Dispersion

Characteristics of Single-Mode Fibers:

The characteristics include index-profile configurations used to produce different fiber types.

- **Refractive-Index Profiles:**
- When creating single-mode fibers, manufacturers pay special attention to how the fiber design affects both chromatic and polarization-mode dispersions.
- Such considerations are important because these dispersions set the limits on long-distance and high-speed data transmission.

Illustrates the chromatic dispersion of a step-index silica fiber is lowest at 1310 nm.

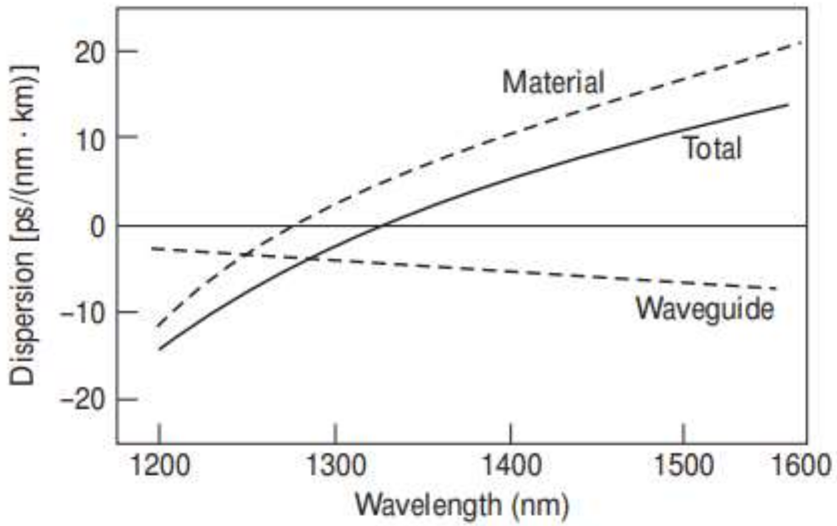

Fig. 3.16 *Examples of the magnitudes of material and waveguide dispersion as a function of optical wavelength for a single-mode fused-silica-core fiber. (Reproduced with permission from Keck,[16] © 1985, IEEE.)*

- If the goal is to transmit a signal as far as possible, it is better to operate the link at 1550 nm (in the C-band) where the fiber attenuation is lower.
- For high-speed links, the C-band presents a problem because chromatic dispersion is much larger at 1550 nm than at 1310 nm.
- The basic material dispersion is hard to alter significantly. However, it is possible to modify the waveguide dispersion by changing from a simple step-index design to more complex index profiles for the cladding,
- thereby creating different chromatic-dispersion characteristics in single-mode fibers.

Shows representative refractive-index profiles of four fiber-design categories:

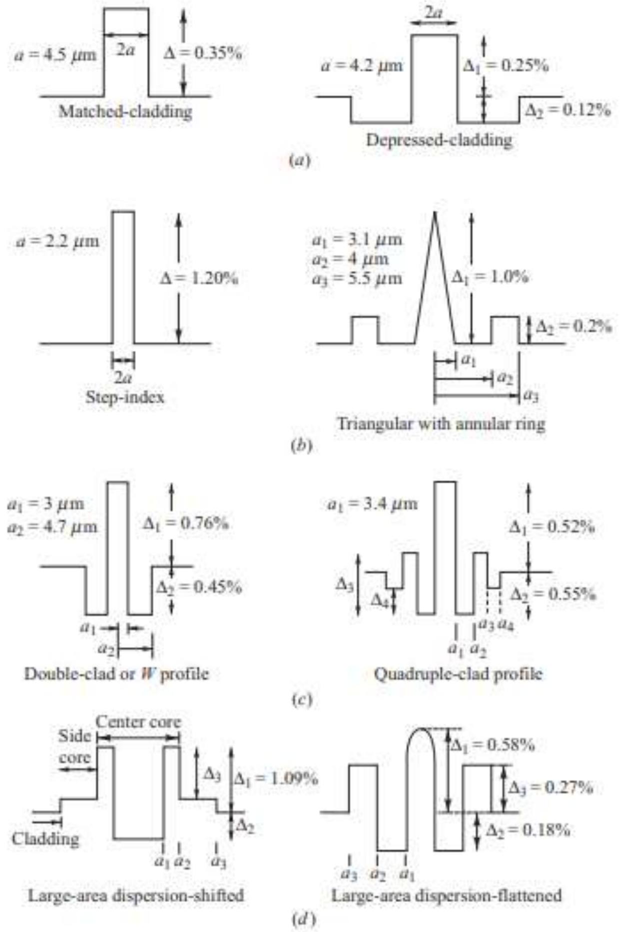

Fig. 3.18 *Representative cross sections of index profiles for (a) 1310-nm-optimized, (b) dispersion-shifted, (c) dispersion-flattened, and (d) large-effective-core-area fibers*

- Popular single-mode fibers that are used widely in telecommunication networks are near-step-index fibers, which are optimized for use in the O-band around 1310 nm.

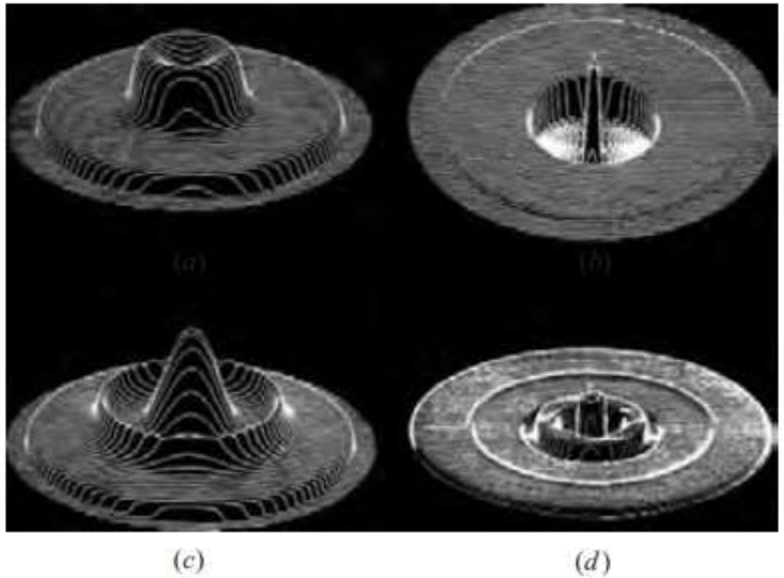

Fig. 3.19 *Three-dimensional refractive index profiles for (a) matched-cladding 1310-nm-optimized, (b) depressed-cladding 1310-nm-optimized, (c) triangular dispersion-shifted, and (d) quadruple-clad dispersion-flattened single-mode fibers. [(a) and (c) Courtesy of Corning, Inc.; (b) Courtesy of York Technology; (d) Reproduced with permission from H. Lydtin, J. Lightwave Tech., vol. LT-4, pp. 1034–1038, Aug. 1986, © 1986, IEEE.]*

Flattening:

- An alternative fiber design concept is to distribute the dispersion minimum over a wider spectral range.
- This approach is known as dispersion flattening. 62,63
- Dispersion-flattened fibers are more complex to design than dispersion-shifted fibers, because dispersion must be considered over a much broader range of wavelengths.

Cutoff Wavelength:

- The cutoff wavelength of the first higher-order mode (LP11) is an important transmission parameter for single-mode fibers because it separates the single-mode from the multimode regions.64–65

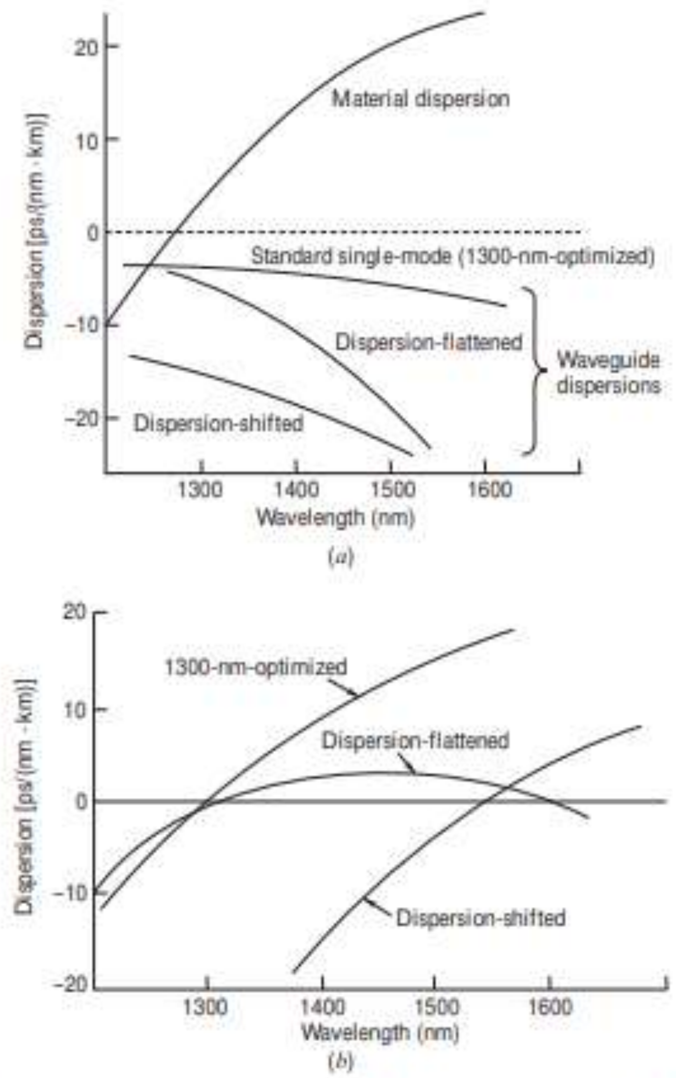

Fig. 3.20 *(a) Typical waveguide dispersions and the common material dispersion for three different single-mode fiber designs; (b) resultant total dispersions*

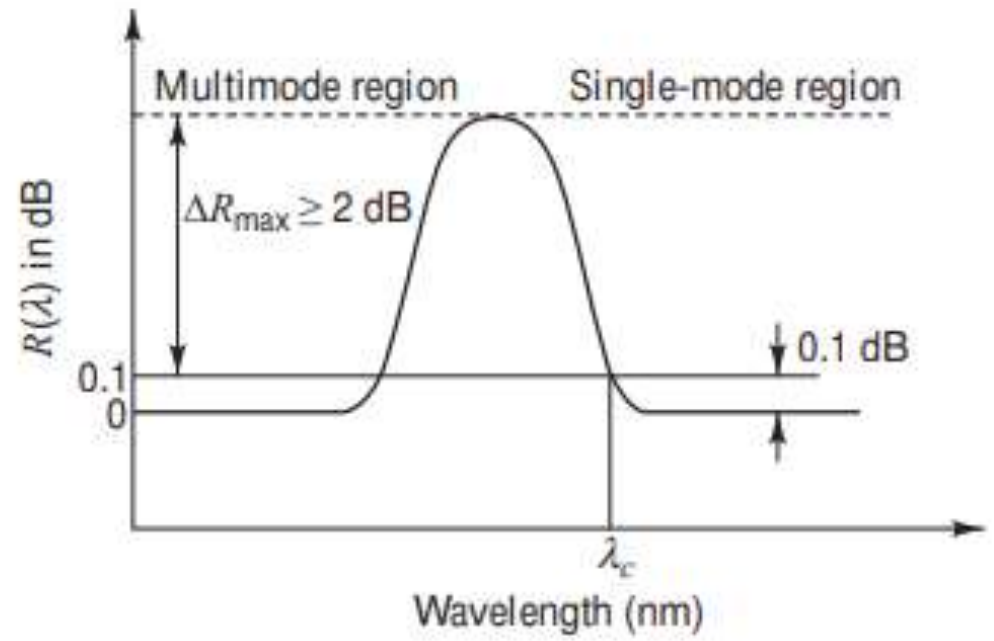

Fig. 3.21 *Typical attenuation-ratio versus wavelength plot for determining the cutoff wavelength using the bend-reference (or single-mode-reference) transmission method. The peak ratio should be at least 2 dB above the cutoff level.*

Chromatic dispersion:

- The total chromatic dispersion in single-mode fibers consists mainly of material and waveguide dispersions.

Equation:

$$D(\lambda) = \frac{1}{L}\frac{d\tau}{d\lambda}$$

The resultant intramodal or chromatic dispersion is represented by65,67–70

- The broadening s of an optical pulse over a fiber of length L is given by:

- To measure the dispersion, one examines the pulse delay over a desired wavelength range.

$$\sigma = D(\lambda)\, L \sigma_{\lambda}$$

- The dispersion behavior varies with wavelength and also with fiber type.
- To calculate the dispersion for a nondispersion-shifted fiber (called a Class IVa fiber by the EIA) in the 1270-to-1340-nm region, the standards recommend fitting the measured group delay per unit length to a three-term Sellmeier equation of the form65.

$$\tau = A + B\lambda^2 + C\lambda^{-2}$$

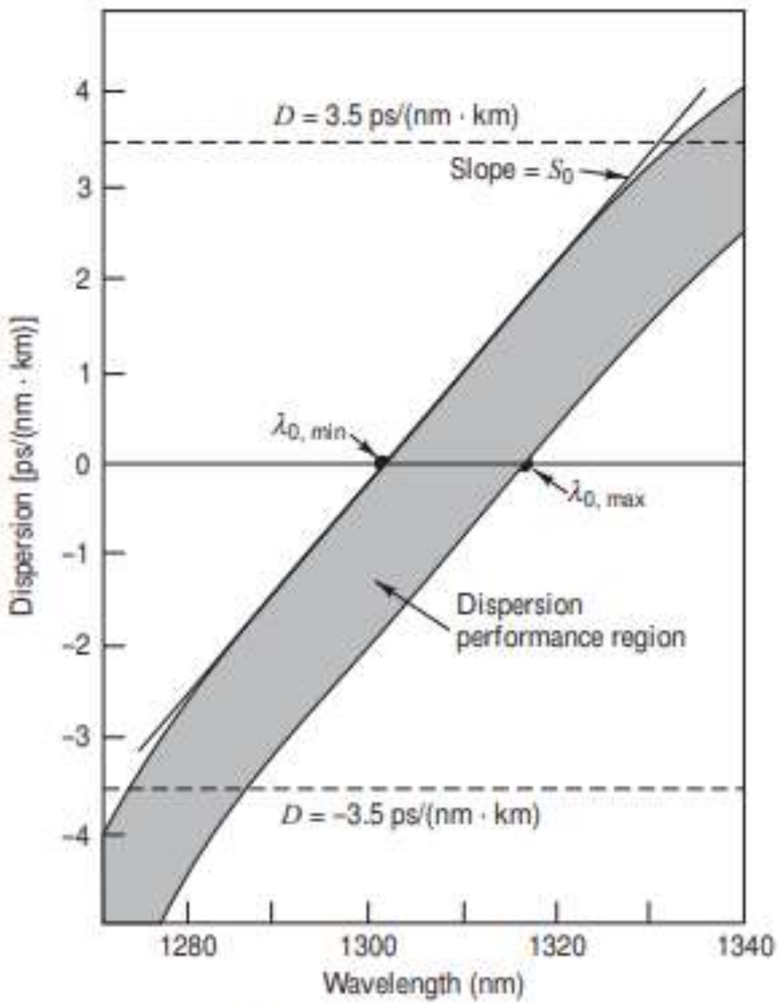

Fig. 3.22 *Example of a dispersion performance curve for a set of single-mode fibers. The two slightly curved lines are found by solving Eq. (3.47). S_0 is the slope of $D(\lambda)$ at the zero-dispersion wavelength λ_0.*

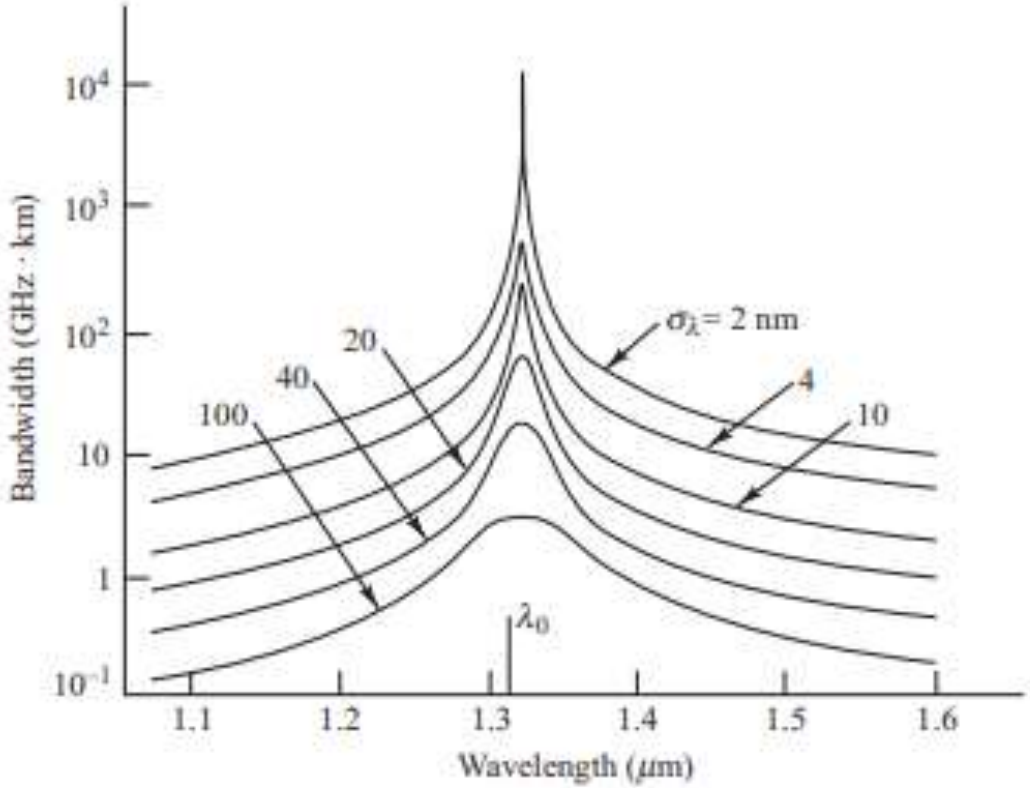

Fig. 3.23 *Examples of bandwidth versus wavelength for different source spectral widths σ_λ in a single-mode fiber having a dispersion minimum at 1300-nm. (Reproduced with permission from Reed, Cohen, and Shang,[56] © 1987, AT&T.)*

- As optical pulses travel down a fiber, temporal broadening occurs because material and waveguide dispersion cause different wavelengths in the optical pulse to propagate with different velocities.