UNIT-III

OBJECTIVES:

Optical fiber Connectors-Connector types, Single mode fiber connectors, Connector return loss, Fiber Splicing- Splicing techniques, Splicing single mode fibers, Fiber alignment and joint loss-Multimode fiber joints, single mode fiber joints.

Fiber Optic Connectors:

Connectors are mechanisms or techniques used to join an optical fiber to another fiber or to a fiber optic component.

Different connectors with different characteristics, advantages and disadvantages and performance parameters are available. Suitable connector is chosen as per the requirement and cost.

Various fiber optic connectors from different manufacturers are available SMA 906, ST, Biconic, FC, D4, HMS-10, SC, FDDI, ESCON, EC/RACE,

Principles of good connector design

1. Low coupling loss.
2. Inter-changeability.
3. Ease of assembly.
4. Low environmental sensitivity.
5. Low cost.
6. Reliable operation.
7. Ease of connection.

Connector Types: Connectors use variety of techniques for coupling such as screw on, bayonet mount, push-pull configurations, butt joint and expanded beam fiber connectors.

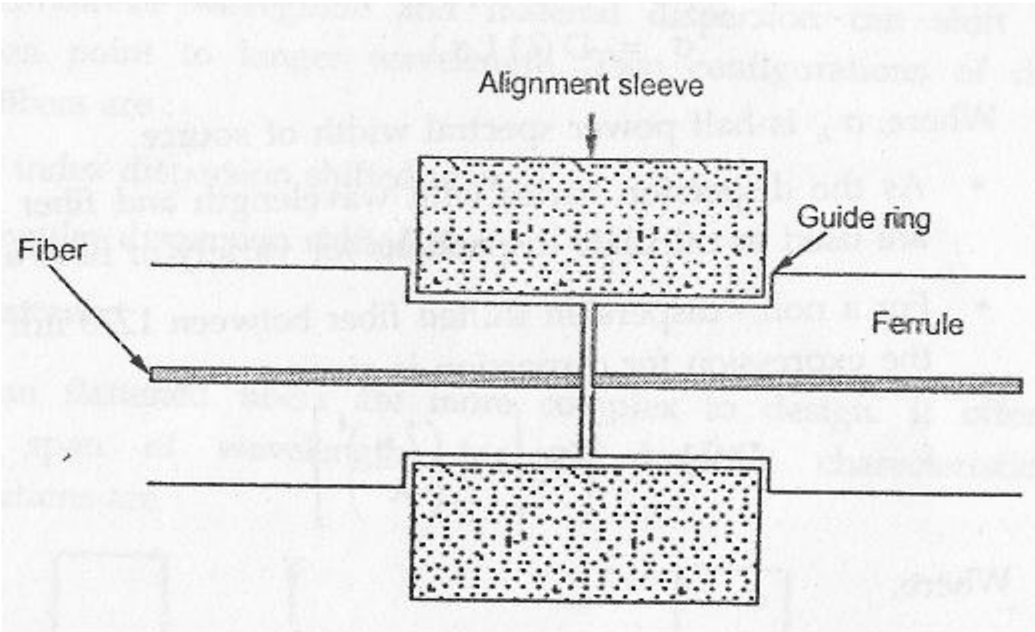
Butt Joint Connectors:

Fiber is epoxies into precision hole and ferrules arc used for each fiber. The fibers are secured in a precision alignment sleeve. Butt joints are used for single mode as well as for multimode fiber systems. Two commonly used butt-joint alignment designs are:

1. Straight-Sleeve.

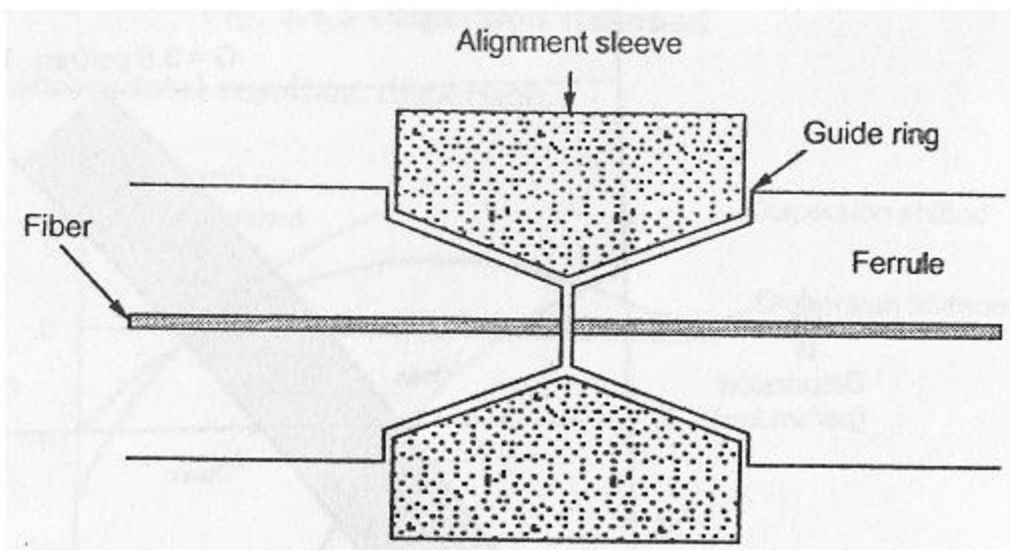
2. Tapered-Sleeve/Bi conical.

In straight sleeve mechanism, the length of the sleeve and guided ferrules determines the end separation of two fibers. The below Figure shows straight sleeve alignment mechanism of fiber optic connectors



Straight sleeve connector

In tapered sleeve or bi conical connector mechanism, a tapered sleeve is used to accommodate tapered ferrules. The fiber end separations are determined by sleeve length and guide rings. The below figure shows tapered sleeve fiber connectors



Tapered sleeve connector

PROBLEMS

∗ A multi mode graded index fiber exhibits the pulse broadening of 0.2μs over a distance of 15Km.Estimate,

(i) Optimum bandwidth of the fiber

(ii) Dispersion per unit length

(iii)Band width length product

Solution:

Given that,

For a multimode graded index fiber,

Total pulse boarding, $\tau = 0.2\mu s$

Distance, L =15km

(i) The maximum possible optical bandwidth is equivalent to the maximum possible bit rate assuming no inter symbol interference (ISI) and is given by

$$Bopt = B_T = 1/2\tau$$

$$= 1/(2*0.2*10^{-6})$$

$$= 2.5 \text{ MHz}$$

Therefore Bopt = 2.5MHz

(ii) The dispersion per unit length may be acquired by dividing the total dispersion by total length of the fiber i.e,

Dispersion per unit length = Total dispersion / Total length of fiber

$$= \tau/L$$

$$= (0.2*10^{-6})/15$$

$$= 13.33 \text{ns Km}^{-1}$$

Therefore Dispersion per unit length =13.33ns Km^{-1}

(iii) The band width length product may be obtained by simple multiplying the maximum band width for the link by its length as,

$$Bopt.L = 2.5*10^{6}*15$$

$$= 37.5 \text{ MHz Km}$$

Alternately, the band width product may be obtained from the dispersion per unit length as,

Bopt .L = 1/ (2*Dispersion per unit length

= 1/ (2*1.33*10^{-9})

= 37.5MHz.Km

Phase velocity: All electromagnetic waves which travel along a waveguide have points of constant phase. As a monochromatic light wave propagates along a waveguide in z-direction, this point of constant phase travel at particular velocity termed as phase velocity. It is denoted by V_P

Therefore $V_P = \frac{\omega}{\beta}$

Where ω = angular frequency of the wave and

β = Phase propagation constant

Group Velocity:

Group of waves with closely similar frequencies propagate along the waveguide so that there exists a resultant in the form of packet of waves. This wave packet moves at a velocity termed as group velocity V_g

$$V_g = \frac{\delta\omega}{\delta\beta}$$

The formation of wave packets from combination of waves of nearly equal frequencies is,

Propagation constant can be given as,

$\beta = n_1 (2\Pi/\lambda) = (n_1 \omega)/c$

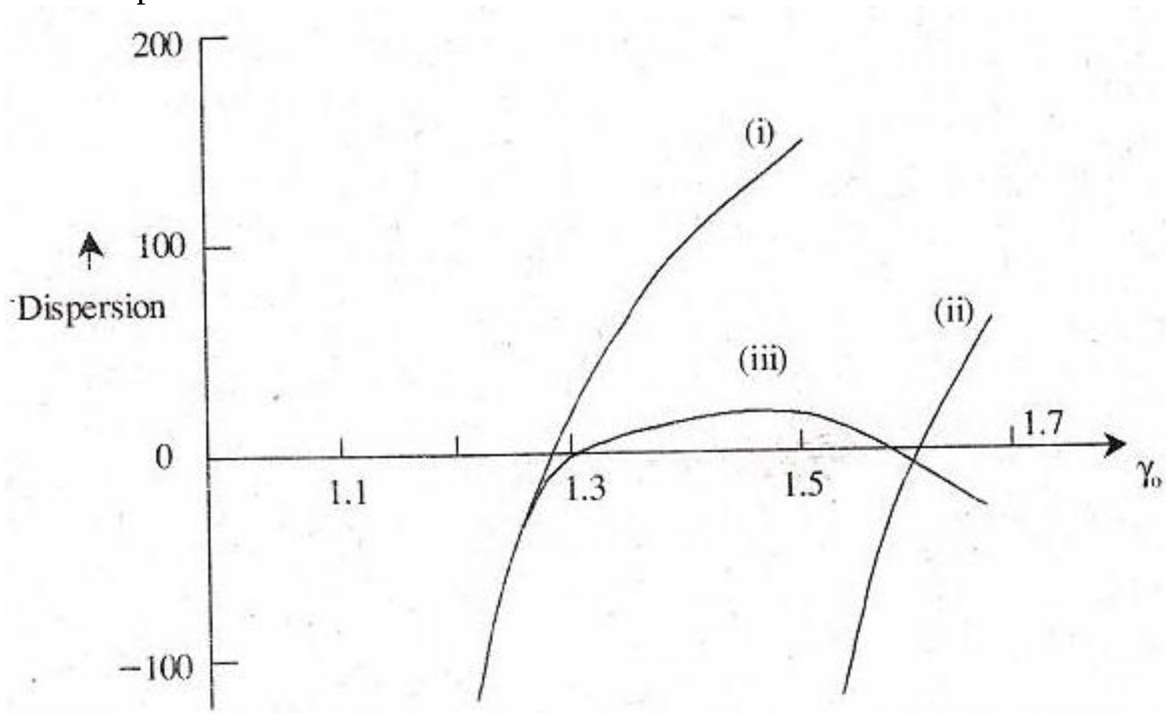
where n_1= Refractive index of medium

Phase velocity V_P can be given as

$$V_P = \frac{c}{n1}$$

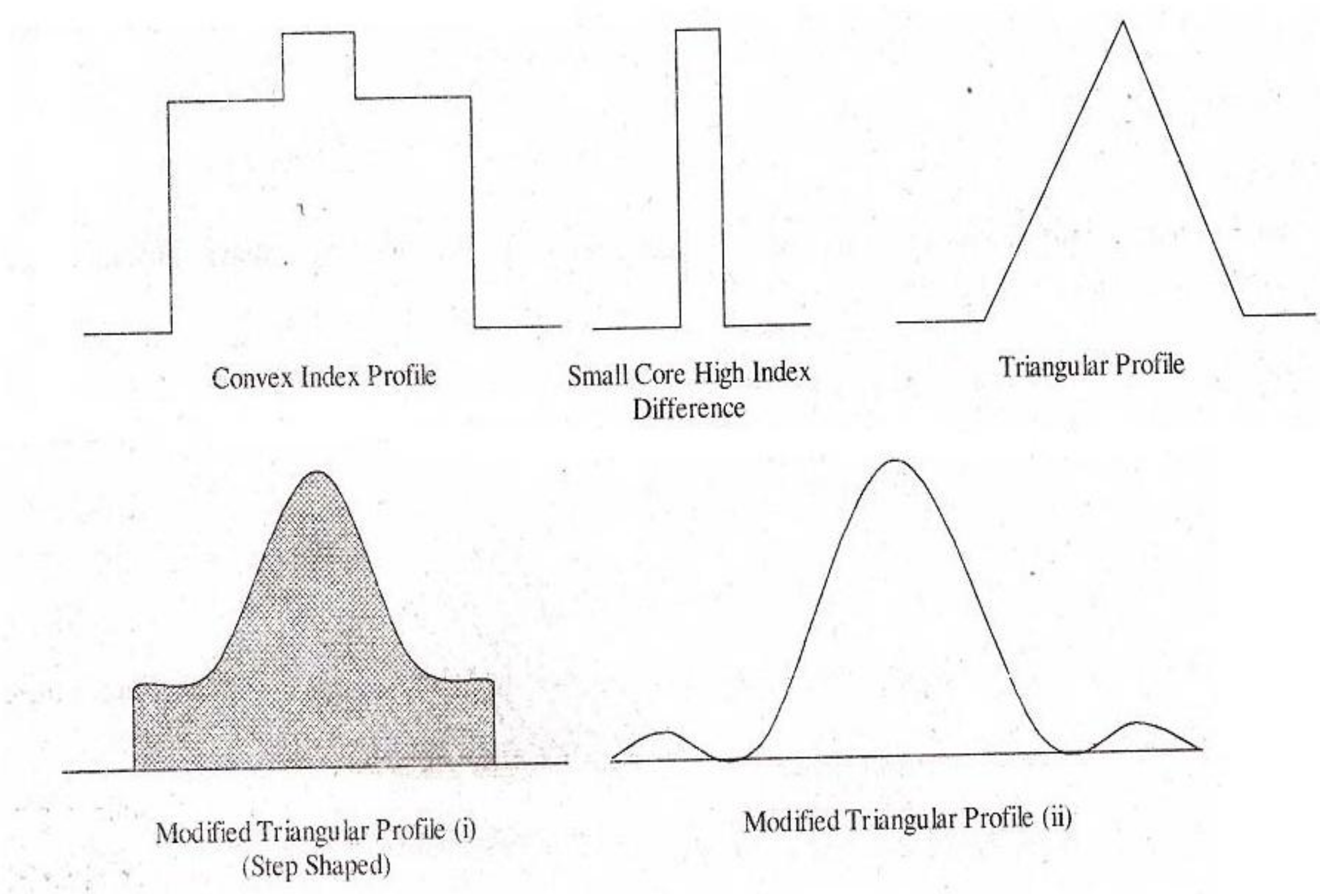
DISPERSION SHIFTED FIBER:

Single mode fibers which are designed to offer simultaneously zero dispersion and minimum attenuation at λ = 1.55μm is called dispersion shifted fibers. The dispersion classifications of various fibers are shown in the below figure, which depicts the shifting of zero dispersion wavelength from λ = 1.33 um to λ= 155 mm. This can be achieved by changing the fiber parameters, namely, the refractive index dispersion shifted fiber.



(i) Standard fiber (ii) Dispersion shifted fiber (iii)Dispersion Flatted fiber

For example, by reducing the fiber core diameter from 8-10μm to 4.5μm and increasing the refractive index difference between core and cladding from 0.003 to greater than 0.01 yields zero dispersion wavelength shifted from 1.33μm to 1.55μm. This may lead to substantial excess loss. Triangular core profile also yields dispersion shifted fibers and moreover it solves the above excess loss problem. So, for better results we have to modify the triangular profile. These profiles are shown in the below figure.

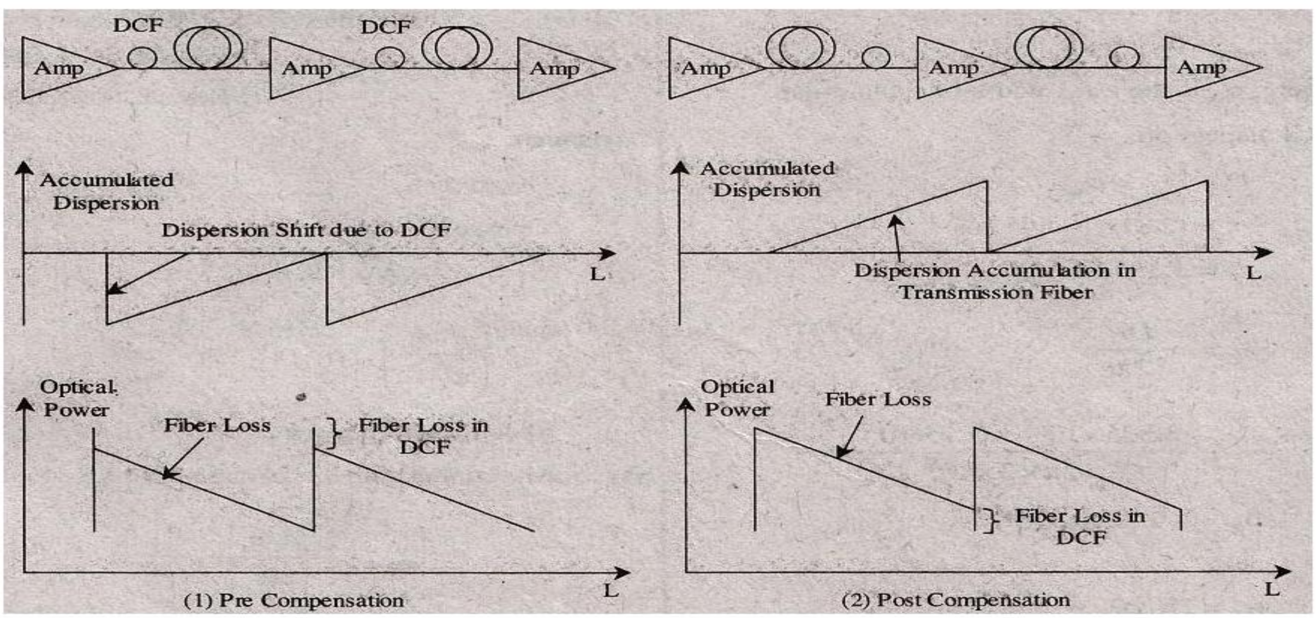


To achieve dispersion shifted fiber from refractive index profile

The above Figure shows that the convex index profile also gives the dispersion shifted fiber. Dispersion shifted fibers have the advantage of increased guiding strength, increase in the cut-off wavelength of second order mode and better resistance to bending losses. Such dispersion shifted fibers have been produced by BTRL and others and are now commercially available from any glass company. The below Table compares the characteristics of triangular refractive index profile dispersion shifted fiber with that of simple step index fiber.

DISPERSION COMPENSATING FIBER:

The process of dispersion compensation and the fiber loop is referred as dispersion compensating fiber. A large base of dispersion shifted fiber has been installed throughout the world for use in the single wavelength transmission systems. For these kinds of links the complexity arises from Four Wave Mixing (FWM), when one attempt to upgrade them with high speed dense WDM technology in which the channel spacing is less than 100 GHz and the bit rates are in excess of 2.5 Gb/s. By using the passive dispersion compensation technique we can reduce the effect of FWM (four wave mixing). This consists of inserting into the link a loop of fiber having a dispersion characteristic that negates the accumulated dispersion of the transmission fiber. This process is known as dispersion compensation. If the transmission fiber has a low positive dispersion, the dispersion compensating fiber will have a large negative dispersion. By using this technique, the total accumulated dispersion will become zero after some distance, but the absolute dispersion per length is non-zero at all points along the fiber. The below Figure depicts the Dispersion Compensating Fiber (DCF) which can be inserted at either the starting (or) the end of an installed fiber span between two optical amplifiers. A third option is to have DCF (Dispersion Compensating Fiber) at both ends



Dispersion and Power Maps

In pre-compensation schemes, the DCF is located just after the optical amplifier and just before the transmission fiber. Where as in post compensation schemes, the DCF is located just after the transmission fiber and just before the optical amplifier. Figure 8.3 also depicts the plots of accumulated dispersion and optical power level as functions of distance along the fiber. The above figure is known as dispersion and power maps respectively.

INTERCONNECTION OF TWO FIBERS IN A LOW LOSS MANNER:

The major factor in any fiber optic system is the requirement to interconnect fibers in a low loss manner. These interconnections occur in three stages namely.
1. at the optical source
2. at the photo detector
3. at intermediate points.

1. Optical Sources
The optical sources such as Light Emitting Diodes (LEDs), Solid state lasers and semiconductor injection lasers are used because of their efficiency, low cost, longer life, sufficient power output, compatibility and ability to give desired modulations.

2. Photo Detectors
Photo detectors such as semiconductor photodiodes are used because of their high quantum efficiency, adequate frequency response, low dark current and low signal impedance.

3. Intermediate Points
The two fibers are joined at intermediate points with two cables within a cable. The two major methods for the interconnection of fibers in a low loss manner are as follows,
(i) Fiber Splices
(ii) Simple Connectors.

(i) Fiber splices
In this, the fiber splices are the semi permanent (or) permanent joints which are mostly used for interconnection in optic-telecommunication system.
(ii) Simple Connectors
Simple connectors are the removable joints which allow easy, fast manual coupling of fibers. We can say that losses in interconnection of two fibers depend on factors like input power distribution to joints, length of fiber between optical source and joint, wave characteristics of two fibers at joint and fiber end face qualities. If these factors are satisfied low-loss in the interconnection of two fibers is achieved.

LOSSES IN END SEPARATION, CONNECTING DIFFERENT FIBERS WHEN JOINING TWO FIBERS:

When an optical fiber communication link is established, interconnections occur at the optical source, at the photo detector, at intermediate points within a cable where two fibers are joined and at intermediate points in a link where two cables are connected. If the interconnection is permanent bound then it is generally referred to as splicing whereas a demountable joint is known as connector. At every joint optical power loss takes place depending on input power distribution to the joint, the length of the fiber between the optical source and the joint, the geometrical and waveguide characteristics of the two fiber ends at the joint and the fiber end face qualities.

These losses are classified into

(i) Intrinsic losses

(ii)Extrinsic losses and

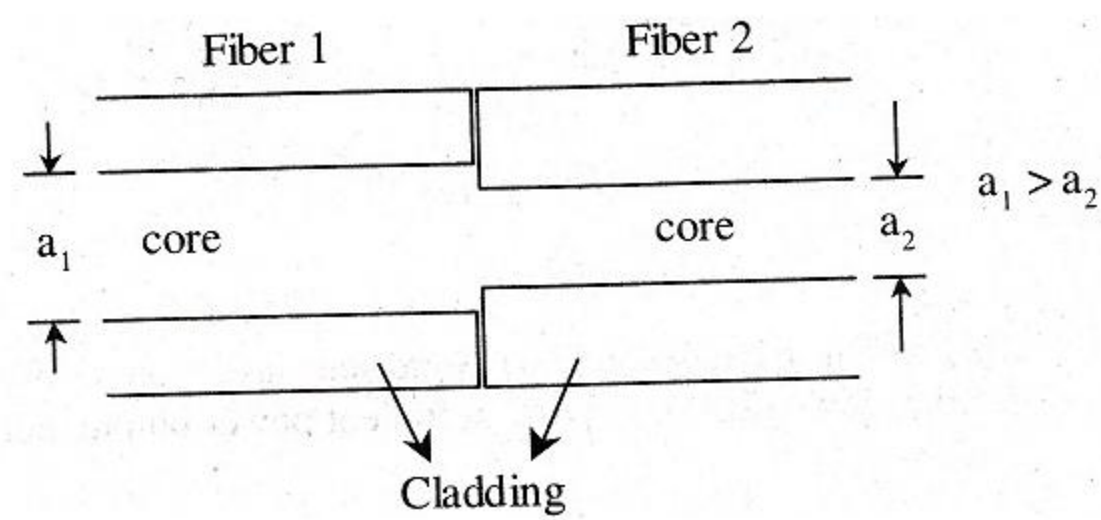
(iii) Reflection loss.

(i) Intrinsic Losses

Intrinsic losses occur when a mismatch occurs between two connecting fibers. Mismatch occurs when fiber's mechanical dimensions are out of tolerance limit. The mismatch can occur due to the following.

(a) Core-Diameter Mismatch

If the core of two joining, fibers has different diameter then core-diameter Mismatch occurs. The loss will be more if the light is travelling from larger core into a smaller core than if it is in reverse direction.



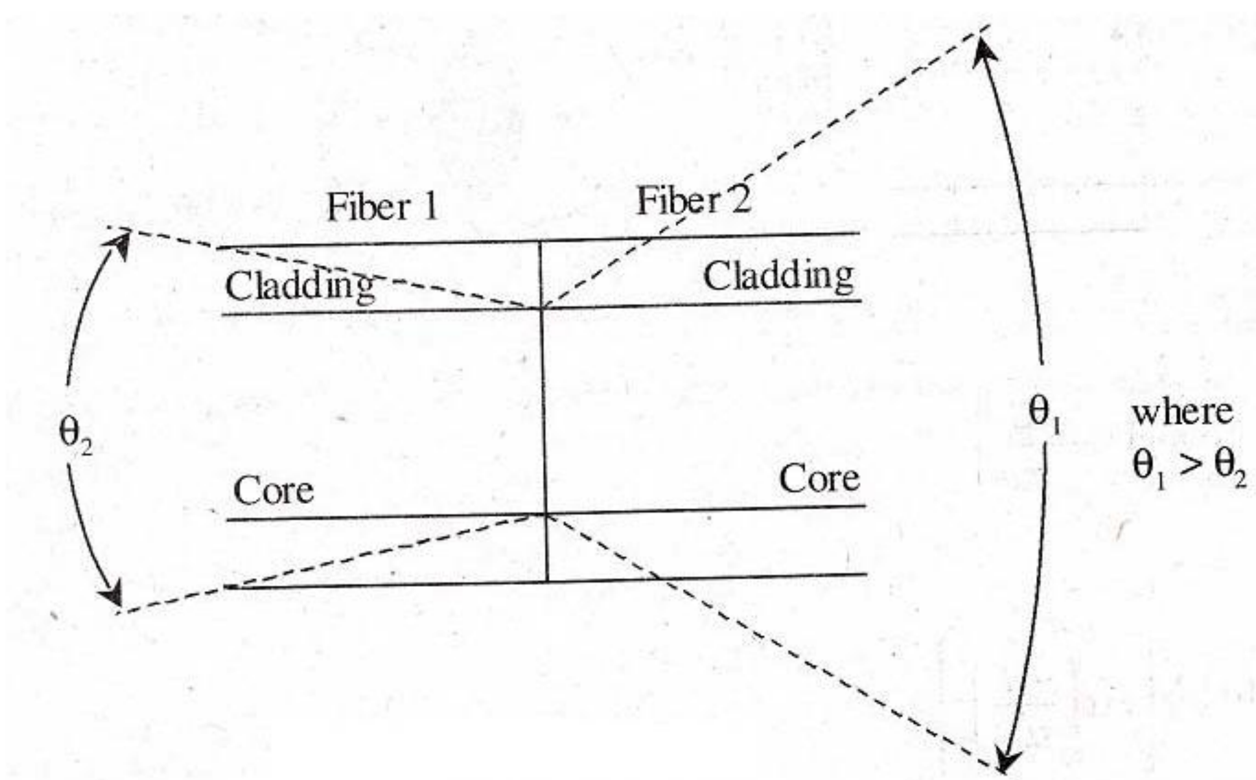
For a gradient multi mode fiber the loss due to core-diameter mismatch is given by,

$$\text{LOSS (core)} = -10\log\left[\left(\frac{a_2}{a_1}\right)^2\right]$$

(b) Numerical Aperture Mismatch

The light beam from emitting fiber fills the entire exit aperture of the emitting fiber. The receiving fiber has to accept all the optical power emitted by the first fiber. If there is a mismatch in waveguide characteristics of the two fibers resulting in smaller NA per second fiber, then it results in optical power loss. This loss is called numerical aperture mismatch loss given by,

$$\text{LOSS}_{\text{NA}} = -10\log\left[\left(\frac{\text{NA}_2}{\text{NA}_1}\right)^2\right]$$



Numerical Aperature Mismatch

(c) Mode-Field-Diameter (MFD) Mismatch or Refractive Index Profile (α)Mismatch:

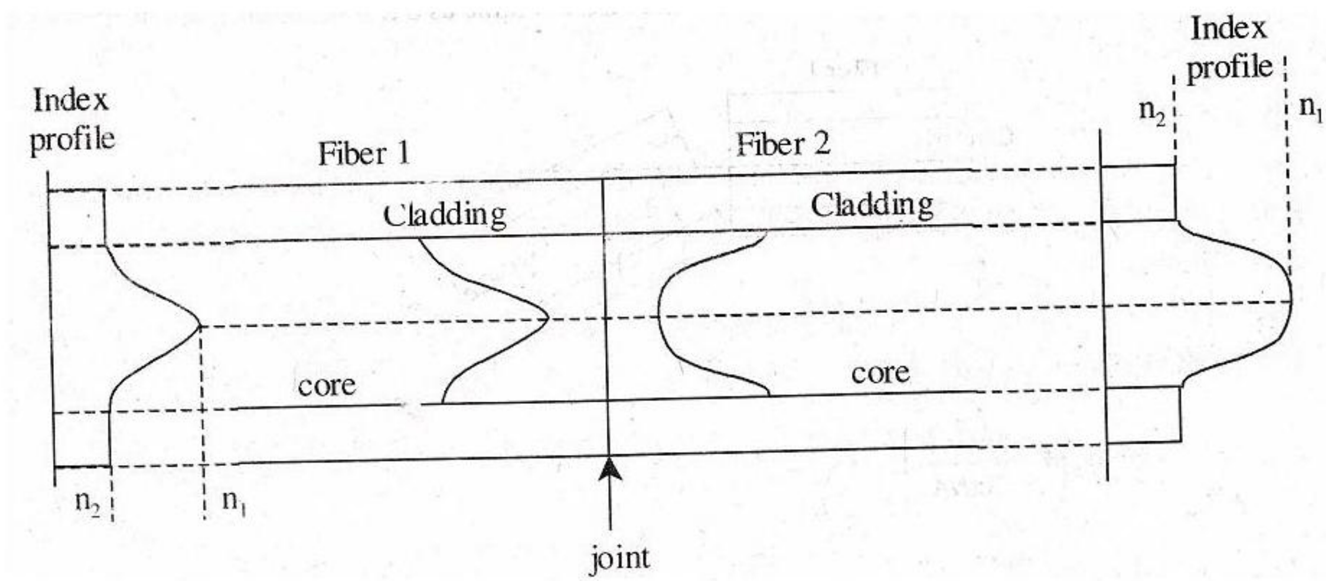
This loss takes place only in graded-index fiber where the index profile emitting fiber is different from the index profile of receiving fiber.

The loss due to MFD is given by

$$LOSS_{MFD} = -10\log\left[\frac{\alpha_1(\alpha_1+\alpha)}{\alpha_2(\alpha_2+\alpha)}\right]$$

Where α_1 = index profile of fiber 1

α_2 = index profile of fiber 2



Mode Field Diameter Mismatch

(ii) Extrinsic Losses

Extrinsic losses occur due to mechanical misalignment at point of joints. They are,

(a) Lateral Misalignment

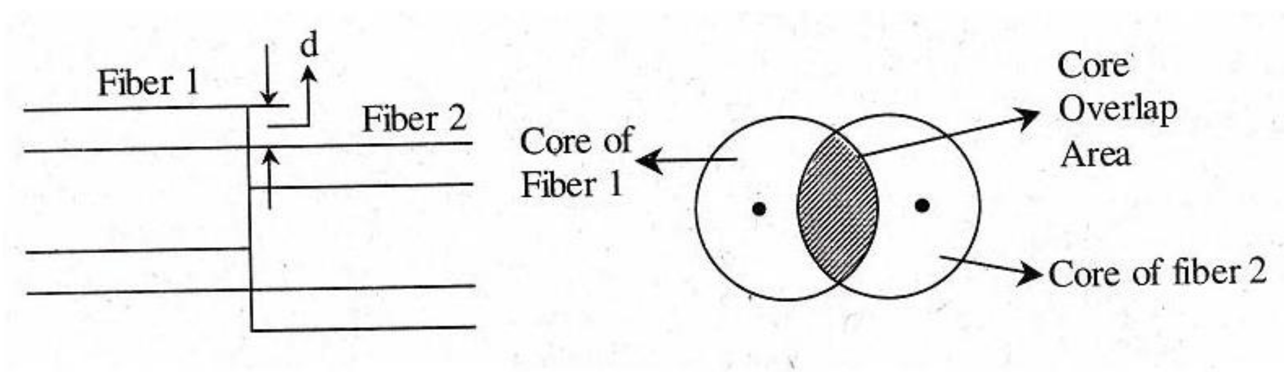
This misalignment occurs when the, fibers are displaced along the face of fiber and hence the core overlapping area is reduced from circular to elliptical form hence power loss from emitting fiber to the receiving is given below,

MMGI Fiber

$$Loss_{lat} = -10\log\left[1 - \frac{8d}{3\Pi a}\right]$$

SM Fiber

$$Loss_{lat} = -10\log\left[exp\left(\frac{-d}{\alpha_0}\right)^2\right]$$



Lateral MisAlignment

b) Angular Misalignment

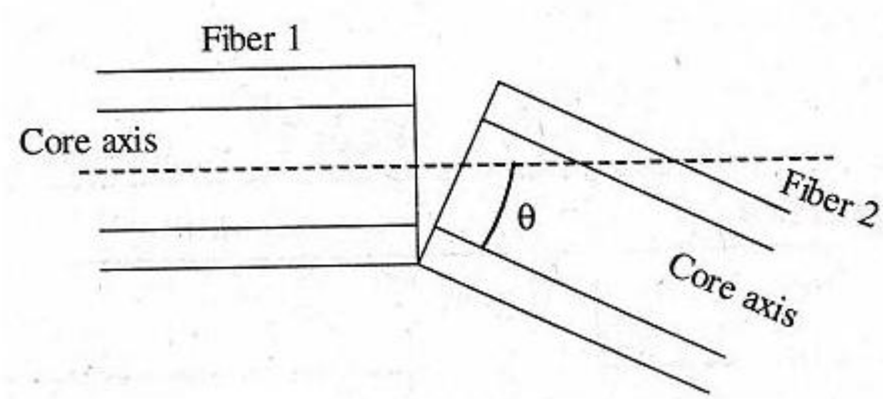
For a perfectly matched fiber, if point of joint at which core axis of fiber 1 is at an angle with the core axis of fiber 2 then angular misalignment occurs and the result is same as due to numerical aperture mismatch.

For MMG1 Fiber,

$$LOSS_{ang} = \text{-10log}\left[1 - \frac{8n\sin\theta}{3\Pi Na}\right]$$

$$LOSS_{ang} = \text{-log}e^{-t^2}$$

Where $t = n\Pi\alpha_0 SM(\theta)/\lambda$



Angular Misalignment

(c)End separation Misalignment

When two fibers are separated longitudinally by a gap of ‘S’ between them, then longitudinal end separation misalignment occurs.

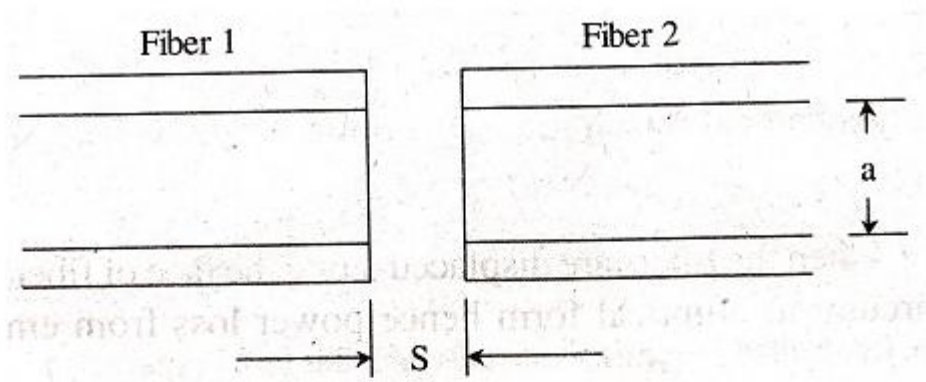
The loss for MGG1 is given by,

$$\text{Loss(end)} = \text{-log}\left[1 - \frac{S(NA)}{2an}\right]$$

And for SM fiber is,

$$\text{Loss(end)} = \text{- 10log}\left[\frac{1}{s^2+1}\right]$$

$$\text{Where } S = \frac{s\lambda}{(2\Pi n\alpha^2)}$$



End separation mis alignment

(iii) Reflection Loss

At the surface of contact some light will be reflected back. This is called Fresnel reflection. This reflection changes the amount of power transmitted towards a receiver. The loss caused by reflection is called Fresnel loss. If the transmitted power is P_{tran} and input power at the source is P_{in} and reflected power is P_{ref} then they are related by, Hence reflection loss is given by,

$$P_{trans} = P_{in} - P_{ref}$$

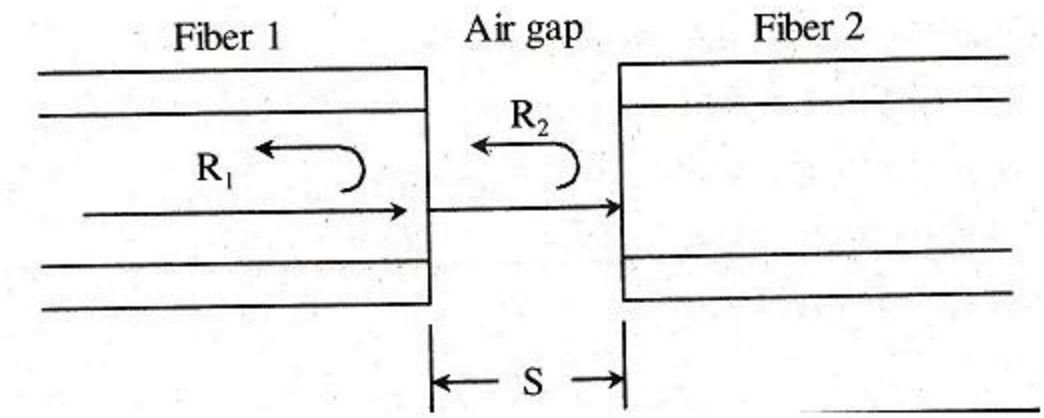
Hence reflection loss is given by,

$$LOSS_{(Fresnel)} = -10\log\left[\frac{4n_1n_2}{(n_1+n_2)^2}\right]$$

or for 2 interface reflections,

$$LOSS_{(Fresnel)} = -10\log(1-R)$$

Where $R = R_1 + R_2 - 2\sqrt{R_1R_2}\cos(4\Pi/\lambda)$ S = The separation between two fiber. R = Total reflection. R_1 and R_2 are reflections at two interfaces



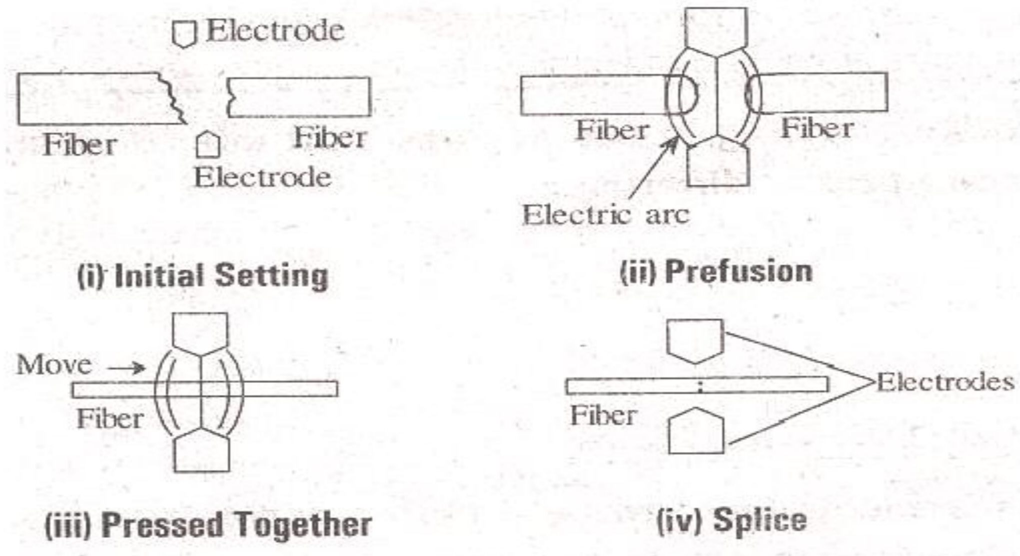
Reflection Losses

SPLICING:

A permanent joint formed between two individual optical fibers in the field is known as splicing. The fiber splicing is used to establish optical fiber links, where smaller fiber lengths are needed to be joined and where there is no requirement for repeated connection and disconnection. Splicing can be divided into two broad categories depending on the splicing technique utilized. These are fusion-splicing, mechanical or welding splicing.

FUSION SPLICING:

Fusion splicing of single fibers involves the heating of the two prepared fiber ends to their fusing point with sufficient axial pressure between the two optical fibers. It is essential that the stripped fiber ends are adequately positioned and clamped with the aid of inspection microscope. The most widely used heating technique is an electric arc. This technique offers advantage of consistent, easily controlled heat with adaptability for use under field conditions.
The welding of 2 fibers can be shown as illustrated in the following figure.



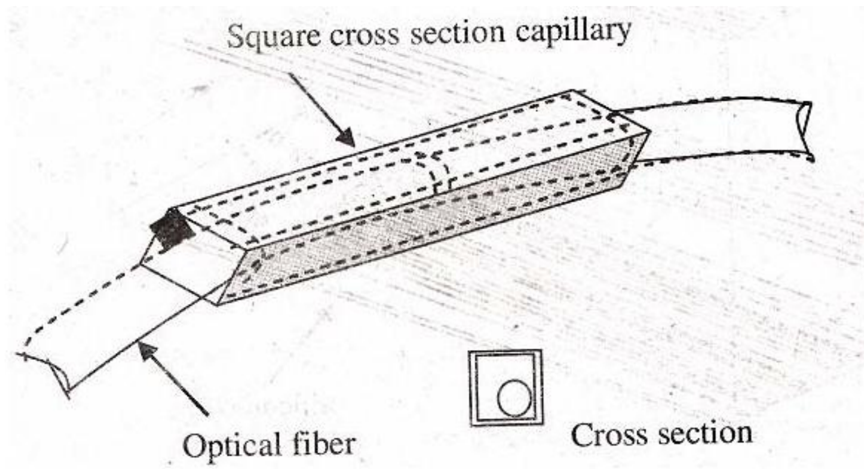
. Fusion Splicing

The above figure shows basic arc fusion process, which involves the rounding of the fiber ends with a low energy discharge before pressing the fibers together and fusing with a stronger arc. This technique is called perfusion. It removes the requirement for fiber end preparation. It has been utilized with multimode fibers giving average splice losses of 0.09 dB. Fusion splicing of single mode fibers with arc diameters between 5 and 10 um present problems of more critical fiber alignment (lateral offsets of less than 1 um are required for low loss joints).

Splice uncertain losses below 0.3 dB may be achieved due to self alignment phenomenon which partially compensates for any lateral offset. The drawback with fusion splicing is that the heat necessary to fuse the fibers may weaken the fiber in the vicinity of the splice. The tensile strength' of the fused fiber may be as low as 30% as that of the uncoated fiber before fusion. The fiber fracture occurs in the heat affected zone adjacent to the fused joint. The reduced tensile strength is attributed, to the combined effects of surface damage caused by handling, surface defect growth during heating and induced stresses due to changes in chemical composition. Hence it is necessary that splice is packaged so as to reduce tensile loading upon the fiber in the vicinity of the splice.

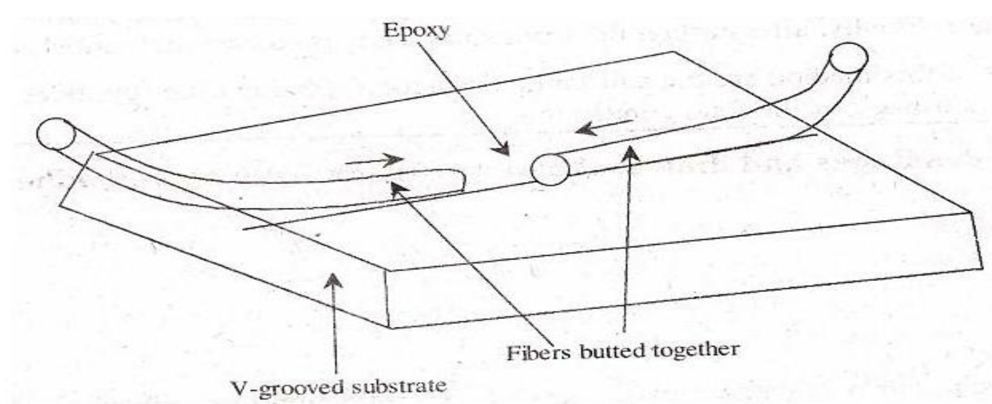
ADHESIVE SPLICING:

A common method involves the use of ah accurately produced rigid alignment tube into which the prepared fiber ends are permanently, bonded. This snug tube splice may utilize a glass or ceramic capillary with an inner diameter just large enough to accept the optical fibers. Transparent adhesive (e.g. epoxy resin) is injected through a transverse bore in die capillary to give mechanical sealing and index matching of the splice. However, in general, snug tube splices exhibit problems with capillary tolerance requirements.



Loose Tube Splice Utilizing Square Coss Section Gallery

A mechanical splicing-technique which avoids the critical tolerance requirements of the snug tube splice is shown in the below figure this loose tube splice uses an oversized square section metal tube which easily accepts the prepared fiber ends. Transparent adhesive is first insulated in the tube followed by the fibers. The splice is self-aligning when the fibers are curved in the same plane, forcing the fiber ends simultaneously into the same corner of tube.

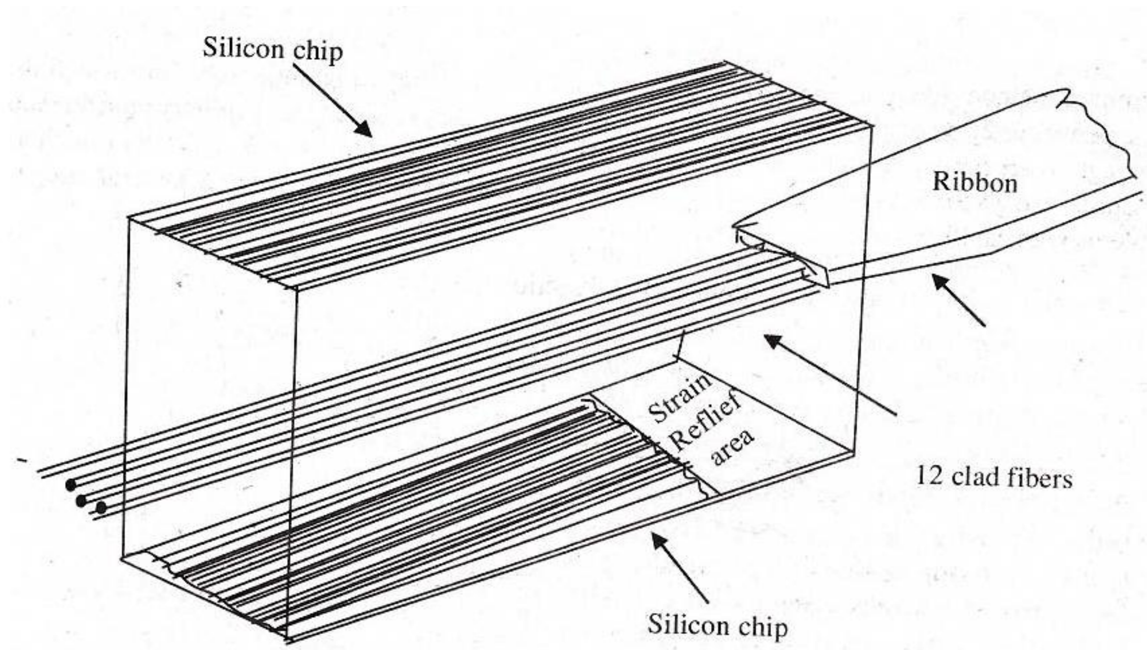


V-Groove Splices

Other common splicing techniques involve the use of grooves to secure the fibers to be jointed. A simple method utilized a V-groove into which the two prepared fiber ends are pressed. The V-groove splice which is shown in figure gives alignment of the prepared fiber ends through insertion in the groove. The splice is made permanent by securing the fibers in the V-groove with epoxy resin (i.e., transparent adhesive).

MULTIPLE SPLICES:

Multiple simultaneous fusions splicing of an array of fibers in a ribbon cable has been demonstrated for both multimode and single mode fibers. In both cases a five fiber ribbon was prepared by scoring and breaking prior to pressing the fiber ends on to a contact plate to avoid difficulties, with varying gaps between the fibers to be fused



Multiplier Fiber Splicing a Silicon Chip Array

The most common technique employed for multiple simultaneous splicing involves mechanical splicing of an array of fibers, usually in a ribbon cable. A V-groove multiple splice secondary element comprising etched silicon chips that has been used extensively for splicing multimode fibers. In this technique a twelve fiber ribbon splice is prepared by stripping the ribbon and coating material from the fibers. Then the twelve fibers are laid into the trapezoidal grooves of a silicon chip using a comb structure, as shown in figure. The top silicon chip is then applied prior to applying epoxy to the chip-ribbon interface. Finally, after curing, the front end face is grounded and polished.
Major advantages of this method are the substantial reduction splicing time (by more than a factor of 10) per fiber and the increased robustness of the final connection.