Optical and Photonic Glasses

Lecture 23:

Optical Fibers A: Structure and Function

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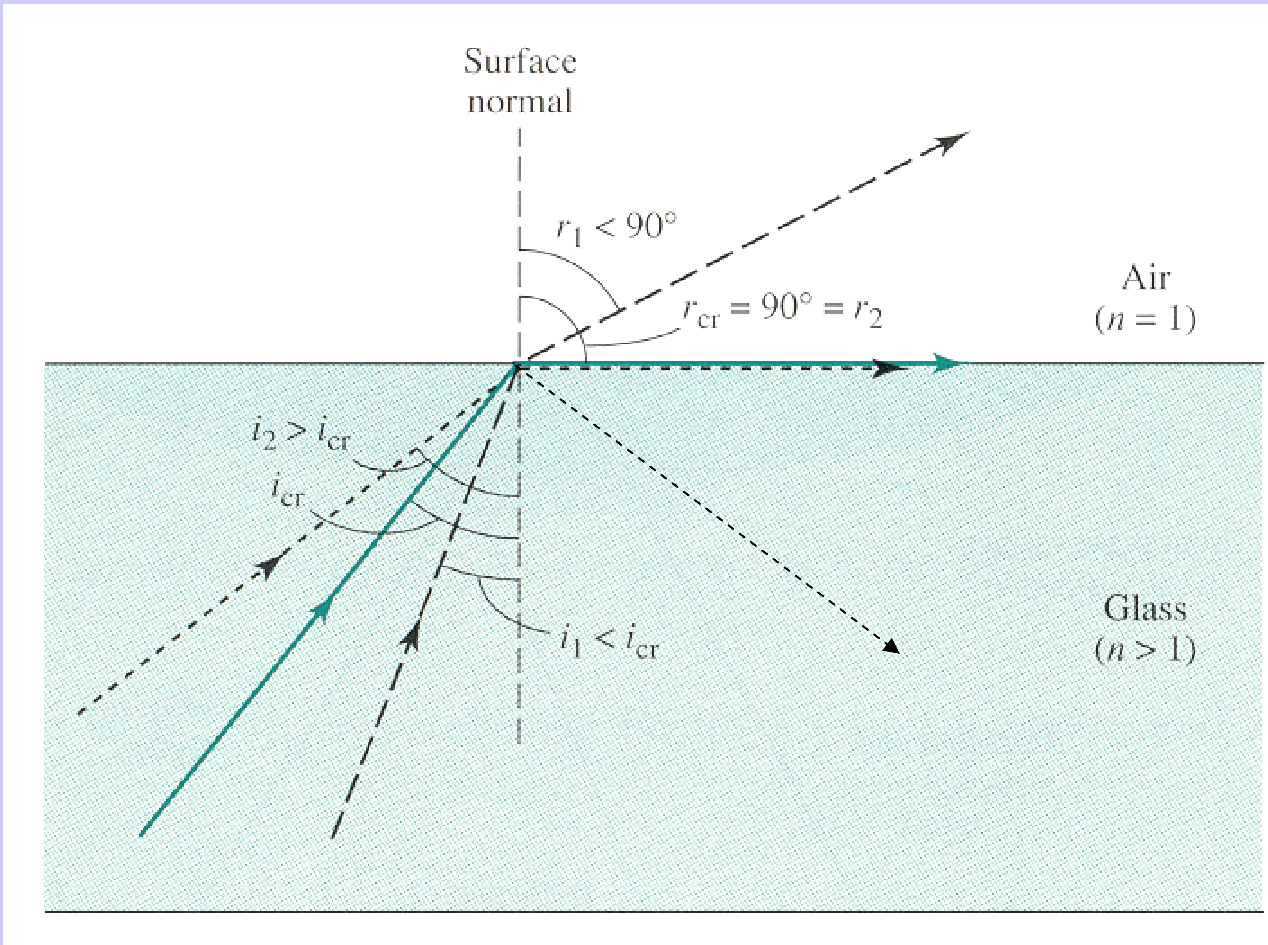
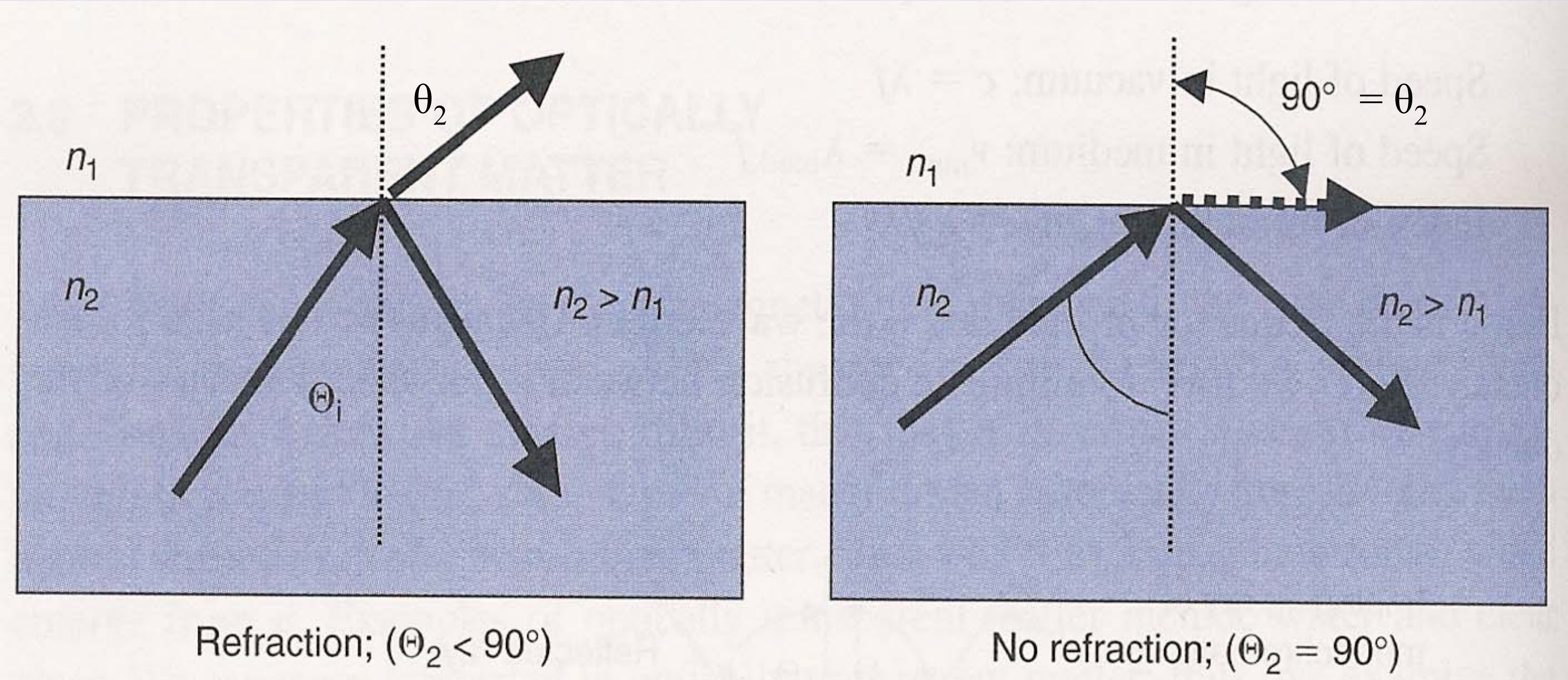
Total internal reflection

The fact that, above a certain *critical angle*, no light escapes from the glass is the key principle in *fiberoptics*. (TIR requires that: $i_{cr} \leq i \leq 90^o$).



(Adapted from: *The science and design of engineering materials*, J.P. Schaffer et al., McGraw-Hill, 1999)

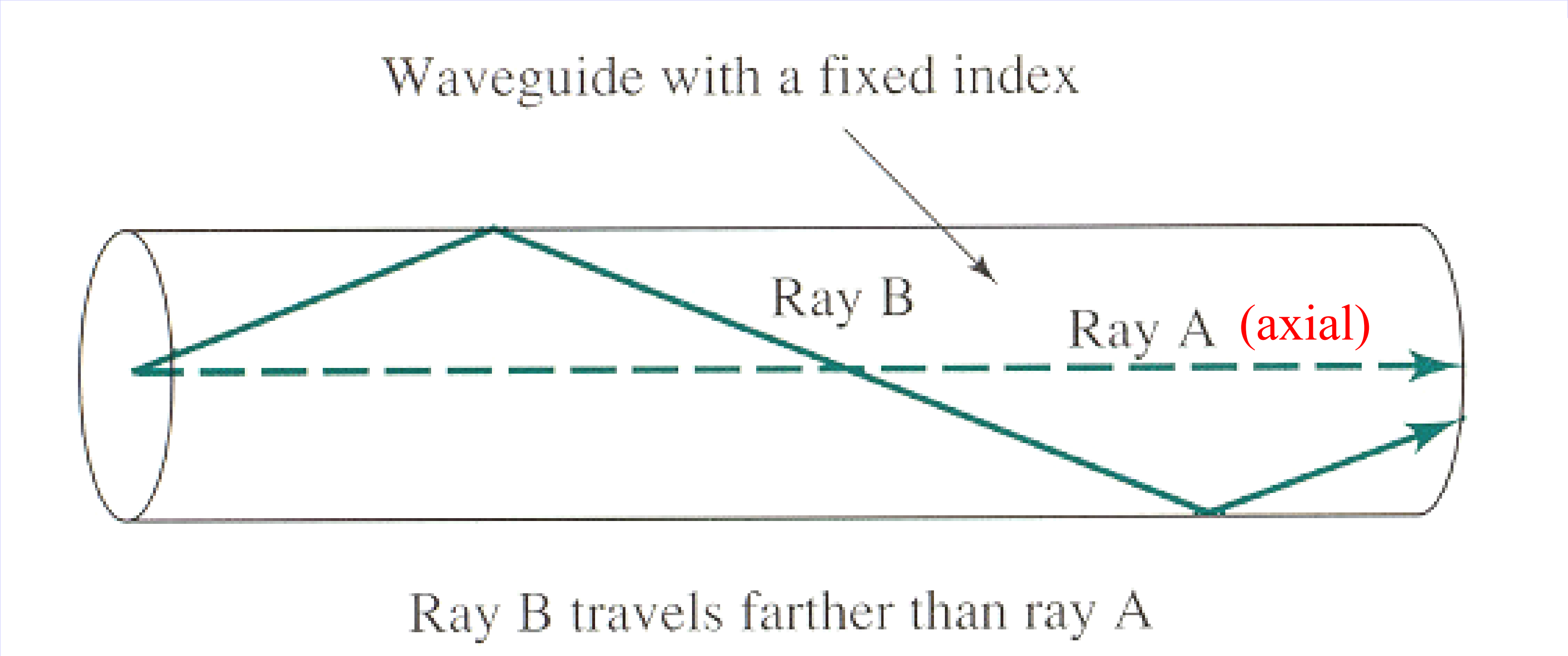
The *critical angle* concept applies only to *internal reflection*, i.e. when light traveling in a medium of a given refractive index $\mathbf{n_2}$ impinges on its the interface with a medium of *lower* refractive index $\mathbf{n_1}$ (which is the opposite of *external reflection*).



Definition of critical angle.

(Adapted from: *Introduction to DWDM Technology*, S.V. Kartalopoulos, IEEE Press, 2000)

Application of total internal reflection to **fiberoptics**



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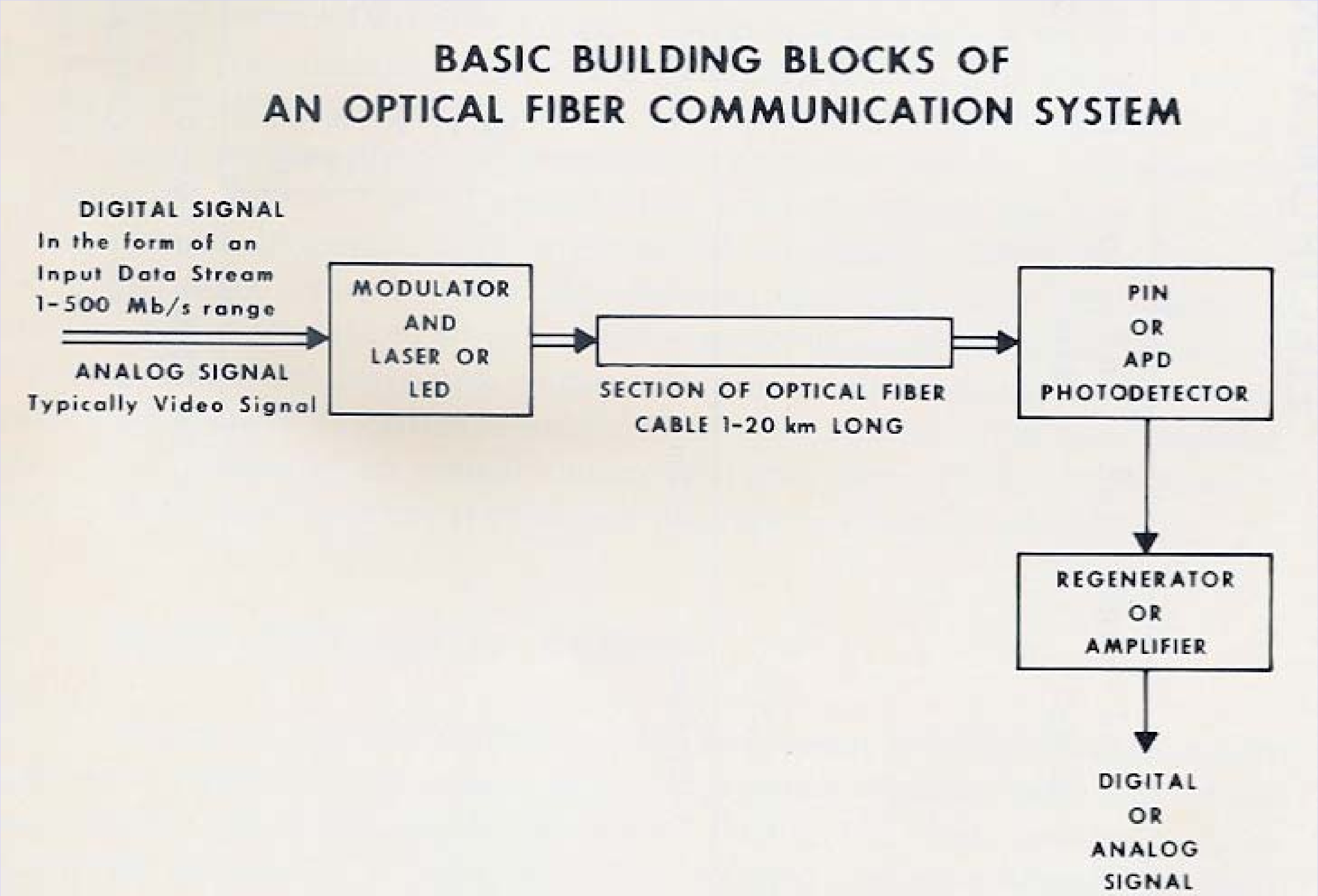


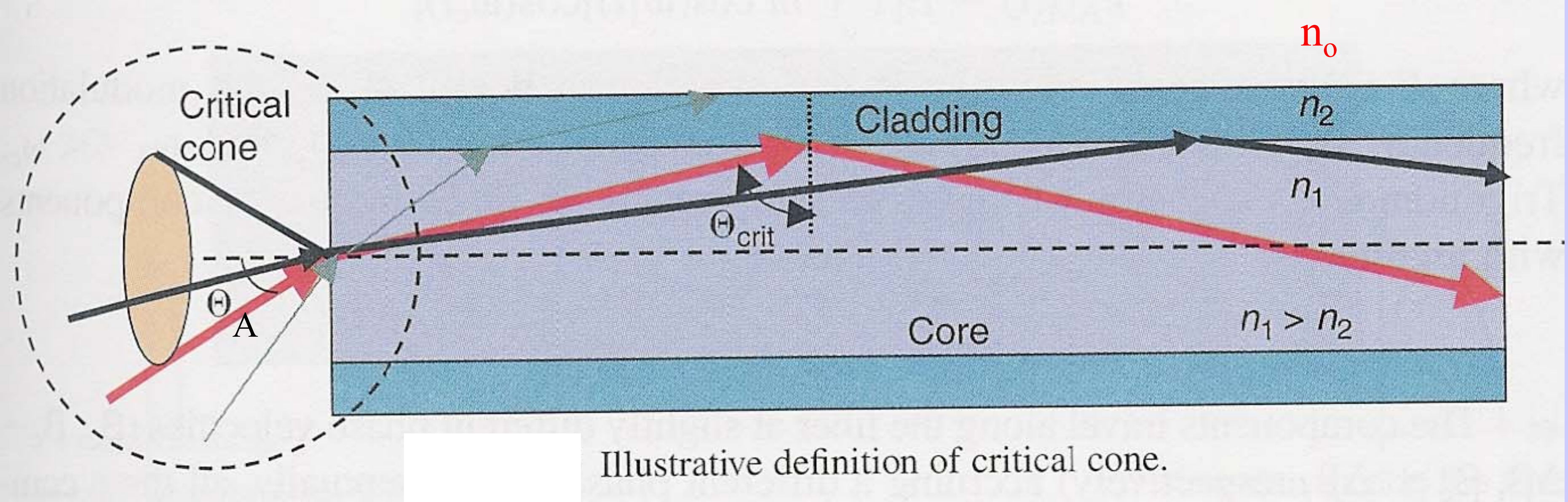
(Adapted from: *An introduction to optical fibers*, A.H. Cherin, McGraw-Hill, 1983)

A typical glass optical fiber has a *core/clad* structure: light propagates in the *core* of higher refractive index n_1, by total internal reflection at the interface with a *cladding* of lower index n_2. The condition for light propagation (in terms of geometrical optics) is that the angle θ, between the light rays and the normal to the interface is larger than the critical angle, θ_{crit}, defined by Snell's law:

$$\theta_{crit} = \arcsin (n_2/n_1)$$

whereas the *critical acceptance cone* (aperture $2\theta_A$) for light launched from a medium of index n_o is related to the *numerical aperture* of the fiber, $NA = (n_1^2 - n_2^2)^{1/2}$:

$$\sin \theta_A = (n_1^2 - n_2^2)^{1/2} / n_o = NA / n_o \qquad (\text{ for air: } \quad \sin \theta_A = NA \ )$$



Illustrative definition of critical cone.

(Adapted from: *Introduction to DWDM Technology*, S.V. Kartalopoulos, IEEE Press, 2000)

Fabrication of optical fibers with a core/clad structure

There are two basic methods for optical fiber fabrication:

I) preform drawing

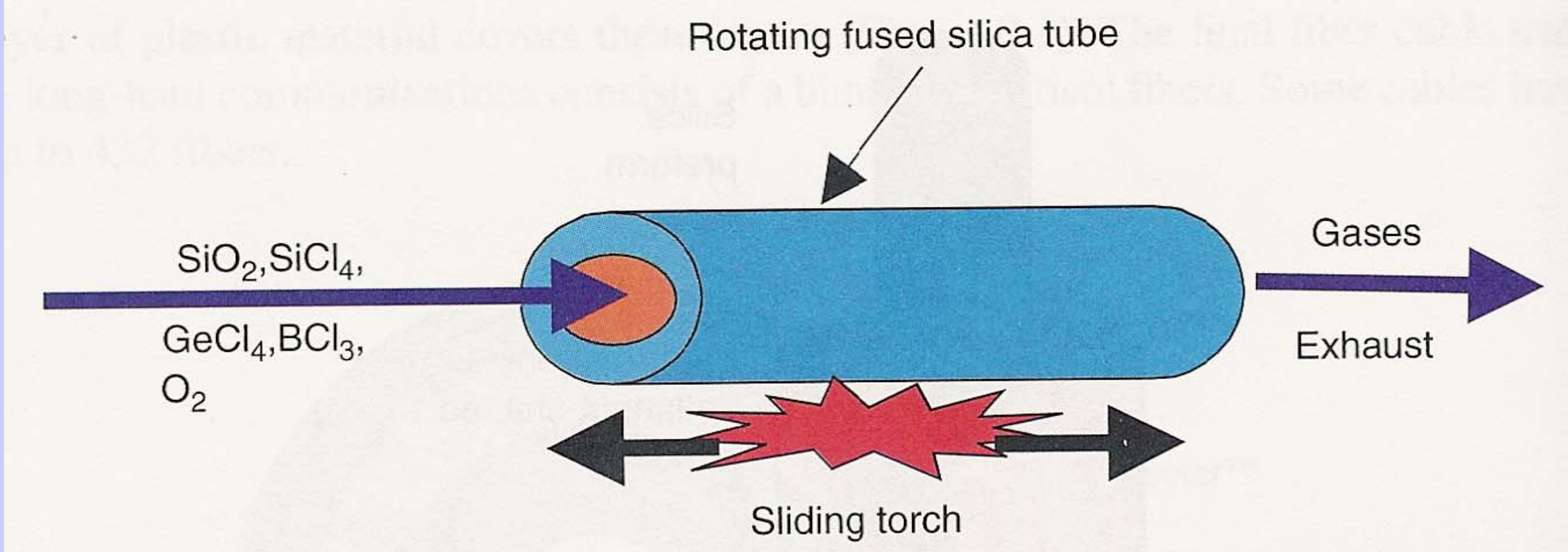
II) drawing from double crucible

The double crucible method may be used for special compositions, when high purity (and consequent low optical loss) are not a serious problem, or with compositions that cannot be deposited from the vapor phase, but it is limited to *step index* fibers.

The most versatile method and by far the more widely used in industrial manufacture is the preform method. Here there are some variants of preform fabrication, all based on *vapor deposition*: (1) the modified chemical vapor deposition (MCVD) process; (2) the vapor axial deposition (VAD) process; (3) the outside vapor deposition (OVD) method; (4) the plasma enhanced CVD (PECVD) method. All these have some aspects in common and only the MCVD method will be briefly described here.

In order to create a core/clad structure in the preform (and later in the drawn fiber), a glass tube, 1 m or more long and 20-30 cm in diameter, with the exact core/clad structure intended for the fiber, called the *preform*, is prepared first. The base composition is pure silica and the index control is achieved by doping it with small amounts of GeO_2 or P_2O_5 (to raise the index of the core) or B_2O_3, to lower the index of the cladding, among other alternatives.

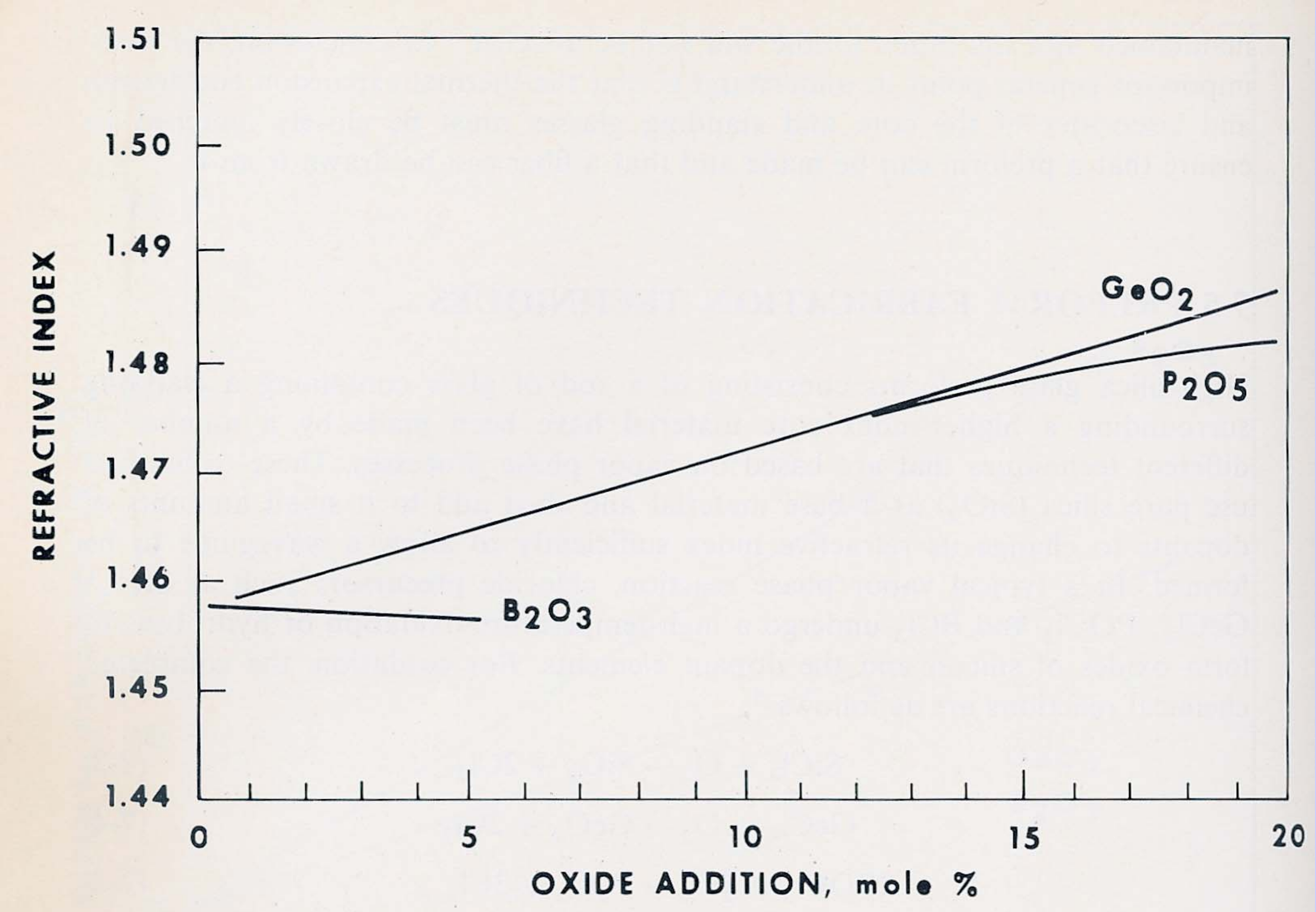
The starting point is an *outer cladding* tube of v-SiO_2 (not prepared by MCVD), where precursor gaseous compounds like $SiCl_4$, $GeCl_4$, $POCl_3$ or BCl_3 are then introduced.



Making a preform with the MCDV method.

(Adapted from: *Introduction to DWDM Technology*, S.V Kartalopoulos, IEEE Press, 2000)

Refractive index modification of v-SiO_2 in high silica fibers



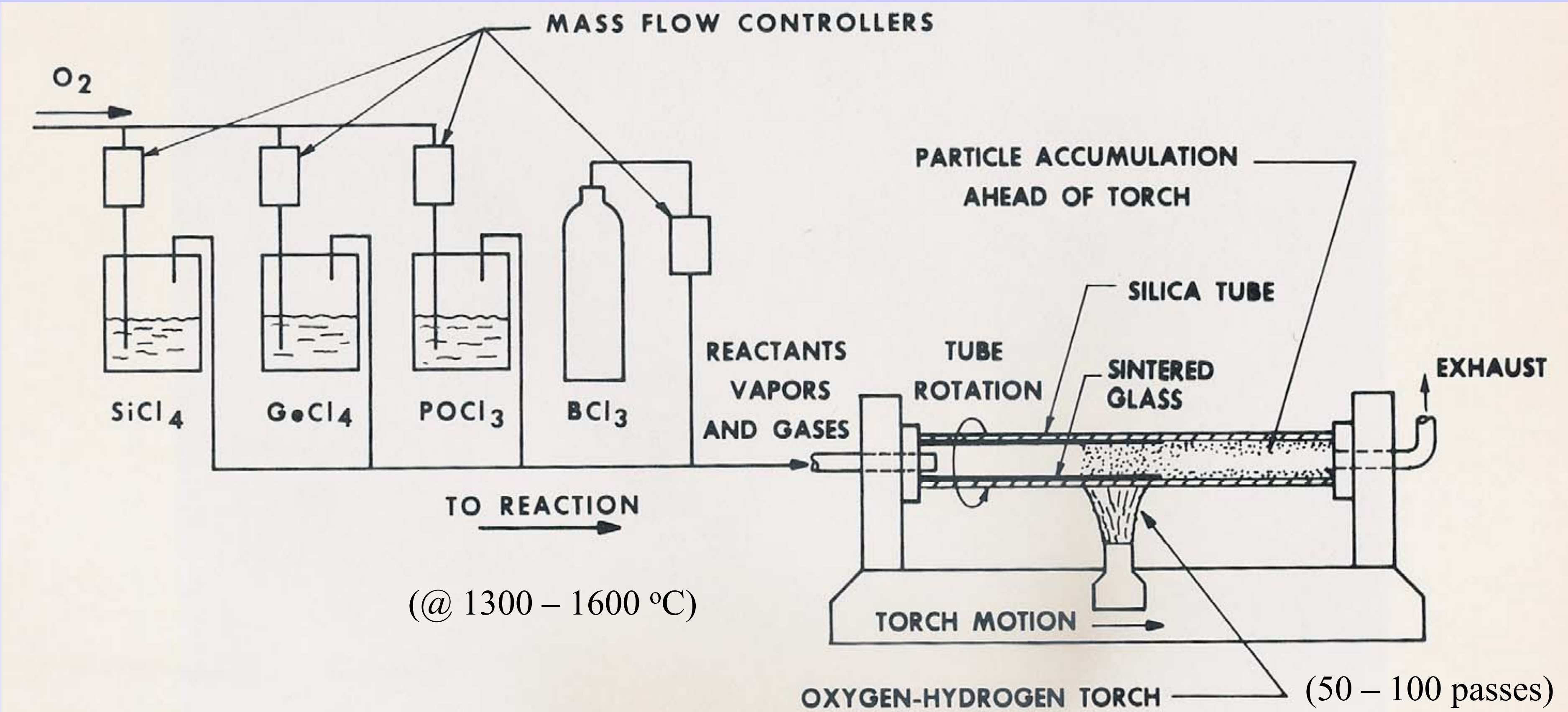
Refractive index of doped silica glasses.

(Adapted from: *An introduction to optical fibers*, A.H. Cherin, McGraw-Hill, 1983)

Schematics of the MCVD process

The basic reactions are, e.g.: $SiCl_4\ (g) + O_2\ (g) = SiO_2\ (gl) + 2\ Cl_2\ (g)$

$2\ BCl_3\ (g) + 3/2\ O_2\ (g) = B_2O_3\ (gl) + 3\ Cl_2\ (g)$



(Adapted from: *An introduction to optical fibers*, A.H. Cherin, McGraw-Hill, 1983)

The final consolidation of the glass preform may be achieved with 4-5 passes of the torch @ ~ 1900 ^oC.

Schematics of the VAD (~ *continuous*) process

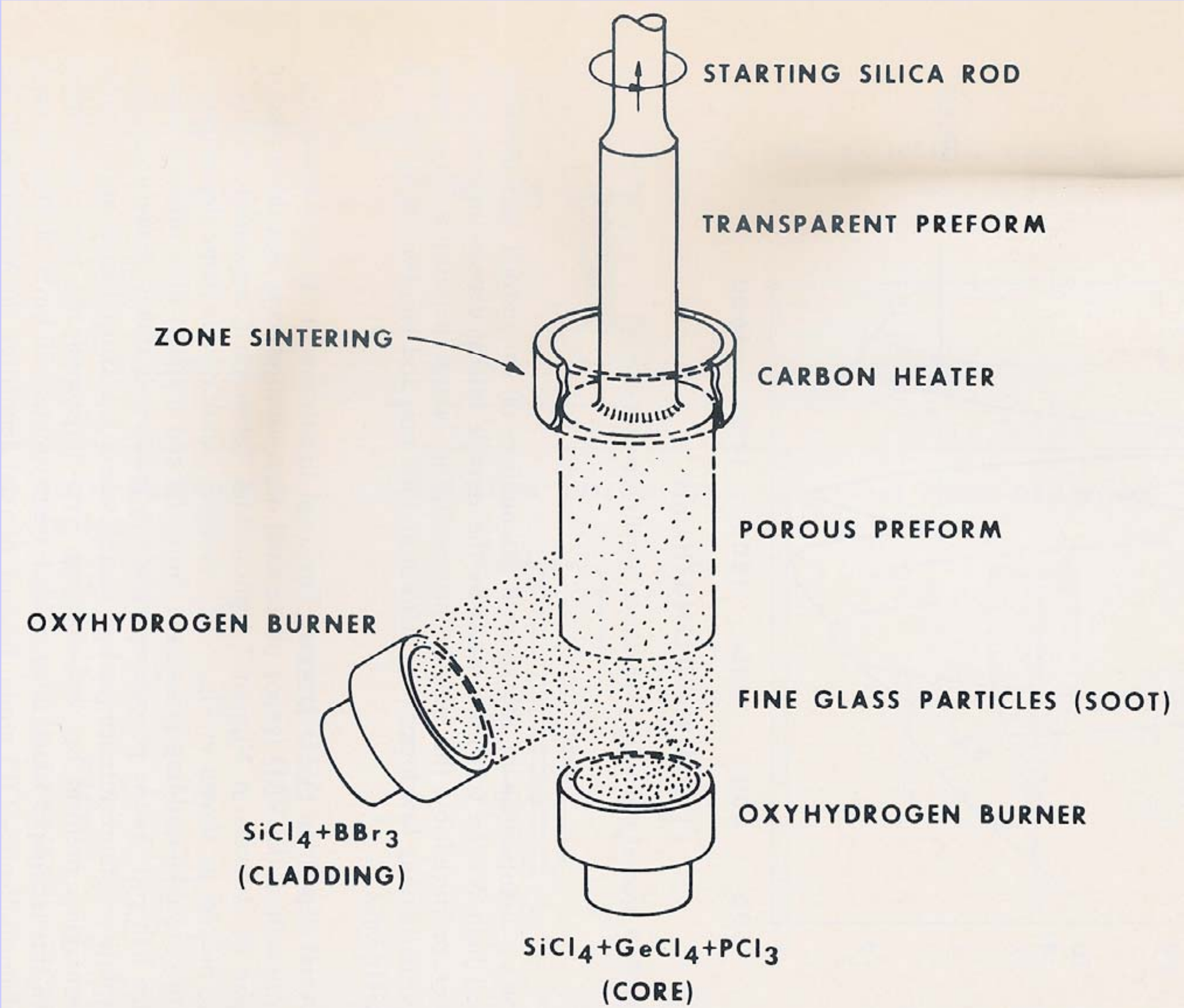
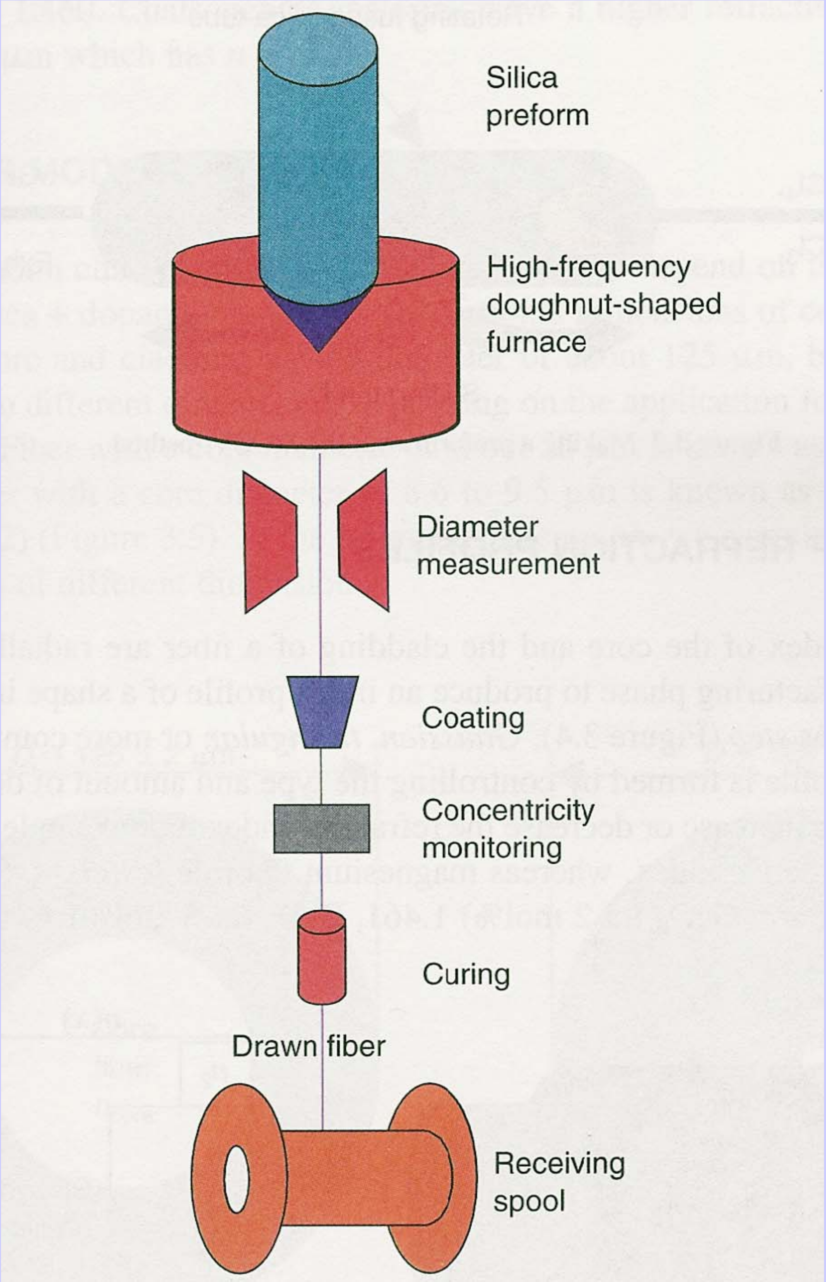


Illustration of vapor axial deposition process (VAD process). (Final drying step with Cl_2).

(Adapted from: *An introduction to optical fibers*, A.H. Cherin, McGraw-Hill, 1983)

Optical fiber drawing using an automated drawing tower



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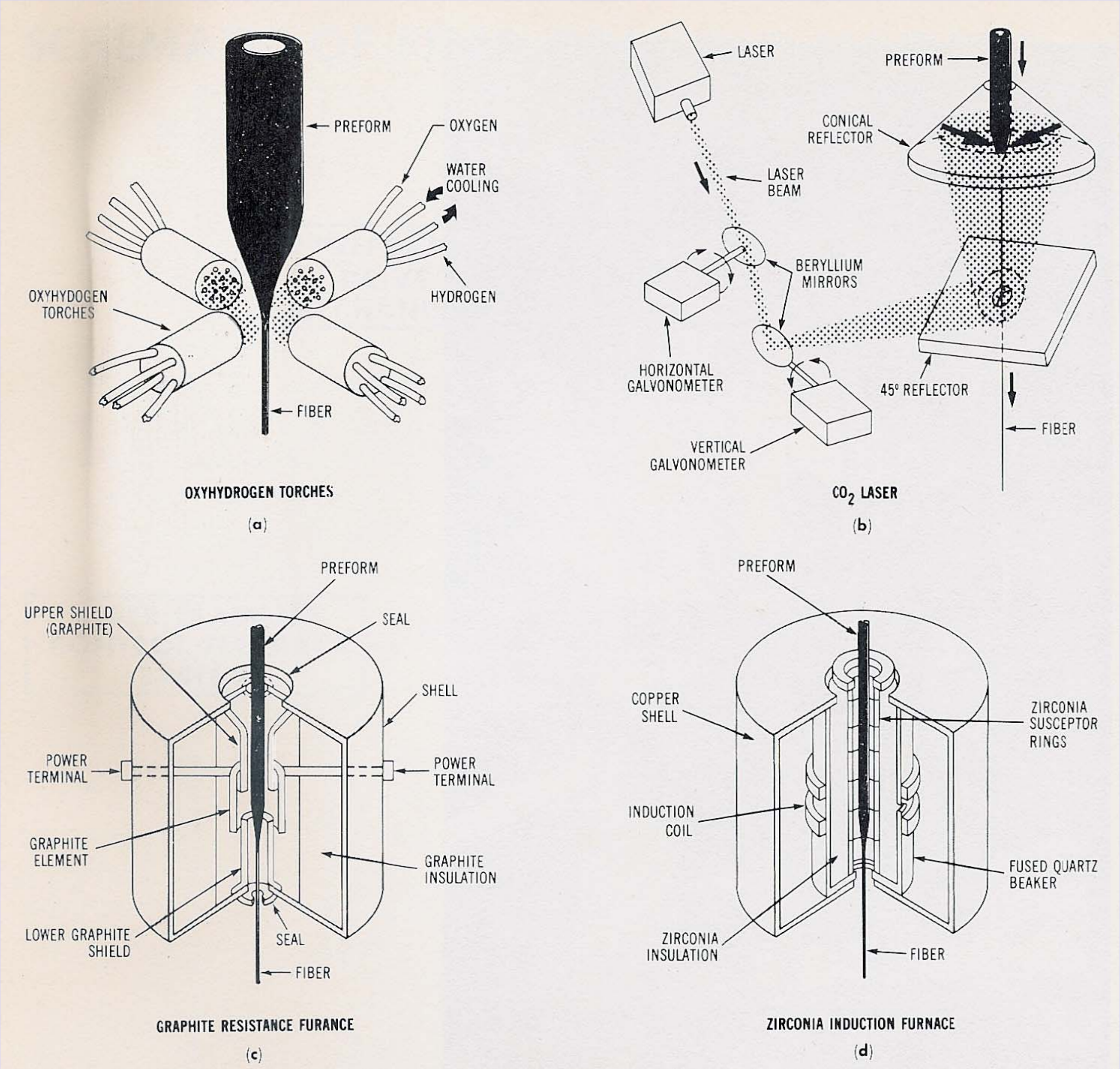
Different types of furnaces used in fiber drawing



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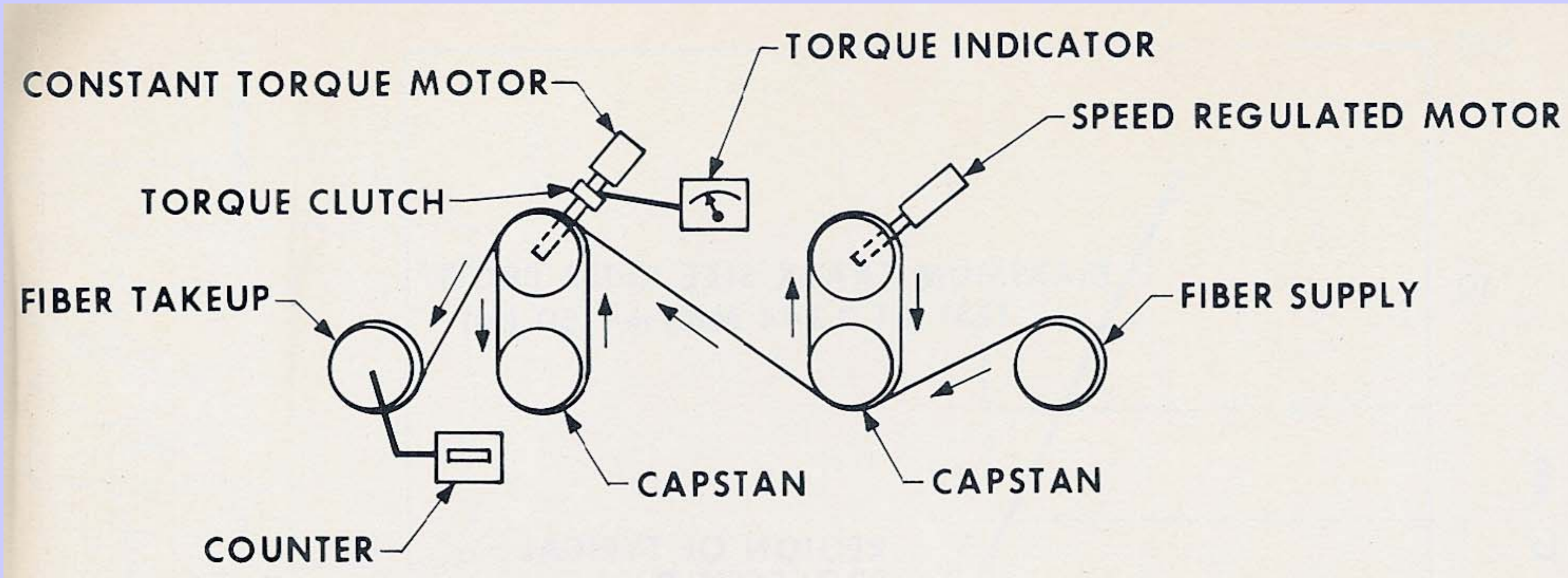
On-line mechanical testing of fibers by **proof-testing** before winding around take-up drums



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Fiber lifetime estimate by proof-testing for failure due to static fatigue

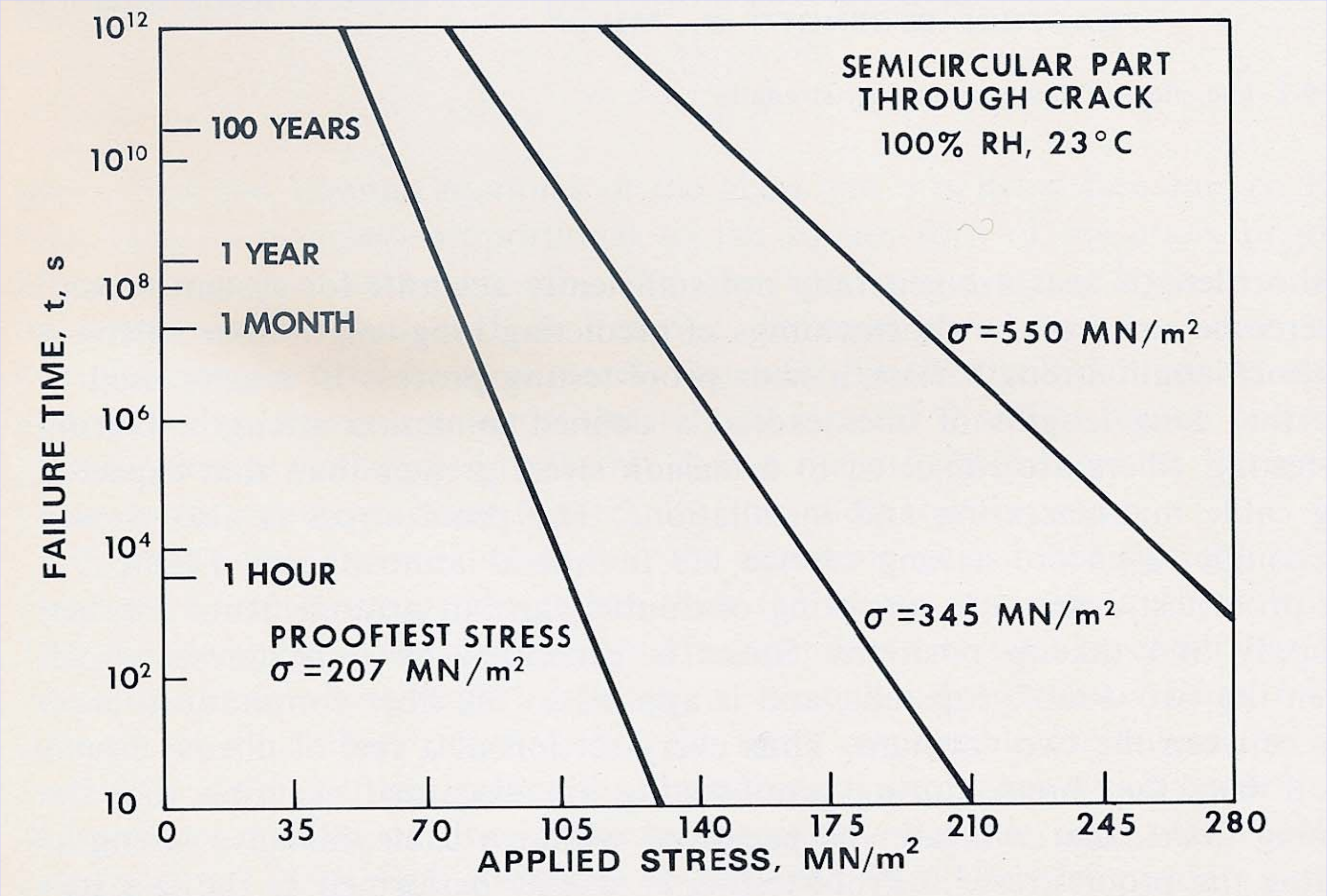

Diagram for estimating long-term static fiber performance from proof-test stress.

(Adapted from: *An introduction to optical fibers*, A.H. Cherin, McGraw-Hill, 1983)