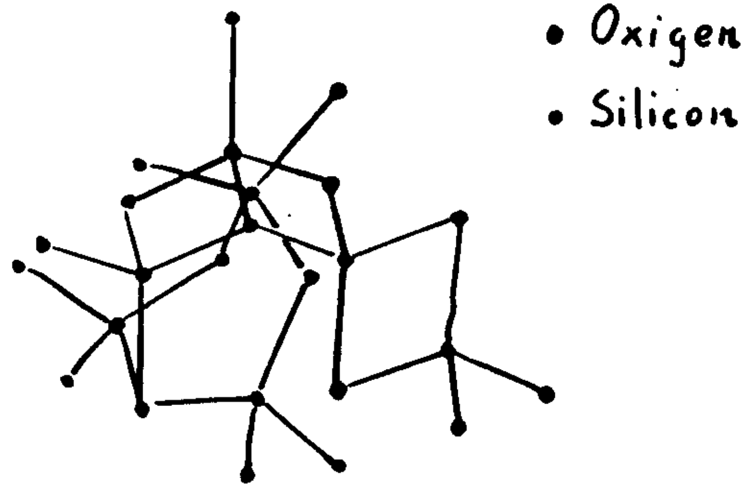
thermal treatments

mechanical processes

"Different process parameters produce materials which are different, even if their compositions are identical"

i.e. faster cooling produces glasses with lower density, greater distance between the atoms, lower refractive index, lower viscosity and so on...

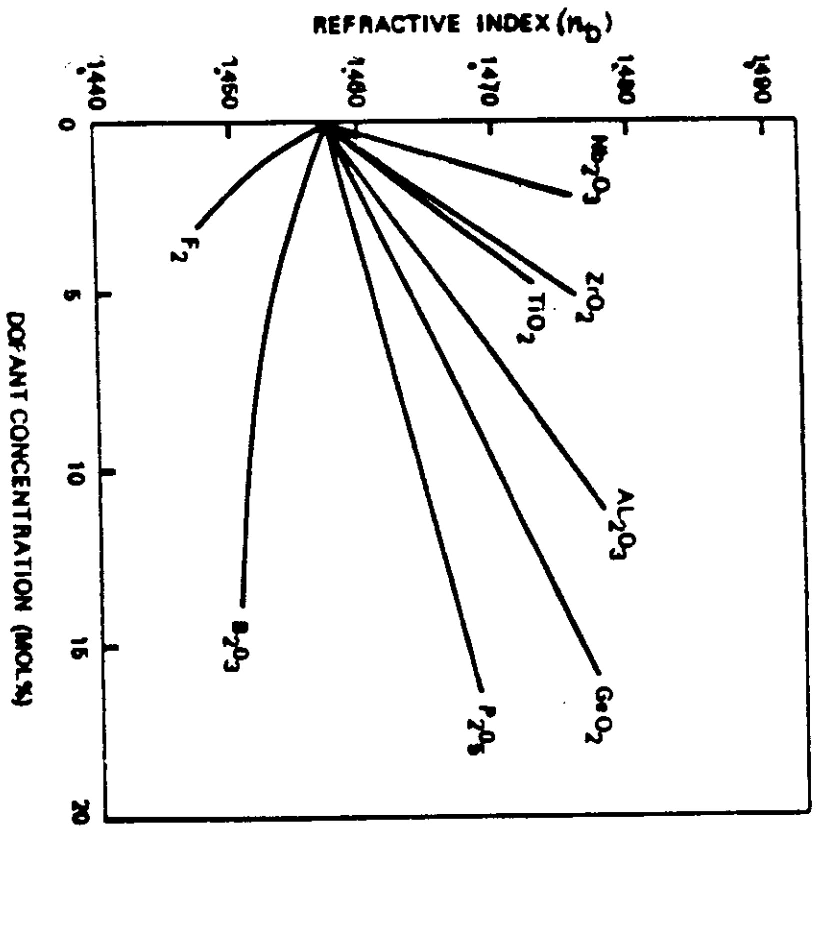
VITREOUS SILICA SiO_2

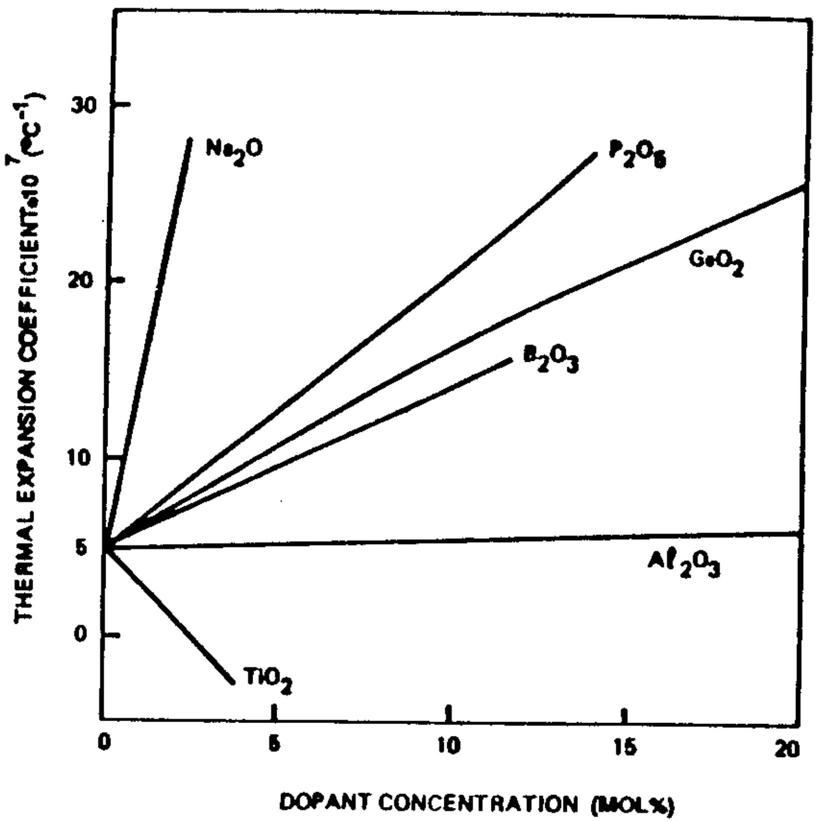


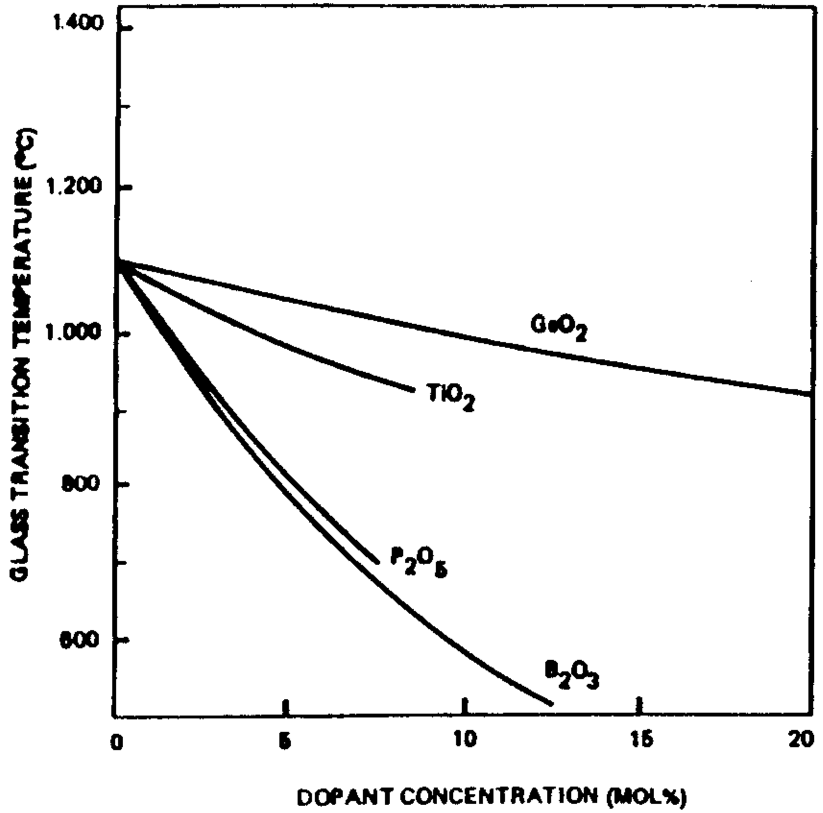
Interatomic Distances

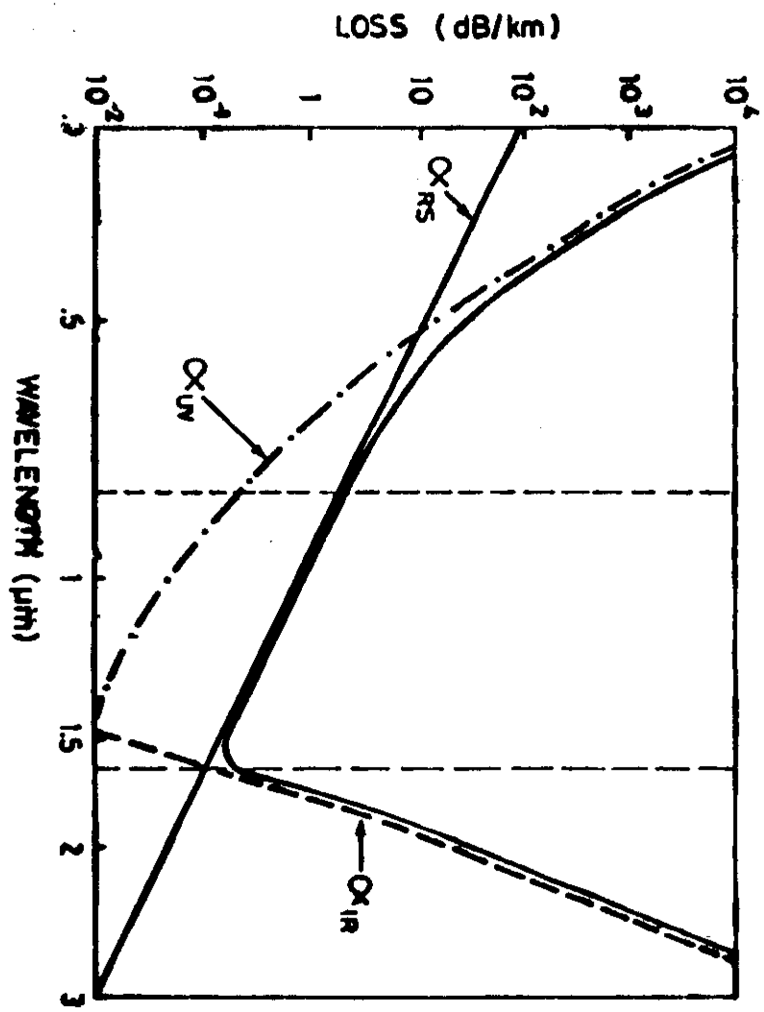
Si — O	1.62 Å
O — O	2.65 Å
Si — Si	3.12 Å
Si — 2nd O	4.15 Å

Density (g/cm^3)	2.2	Strain point (°C)	1070	Bulk modulus (GPa)	~36
Refractive index (n_D)	1.4585	Mohs hardness	4.9	Rigidity modulus (GPa)	31
Thermal expansion coefficient at 20°C + 320°C ($°C^{-1}$)	$5.5 \cdot 10^{-7}$	Vickers hardness (kg/mm^2)	800	Young's modulus (GPa)	71.7
Thermal conductivity at 20°C ($cal\ cm^{-1} s^{-1} °C^{-1}$)	0.0033	Fracture toughness ($MPa\ m^{1/2}$)	0.7-0.8	Shear modulus (GPa)	31
Specific heat at 0 + 100°C ($cal\ g^{-1}$)	0.18	Fracture stength (MPa)	70	Poisson's ratio	0.16
Softening point (°C)	~1665	Tensile strength (MPa)	48	Resistivity at 20°C ($\Omega \cdot cm$)	10^{18}
Annealing point (°C)	~1140	Compressive strength (MPa)	>1100	Dielectric costant at 20°C (1 MHz)	3.75

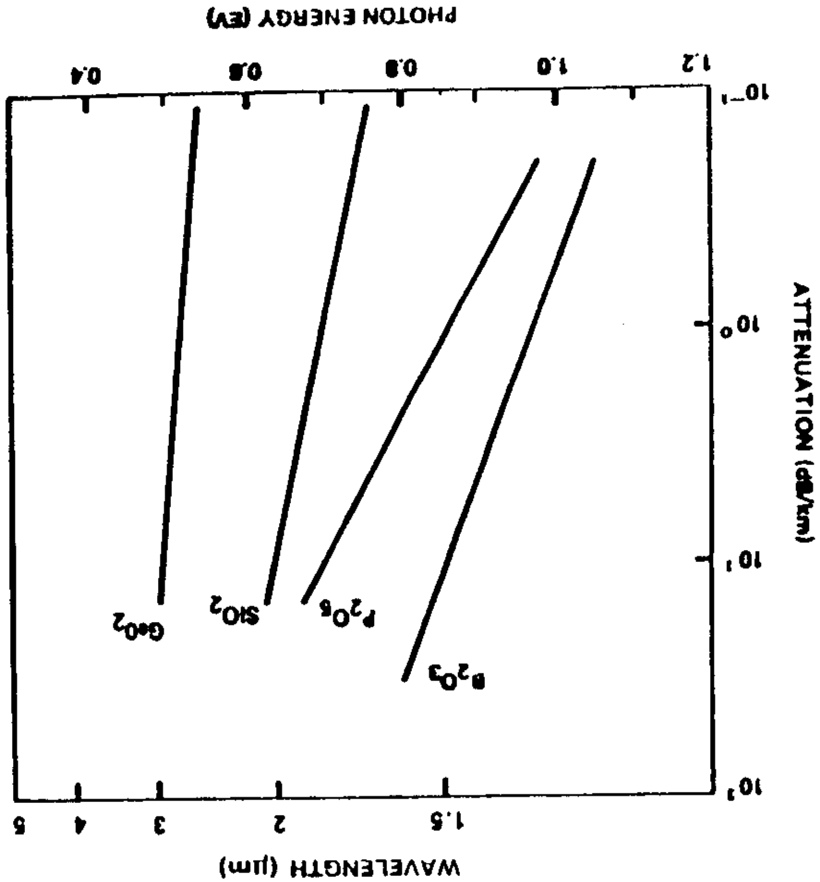



THERMAL EXPANSION COEFFICIENT×10^7 (°C^-1)
30
20
10
5
0
Na2O
P2O5
GeO2
B2O3
Al2O3
TiO2
0
5
10
15
20
DOPANT CONCENTRATION (MOL%)


GLASS TRANSITION TEMPERATURE (°C)
1.400
1.200
1.000
800
600
GeO2
TiO2
P2O5
B2O3
0
5
10
15
20
DOPANT CONCENTRATION (MOL%)



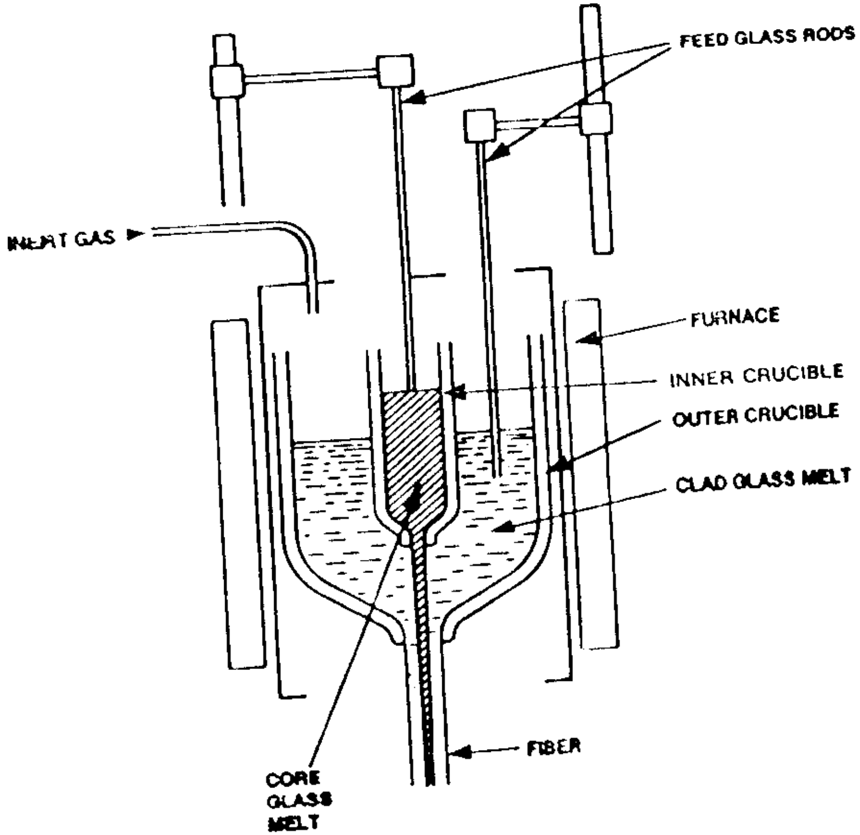
LOSS (dB/km)
WAVELENGTH (μm)
α_{RS}
α_{UV}
α_{IR}



PHOTON ENERGY (EV)
ATTENUATION (dB/km)
WAVELENGTH (μm)
GeO_2
SiO_2
P_2O_5
B_2O_3

In conclusion, the choice of dopants must be made considering their effect on:

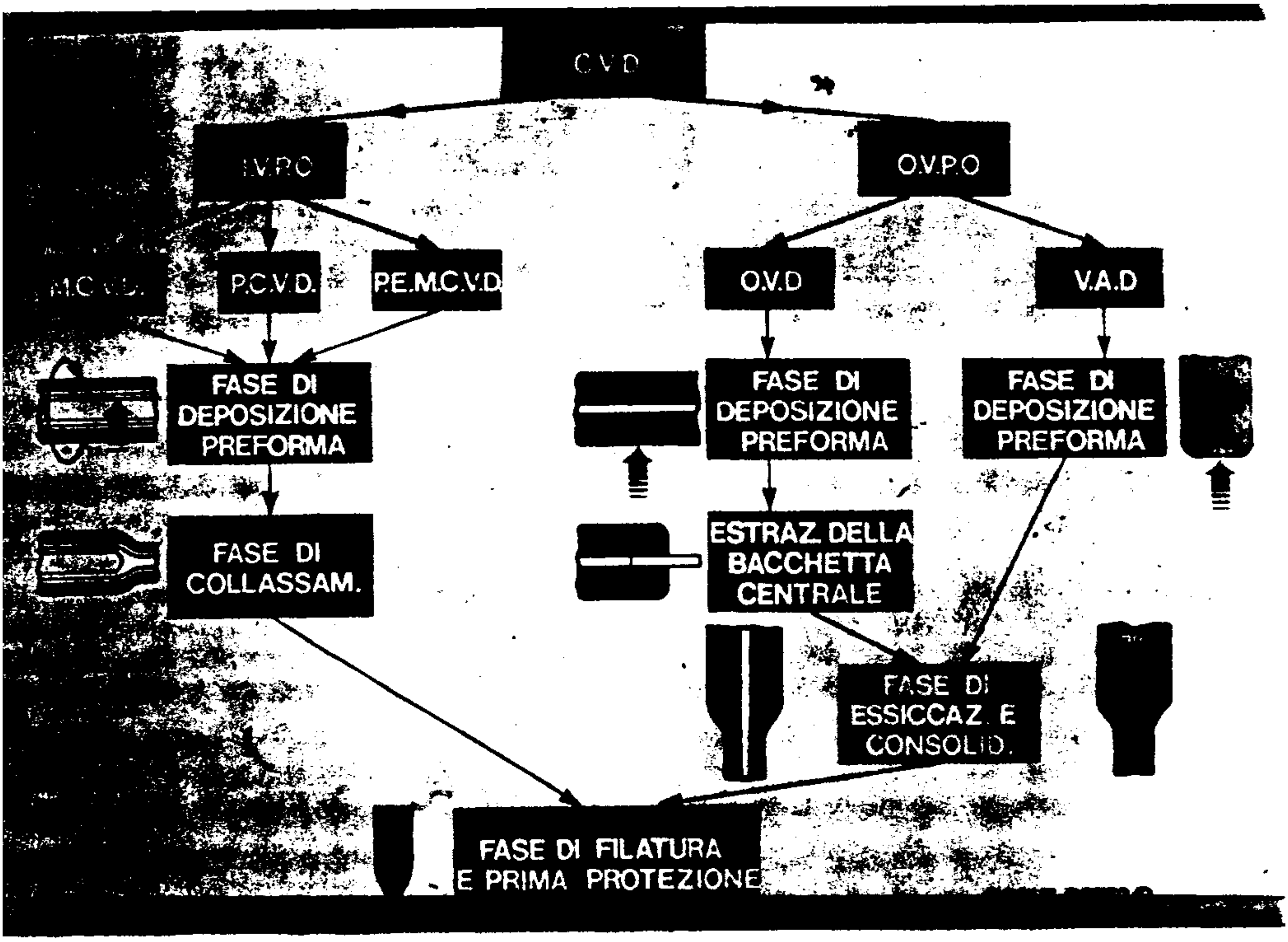
- refractive index
- thermal expansion coefficient
- glass transition temperature
- scattering coefficient
- multiphonon tail

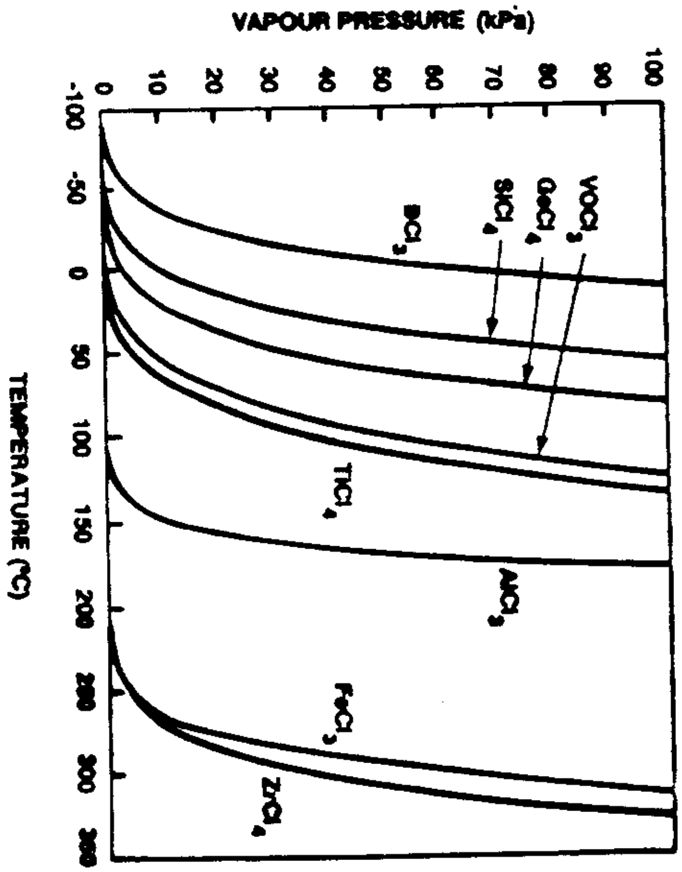


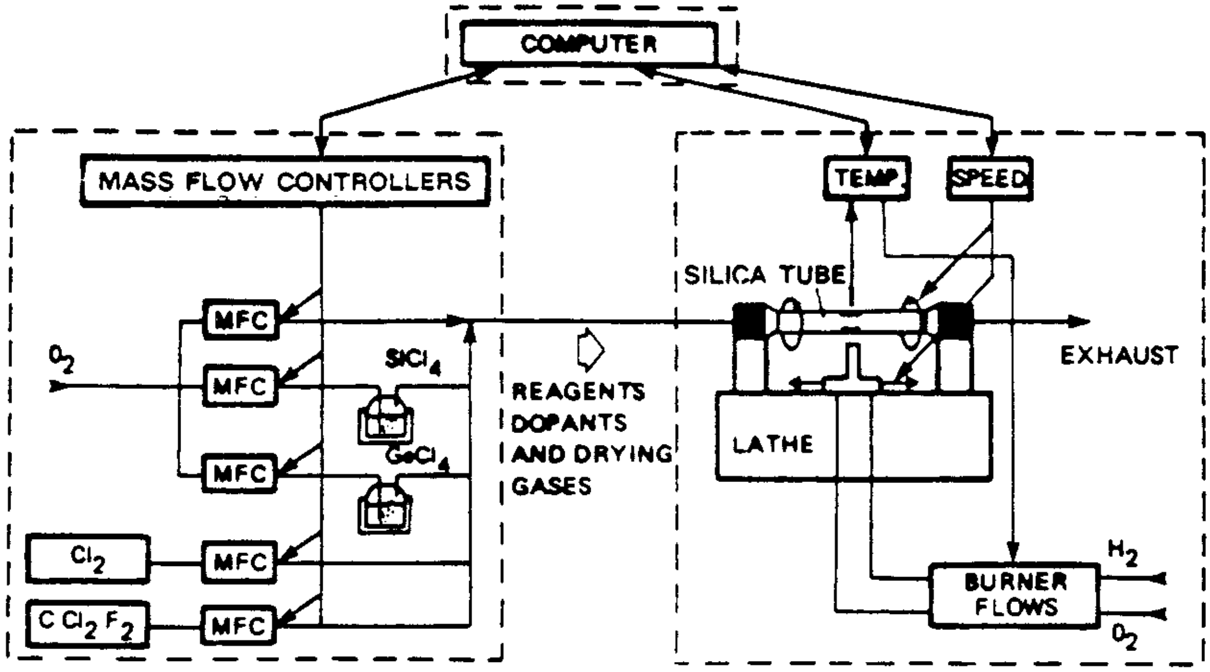
Now the most used dopants are:

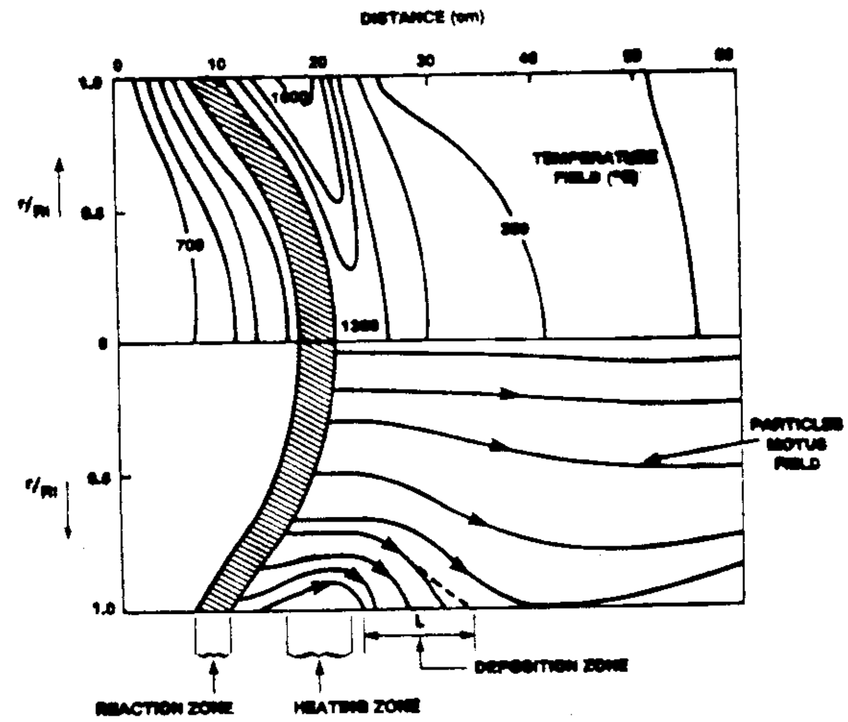
GeO_2 in the core.

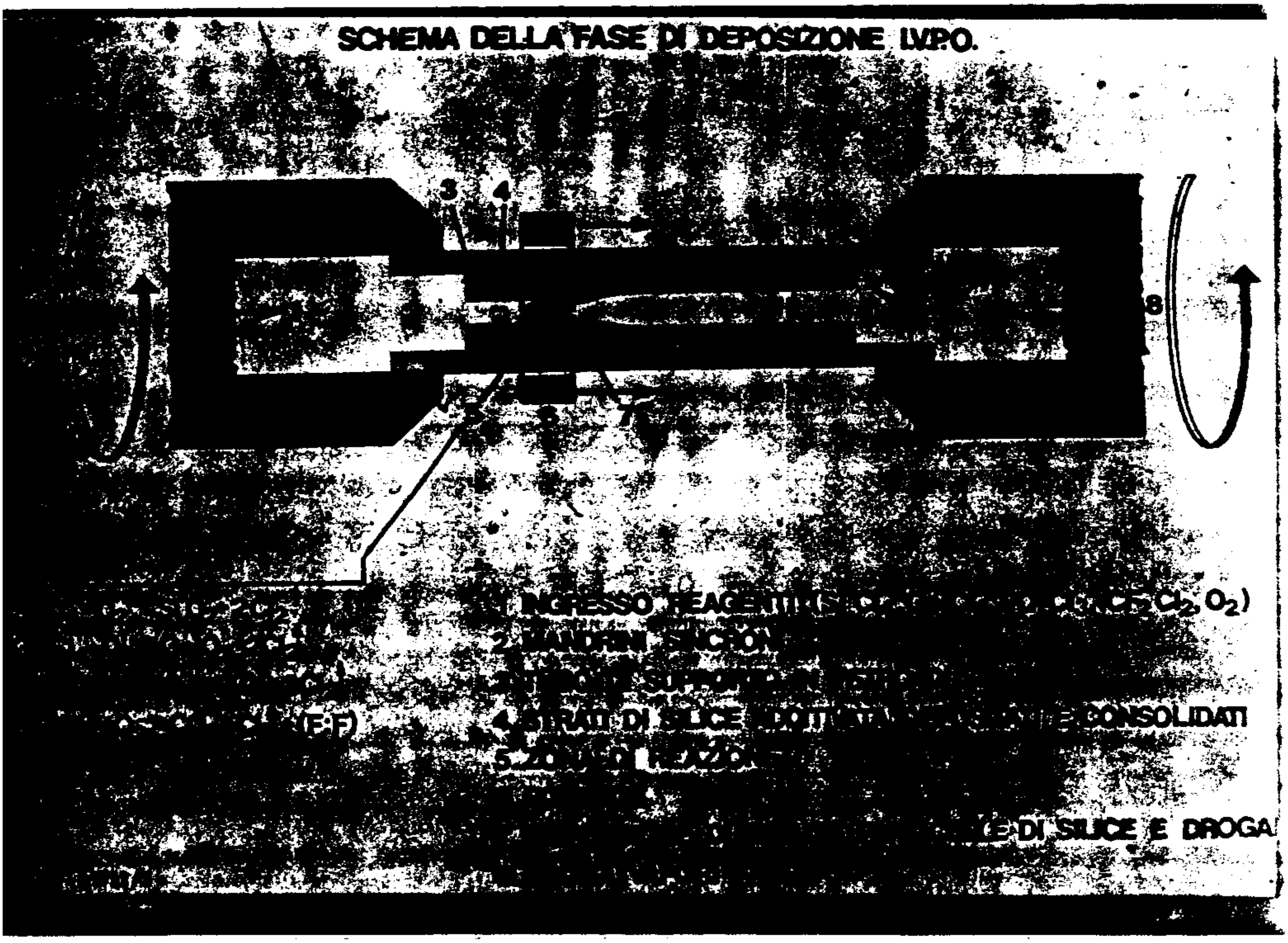
F_2 in the cladding

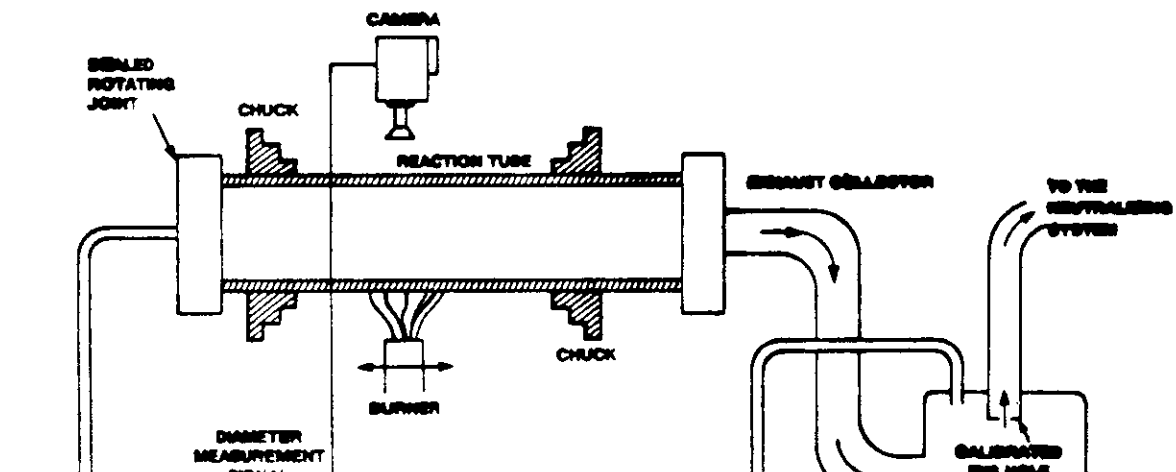

C.V.D
I.V.P.O
O.V.P.O
M.C.V.D.
P.C.V.D.
P.E.M.C.V.D
O.V.D
V.A.D
FASE DI DEPOSIZIONE PREFORMA
FASE DI DEPOSIZIONE PREFORMA
FASE DI DEPOSIZIONE PREFORMA
FASE DI COLLASSAM.
ESTRAZ. DELLA BACCHETTA CENTRALE
FASE DI ESSICCAZ. E CONSOLID.
FASE DI FILATURA E PRIMA PROTEZIONE

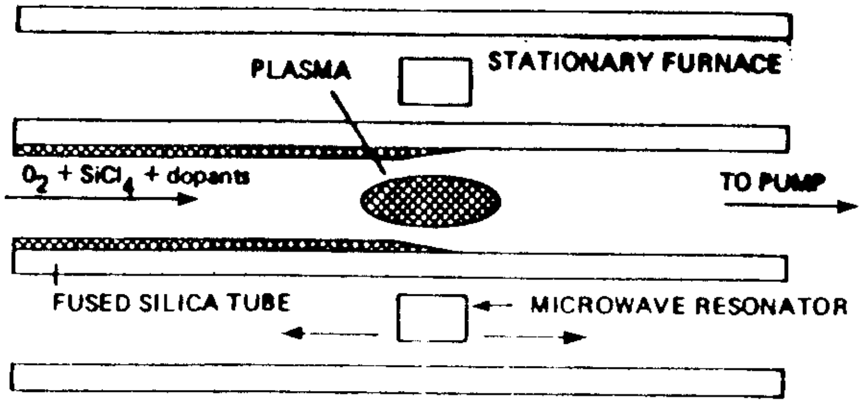

VAPOUR PRESSURE (kPa)
TEMPERATURE (°C)
VOCl3
GeCl4
SiCl4
BCl3
TiCl4
AlCl3
FeCl3
ZrCl4

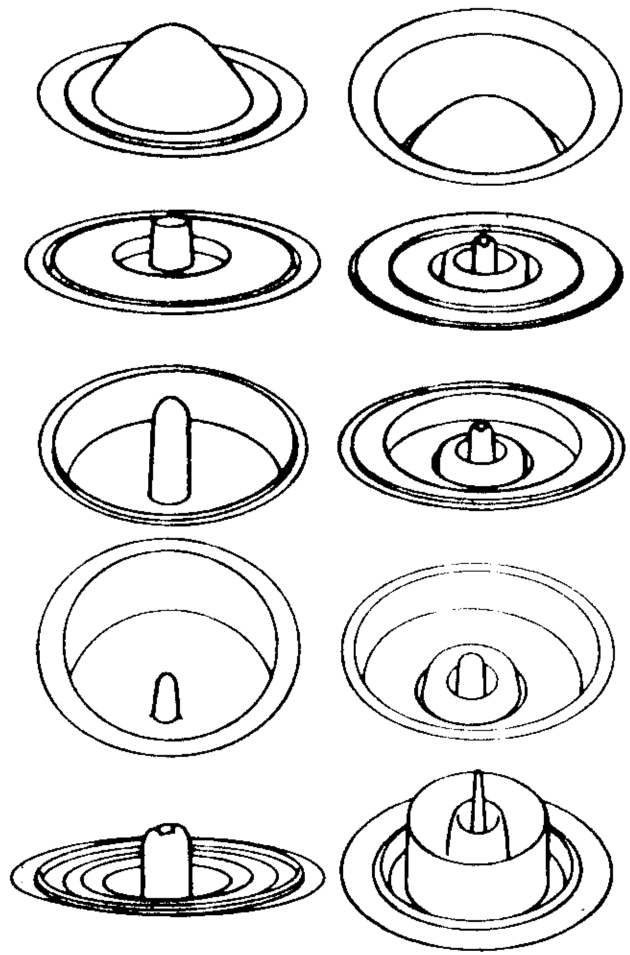

COMPUTER
MASS FLOW CONTROLLERS
MFC
MFC
MFC
MFC
MFC
O_2
$SiCl_4$
$GeCl_4$
Cl_2
CCl_2F_2
REAGENTS
DOPANTS
AND DRYING
GASES
TEMP.
SPEED
SILICA TUBE
EXHAUST
LATHE
BURNER
FLOWS
H_2
O_2

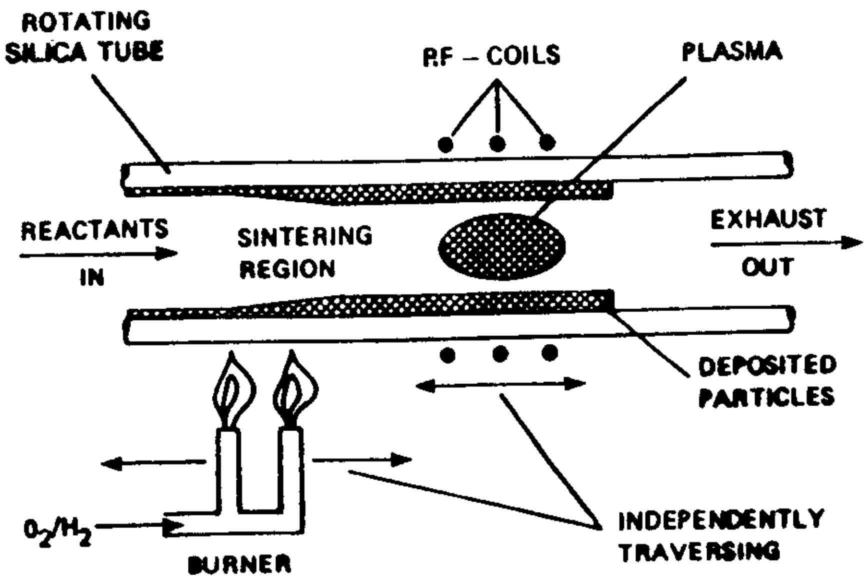

DISTANCE (cm)
0
10
20
30
40
50
60
1.0
0.5
0
0.5
1.0
1600
700
1300
300
TEMPERATURES
FIELD (°C)
PARTICLES
MOTUS
FIELD
L
REACTION ZONE
HEATING ZONE
DEPOSITION ZONE

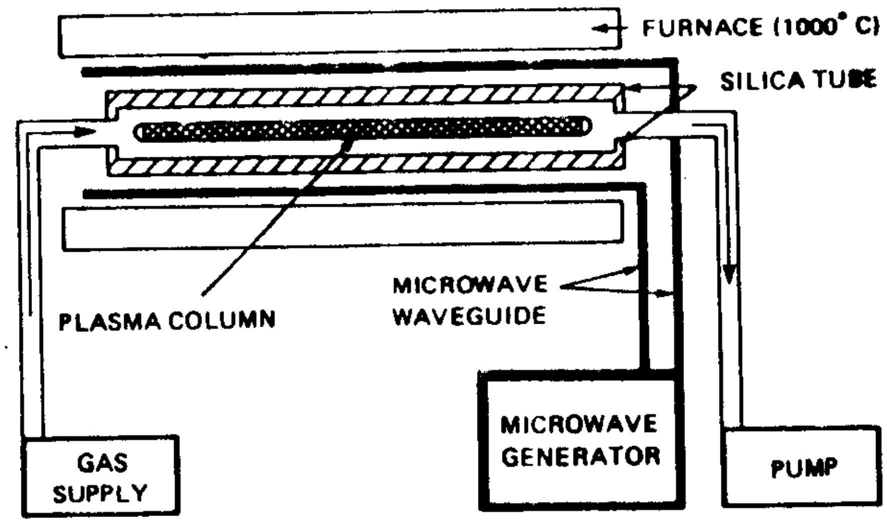

SCHEMA DELLA FASE DI DEPOSIZIONE I.V.P.O.
3
4
8
(E-F)
1 INGRESSO REAGENTI (Cl_2, O_2)
2 MANDRINI SINCRONI
4 STRATI DI SILICE CONSOLIDATI
5
DI SILICE E DROGA

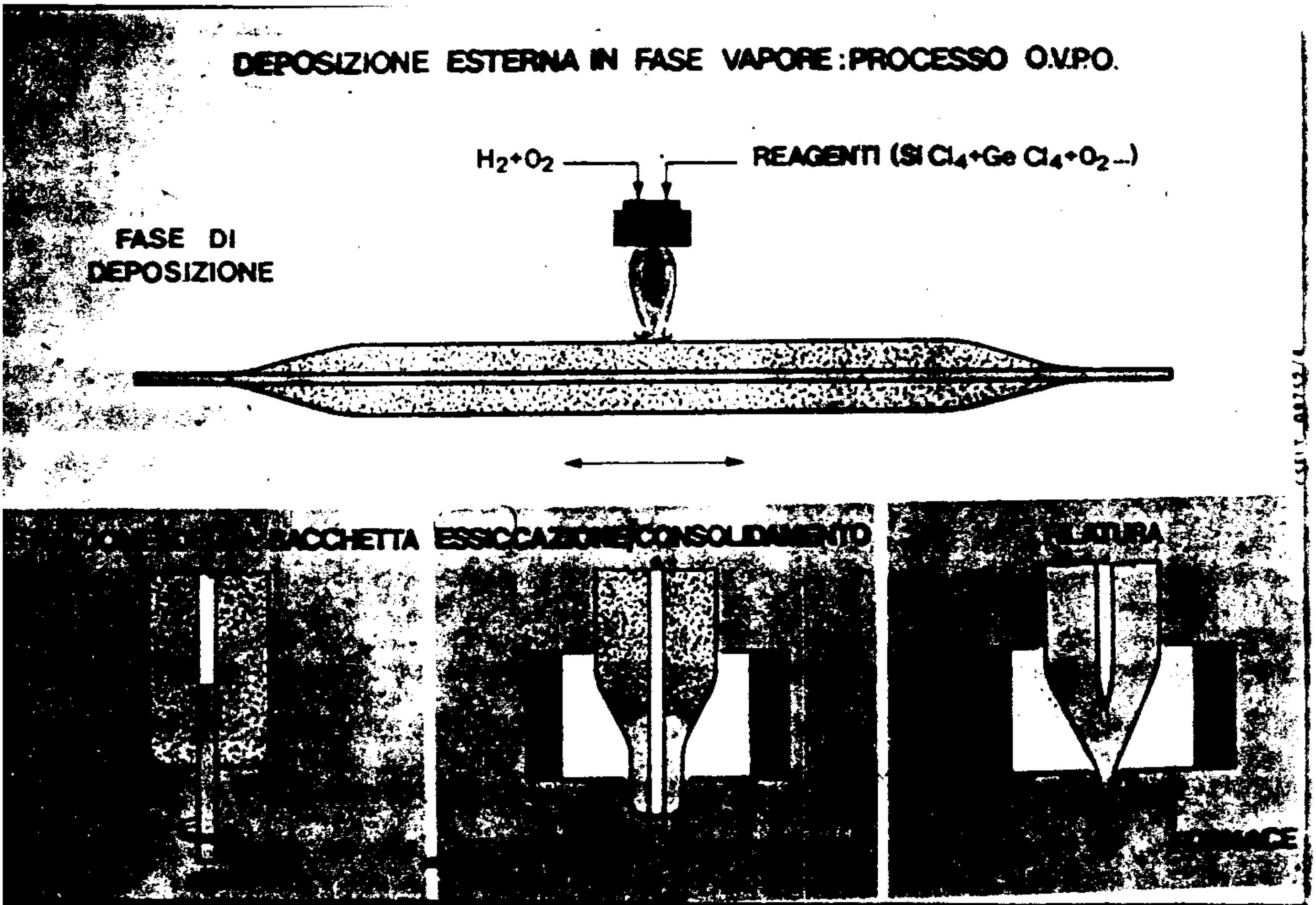

CAMERA
SEALED ROTATING JOINT
CHUCK
REACTION TUBE
EXHAUST COLLECTOR
TO THE NEUTRALIZING SYSTEM
CHUCK
BURNER
DIAMETER MEASUREMENT SIGNAL
MASS- FLOW CONTROLLER
CALIBRATED IRIS HOLE
CYCLONE
CVD REAGENTS AND CARRIER GASES
MICROPROCESSOR CONTROLLER
O_2

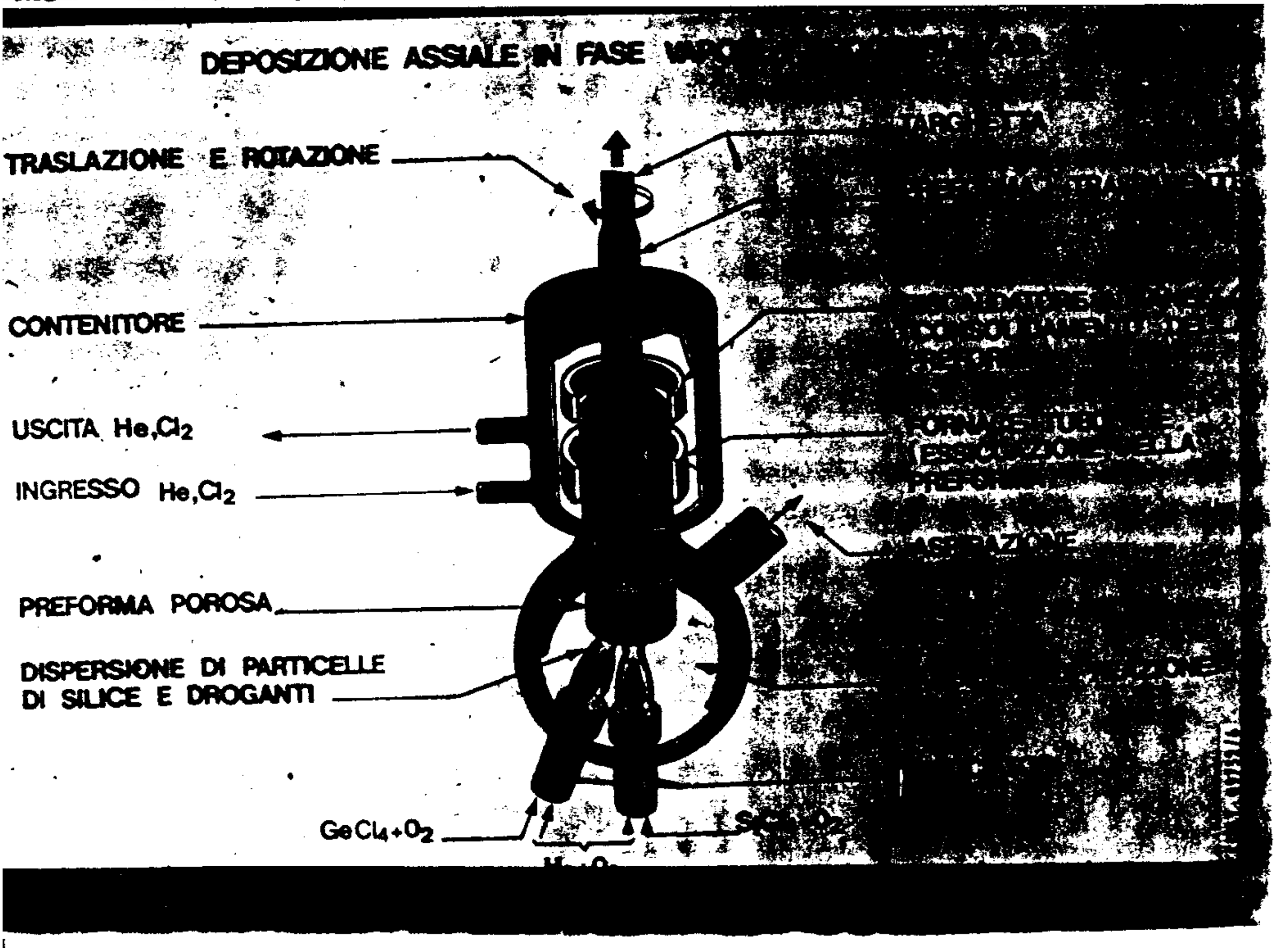

PLASMA
STATIONARY FURNACE
O_2 + $SiCl_4$ + dopants
TO PUMP
FUSED SILICA TUBE
MICROWAVE RESONATOR

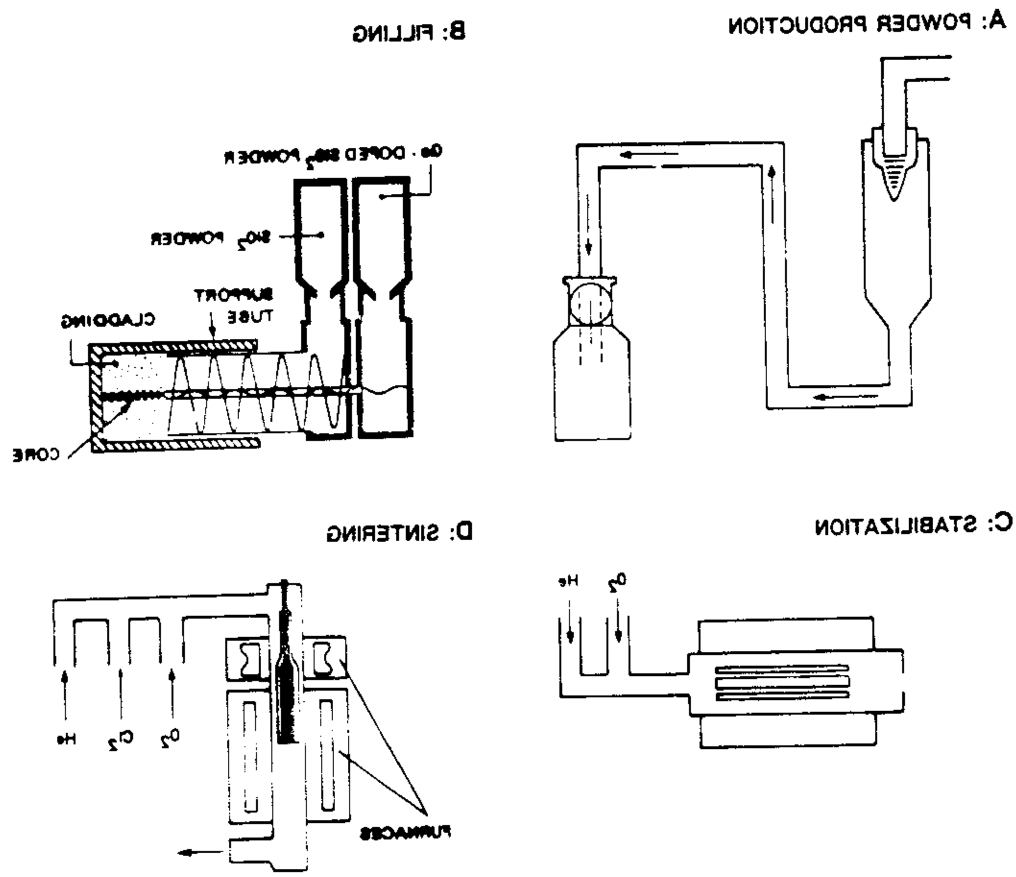



ROTATING
SILICA TUBE
R.F – COILS
PLASMA
REACTANTS
IN
SINTERING
REGION
EXHAUST
OUT
DEPOSITED
PARTICLES
O_2/H_2
BURNER
INDEPENDENTLY
TRAVERSING

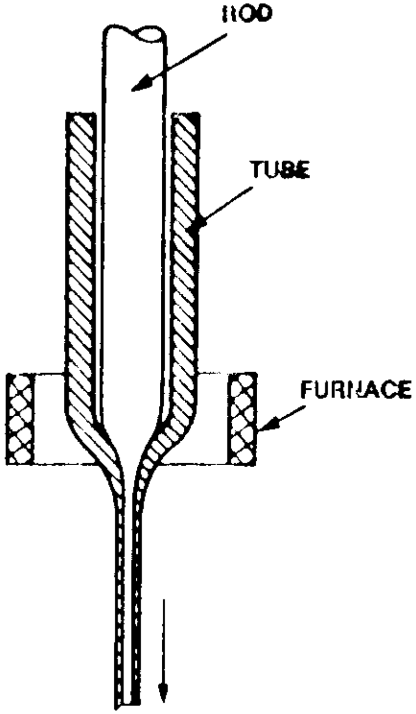

FURNACE (1000° C)
SILICA TUBE
PLASMA COLUMN
MICROWAVE
WAVEGUIDE
GAS
SUPPLY
MICROWAVE
GENERATOR
PUMP


DEPOSIZIONE ESTERNA IN FASE VAPORE: PROCESSO O.V.P.O.
H_2+O_2
REAGENTI ($SiCl_4+GeCl_4+O_2$...)
FASE DI DEPOSIZIONE
ESSICCAZIONE/CONSOLIDAMENTO

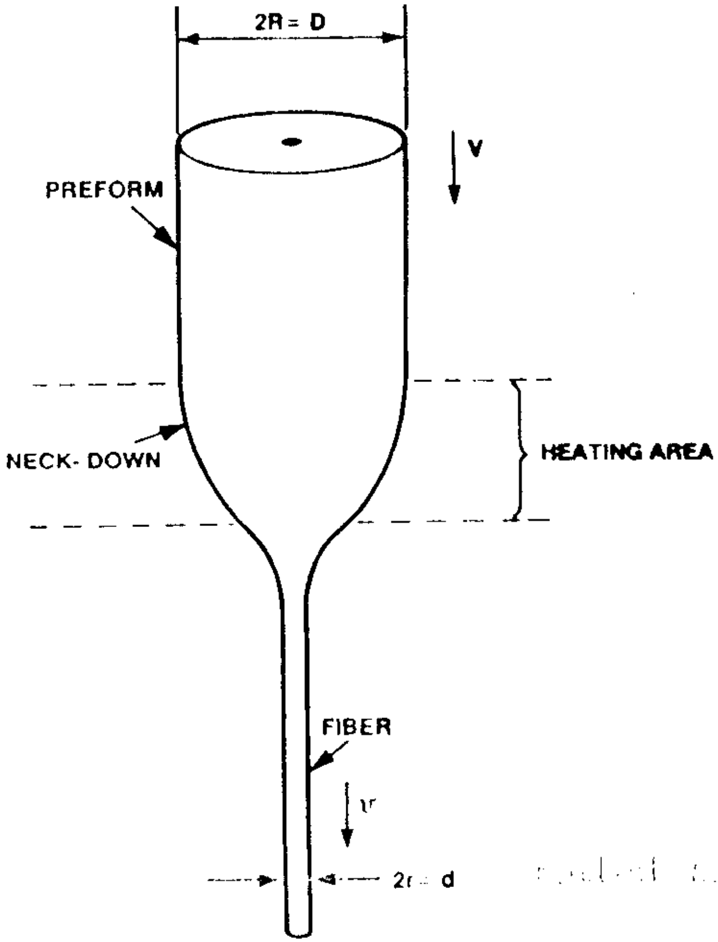

DEPOSIZIONE ASSIALE IN FASE
TRASLAZIONE E ROTAZIONE
CONTENITORE
USCITA He,Cl_2
INGRESSO He,Cl_2
PREFORMA POROSA
DISPERSIONE DI PARTICELLE DI SILICE E DROGANTI
$GeCl_4+O_2$



	TEMPERATURE	TIME	DENSITY	RELATIVE VOLUME	SURFACE AREA
OLUTION REPARATION	60°	–	~ 1.0	1	–
ELLATION	20°	50-150 hrs	~ 1.0	1	–
RYING ROCESS	60° - 120°	< 200 hrs	1.5	0.6-0.4	750 m^2/g
URING ROCESS	200° - 1000°	50 hrs	2.15	0.4-0.3	500 m^2/g 16 m^2/g (1000°C)
INTERING ROCESS	> 1100°	1 hr	2.2 (silica)	0.3	–



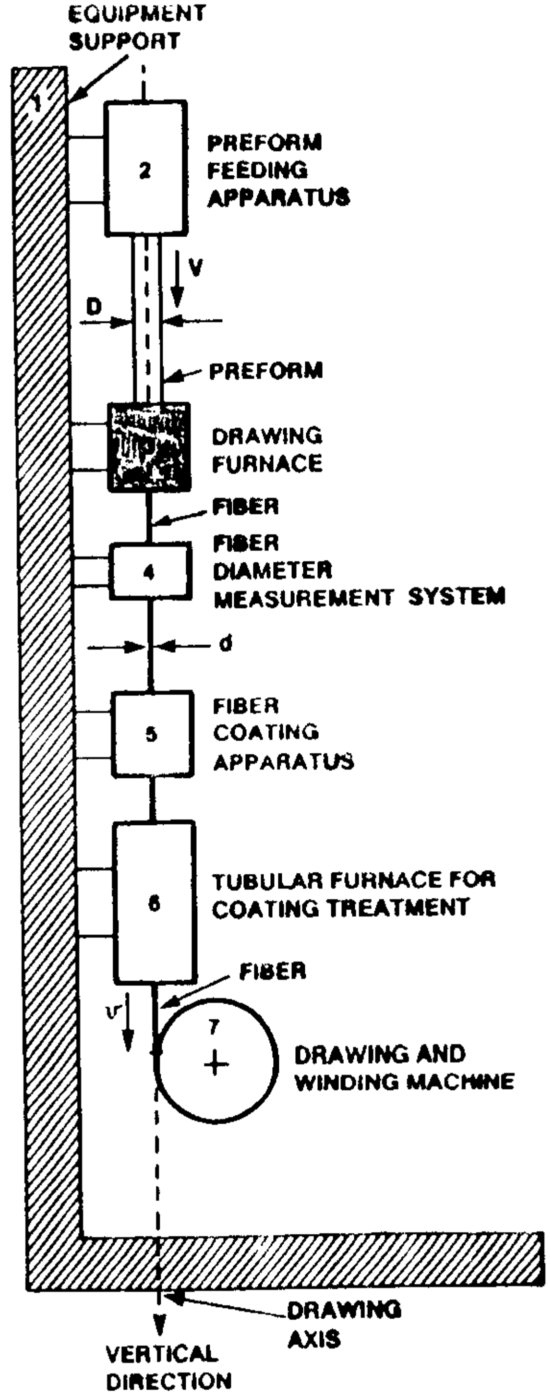
ROD-IN-TUBE PROCESS



$D^2V = d^2v$

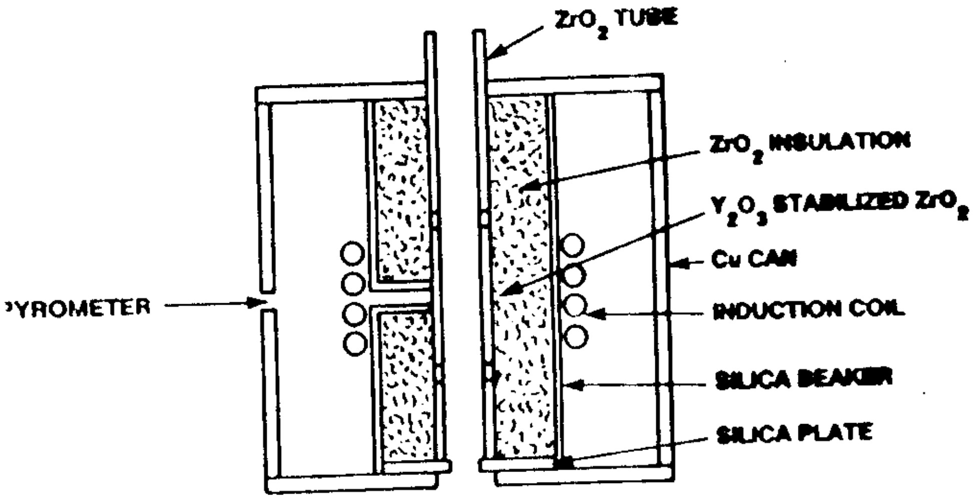
On-line measurement of optical fibre diameter

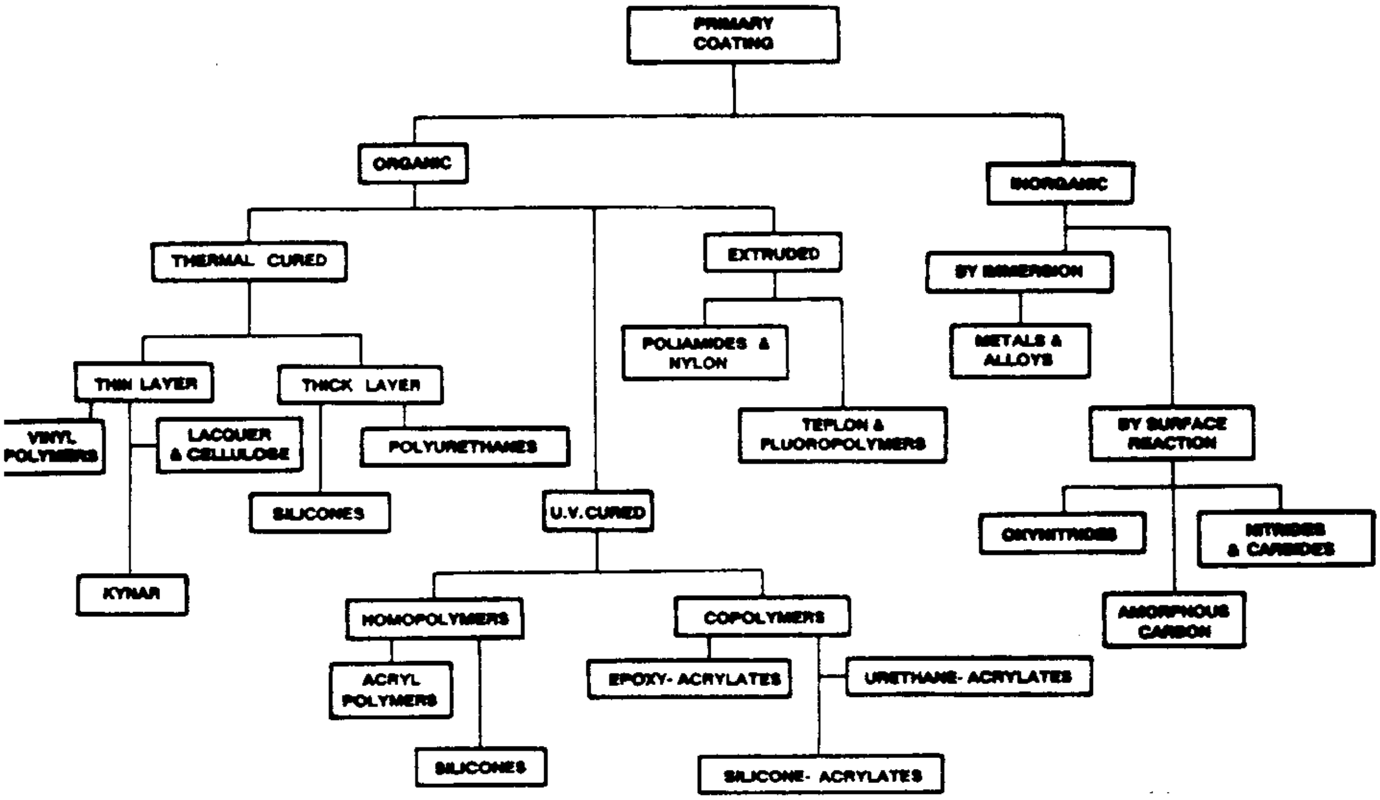
- Method of fibre profile projection
- Dynamic method
- Interferometric method
- Interference finge method
- Electro-optic method

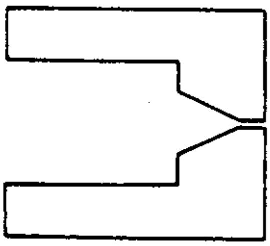


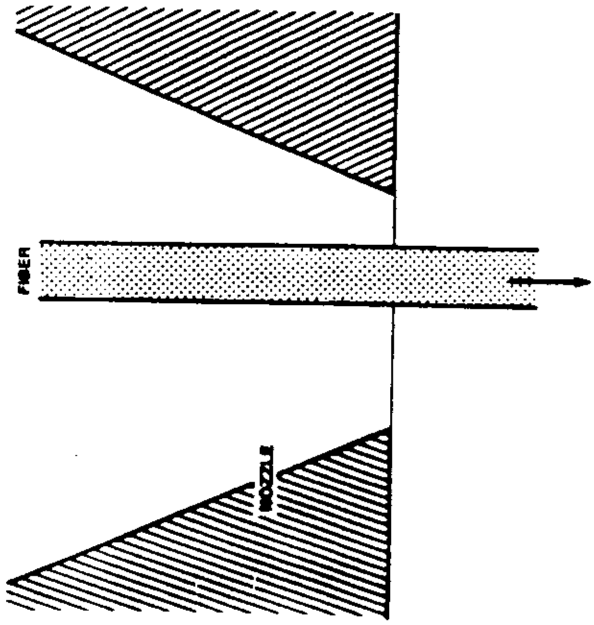
Characteristics of the most commen used heating systems

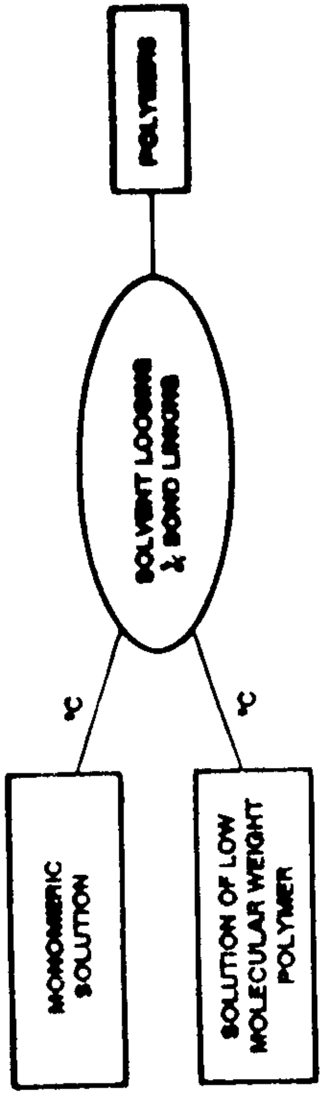
heating system	thermal inertia	atmosphere	spott.	main drawbacks
H_2-O_2 flame	v. low	air	high	thermal instability
CO_2 laser	~zero	air	~zero	confinement difficulties
Grafite resistance	low	inert gas	low	resistance break during drawing
Induction furnace with ZrO_2 susceptor	high	air	high	thermal shock during cooling
Induction furnace with grafite susceptor	high	inert gas	low	inert gas conditioning

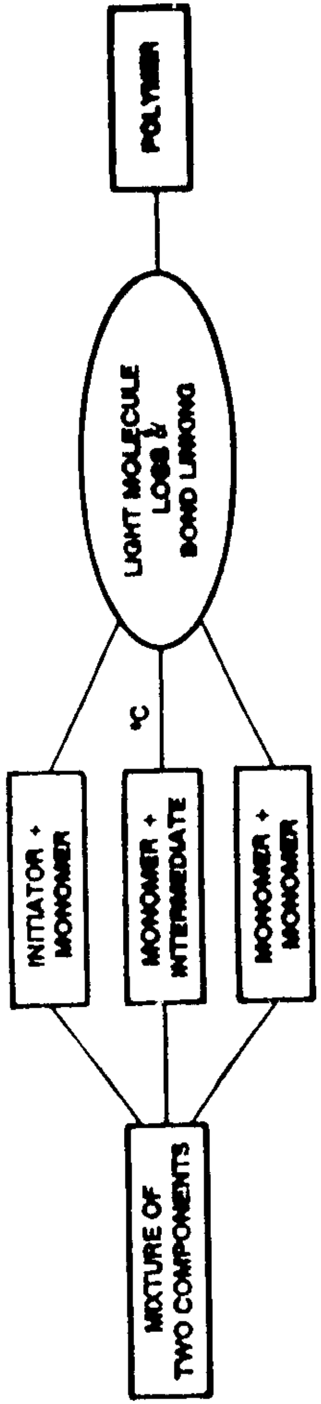



PRIMARY COATING
ORGANIC
INORGANIC
THERMAL CURED
U.V. CURED
EXTRUDED
BY IMMERSION
BY SURFACE REACTION
THIN LAYER
THICK LAYER
VINYL POLYMERS
LACQUER & CELLULOSE
KYNAR
SILICONES
POLYURETHANES
POLIAMIDES & NYLON
TEFLON & FLUOROPOLYMERS
METALS & ALLOYS
OXYNITRIDES
NITRIDES & CARBIDES
AMORPHOUS CARBON
HOMOPOLYMERS
COPOLYMERS
ACRYL POLYMERS
SILICONES
EPOXY- ACRYLATES
URETHANE- ACRYLATES
SILICONE- ACRYLATES

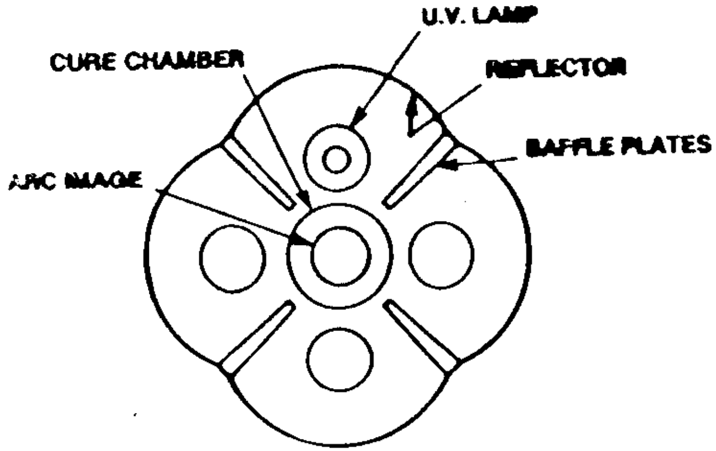



FIBER
NOZZLE



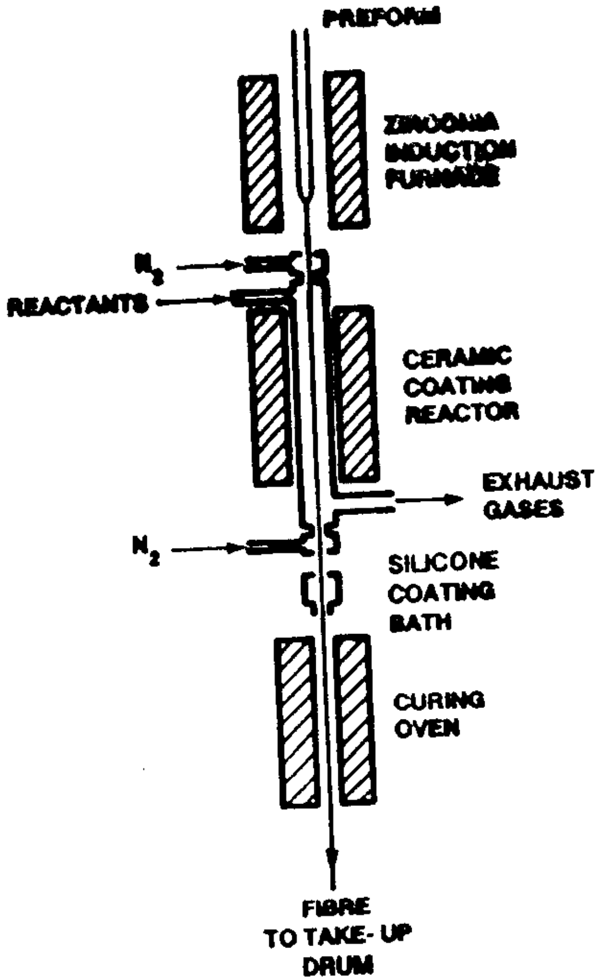


Ultra Violet rays ↔ 200 - 400 nm



UV overexposure $\rightsquigarrow$ hydrogen, methane
carbon monoxide
methanol, formaldehyde

UV underexposure $\rightsquigarrow$ polymer fraction
monomer



Polarization Maintaining Opt. Fibre

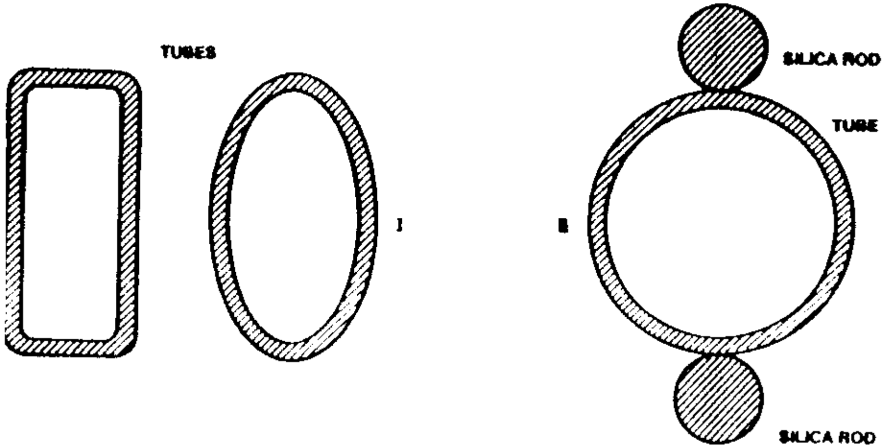
PM fibre is <u>essentially</u> a birefringent element

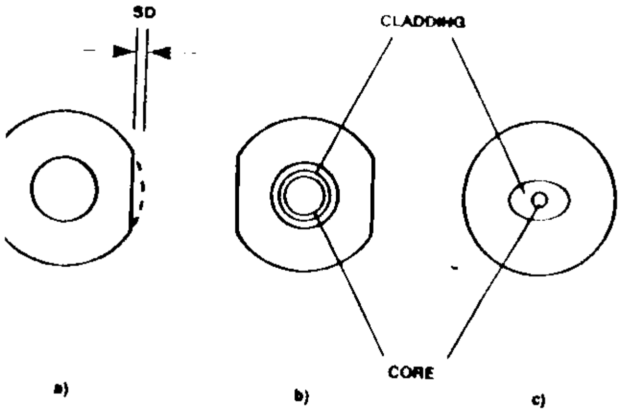
→ Geometric effect : fibres without axial symmetry.

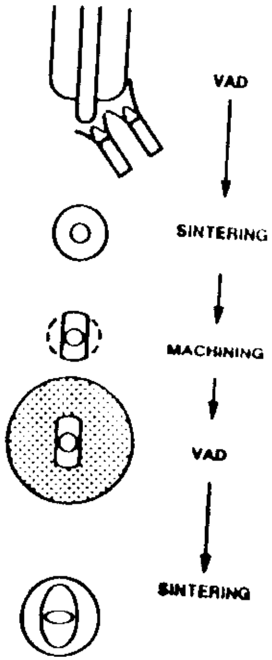
→ Stress effect: core is maintained in a state of transverse stress.

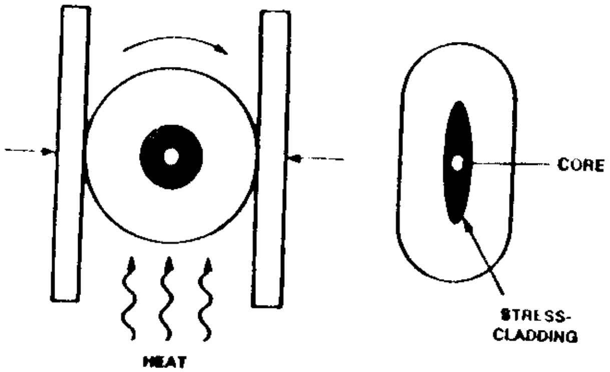
Elliptical core fibre
Elliptical cladding fibre

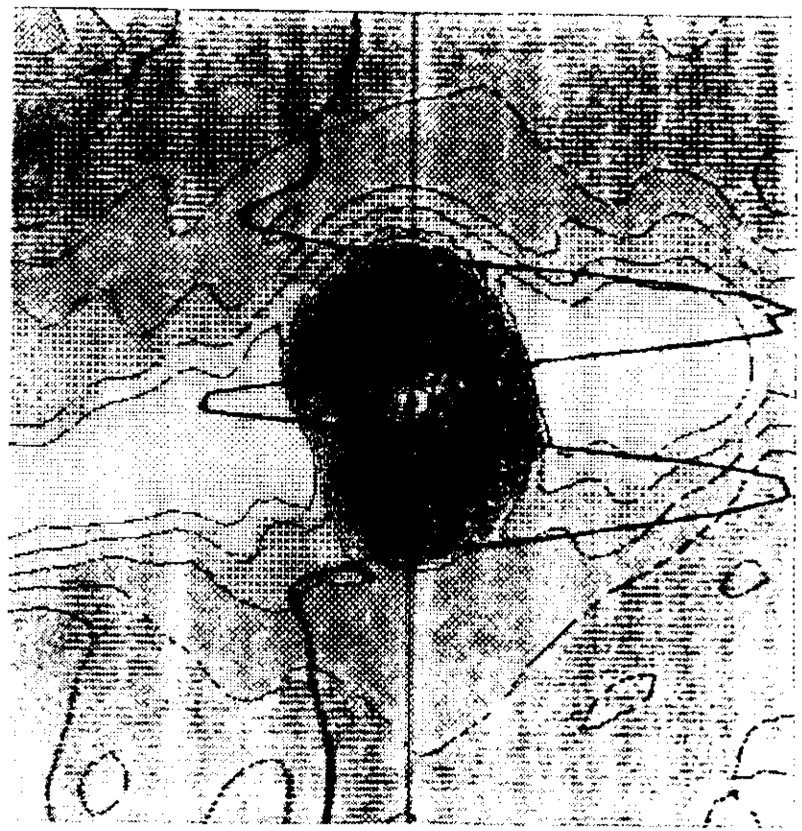
"Bow-tie" fibre
"Panda" fibre







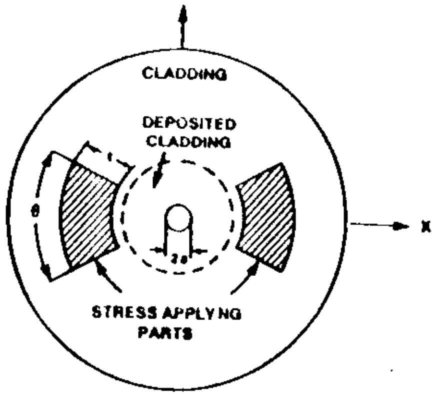


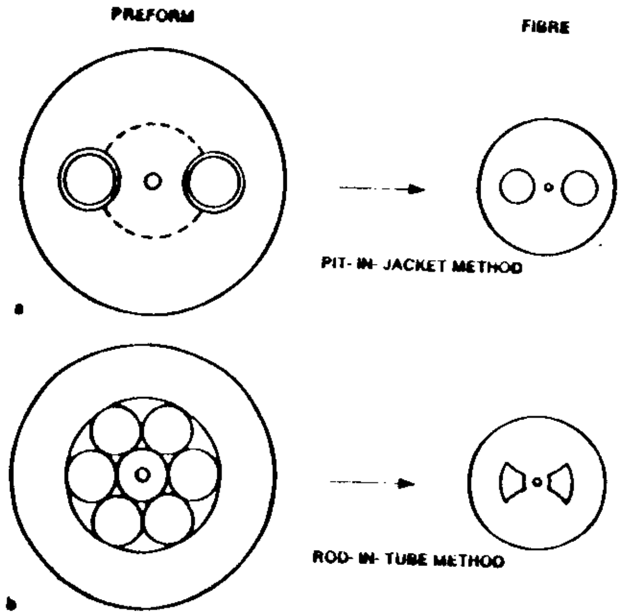


TWO-DIMENSIONAL INDEX DISTRIBUTION OF AN ELLIPTICAL CORE FIBRE

POLARIZATION PRESERVING FIBER

Refractive index profile of Bow-Tie fiber.





Active Fibres

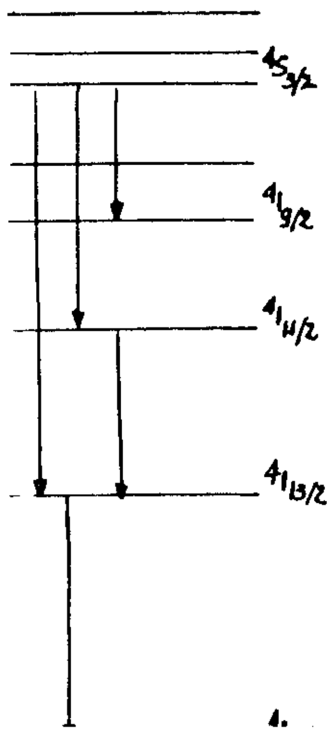
anelastic scattering phenomena

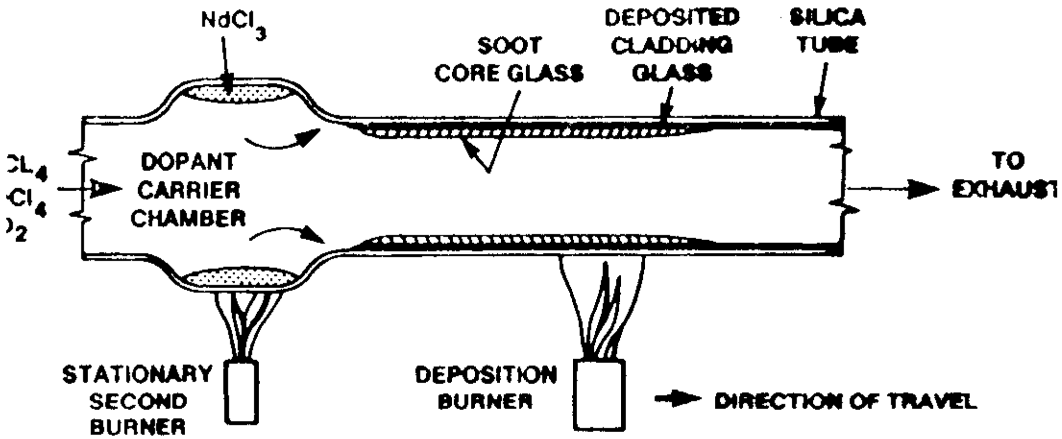
Raman gain

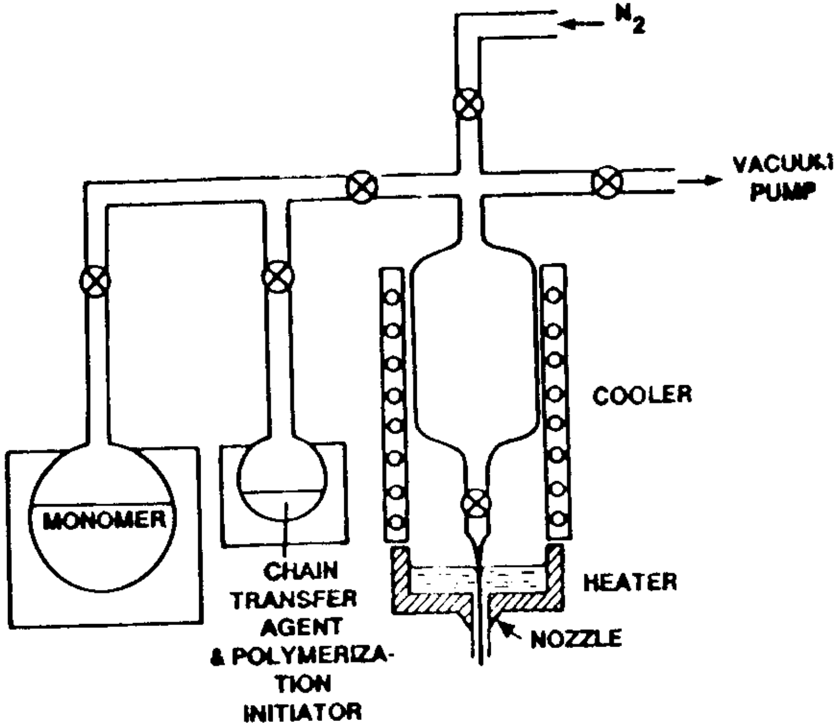
Brillouin gain

spectroscopic effect due to

rare earth ions doping






N2
VACUUM PUMP
COOLER
MONOMER
CHAIN TRANSFER AGENT & POLYMERIZATION INITIATOR
HEATER
NOZZLE