

# Appendix A

## A.1 Interference Visibility

In Fig. 2.19 we have illustrated the measurement of the longitudinal coherence length with a Michelson interferometer showing a curve of the intensity of the interfering waves versus the path difference  $2\Delta L$ . The degree of modulation of this curve decreases with increasing path difference. If the path difference is large compared to the coherence length  $L_c$ , then this modulation vanishes. In the following we present a more precise description of interference visibility related to the spectral width of the light source. This interference visibility or *contrast of interference* is defined as follows:

$$C = \frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}}, \quad (\text{A.1.1})$$

where  $I_{\max}$  and  $I_{\min}$  are the maximum and minimum intensities of the superimposed waves. For  $I_{\min} = 0$  the contrast achieves its maximum value  $C = 1$ . In general the interference of two waves leads to the resulting intensity described by (cf. 7.18):

$$I = I_1 + I_2 + 2\sqrt{I_1 I_2} \cos \delta, \quad (\text{A.1.2})$$

with  $I_1, I_2$  intensity of the single waves and  $\delta$  the phase difference between the two waves at the point of interference. The phase difference is described by:

$$\delta = k(s_1 - s_2) + \delta_1 - \delta_2, \quad (\text{A.1.3})$$

where  $k$  is the angular wave number for each wave,  $s_1$  and  $s_2$  the pathes travelled by wave 1 and wave 2;  $\delta_1, \delta_2$  the initial phases of the waves at the chosen origin. In the case of monochromatic waves of the same angular wave number—as assumed so far—we obtain from (A.1.1) and (A.1.2):

$$C = \frac{2\sqrt{I_1 I_2}}{I_1 + I_2}. \quad (\text{A.1.4})$$

For simplicity, we consider the case, where the superimposed waves have the same intensity, i.e.:

$$I_0 = I_1 = I_2. \quad (\text{A.1.5})$$

For two monochromatic waves follows then from (A.1.4) and (A.1.5), that the contrast of interference is  $C = 1$ . With (A.1.5) inserted in (A.1.2) we have:

$$I = 2I_0(1 + \cos \delta). \quad (\text{A.1.6})$$

Let us now extend our considerations by assuming a light source which emits—instead of a single angular wave number, i.e. a pure monochromatic wave—a spectrum of waves. We describe the spectral intensity  $I_k$  of this light source by the following function:

$$I_k = \frac{dI}{dk} = f(k), \quad (\text{A.1.7})$$

with  $k$  angular wave number. We can generalize (A.1.6) with the help of (A.1.7):

$$I = 2 \int_{-\infty}^{\infty} f(k)(1 + \cos(\delta)) dk. \quad (\text{A.1.8})$$

We assume that the function  $f(k)$  describing the spectrum of the light source is symmetric with respect to an angular wave number  $k_0$ . Introducing new variables and definitions:

$$k' = k - k_0, \quad (\text{A.1.9})$$

$$f(k) = f(k' + k_0) = f^*(k') \quad (\text{A.1.10})$$

allows to rewrite (A.1.8) with (A.1.3):

$$I = 2 \int_{-\infty}^{\infty} f^*(k') dk' + 2 \int_{-\infty}^{\infty} f^*(k') \cos[(k' + k_0)(s_1 - s_2) + \delta_1 - \delta_2] dk'. \quad (\text{A.1.11})$$

With the abbreviations  $\Delta s = s_1 - s_2$  and  $\Delta \delta = \delta_1 - \delta_2$  and Euler's formula the second integral in (A.1.11) is rewritten:

$$\begin{aligned} & \int_{-\infty}^{\infty} f^*(k') \frac{e^{i[(k'+k_0)\Delta s + \Delta \delta]} + e^{-i[(k'+k_0)\Delta s + \Delta \delta]}}{2} dk' \\ &= \frac{1}{2} \int_{-\infty}^{\infty} \left[ f^*(k') e^{ik' \Delta s i(k_0 \Delta s + \Delta \delta)} + f^*(k') e^{-ik' \Delta s} e^{-i(k_0 \Delta s + \Delta \delta)} \right] dk'. \end{aligned} \quad (\text{A.1.12})$$

With the substitution  $\tilde{k} = -k'$  follows:

$$\int_{-\infty}^{\infty} f^*(k') e^{-ik'\Delta s} dk' = \int_{\infty}^{-\infty} f^*(-\tilde{k}) e^{i\tilde{k}\Delta s} (-d\tilde{k}) = \int_{-\infty}^{\infty} f^*(\tilde{k}) e^{i\tilde{k}\Delta s} d\tilde{k}. \quad (\text{A.1.13})$$

With (A.1.13) we have for (A.1.12):

$$\frac{1}{2} \int_{-\infty}^{\infty} f^*(k') e^{ik'\Delta s} 2 \cos(k_0\Delta s + \Delta\delta) dk'. \quad (\text{A.1.14})$$

Inserting (A.1.14) into relation (A.1.11) for the second integral then yields:

$$I = 2 \left[ \int_{-\infty}^{\infty} f^*(k') dk' + \cos(k_0\Delta s + \Delta\delta) \int_{-\infty}^{\infty} f^*(k') e^{ik'\Delta s} dk' \right]. \quad (\text{A.1.15})$$

Finally, the interference contrast is with (A.1.15) and (A.1.1):

$$C(\Delta s) = \left| \frac{\int_{-\infty}^{\infty} f^*(k') e^{ik'\Delta s} dk'}{\int_{-\infty}^{\infty} f^*(k') dk'} \right|. \quad (\text{A.1.16})$$

The result (A.1.16) shows that the interference contrast as a function of the path difference  $\Delta s$  is proportional to the Fourier transform of the spectrum of the emitted light of the source.

To demonstrate (A.1.16) we consider the following two spectra of a light source:

$$f_1(k) = \frac{I_0 e^{-\frac{(k-k_0)^2}{2\sigma^2}}}{\sqrt{2\pi\sigma}}, \quad (\text{A.1.17})$$

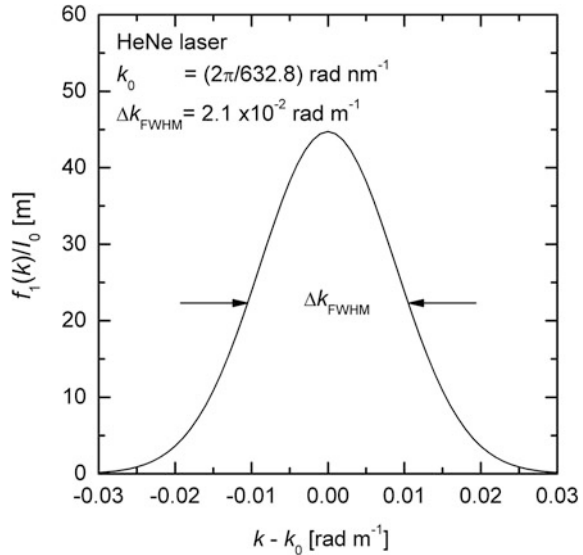
$$f_2(k) = \frac{I_0}{2\sqrt{2\pi\sigma}} \left[ e^{-\frac{(k-k_1)^2}{2\sigma^2}} + e^{-\frac{(k-k_2)^2}{2\sigma^2}} \right], \quad (\text{A.1.18})$$

where  $\sigma$  determines the width of the Gaussian function,  $k_0$  angular wave number at which the function (A.1.17) attains a maximum;  $k_1, k_2$  angular wave numbers at which the function (A.1.18) attains local maxima,  $I_0$  total intensity of both sources. The functions  $f_1(k)$  and  $f_2(k)$  are defined in such a way, that

$$\int_{-\infty}^{\infty} f_j(k) dk = I_0, \quad j = 1, 2 \quad (\text{A.1.19})$$

holds. Spectrum (A.1.17) describes e.g. a single mode laser source, whereas (A.1.18) is a simple representation of a laser running at two axial modes. The full width at half maximum of the function  $f_1(k)$  is given by:

**Fig. A.1** Spectrum of a HeNe laser as a function of the angular wave number difference  $k - k_0$



$$\Delta k_{\text{FWHM}} = 2\sqrt{2 \ln 2} \sigma. \quad (\text{A.1.20a})$$

Figure A.1 shows an example of the function  $f_1(k)/I_0$ .

(a) Contrast function (A.1.17):

Inserting (A.1.17) into (A.1.16) yields for the contrast function:

$$C_1(\Delta s) = e^{-\Delta s^2 \sigma^2 / 2}. \quad (\text{A.1.20b})$$

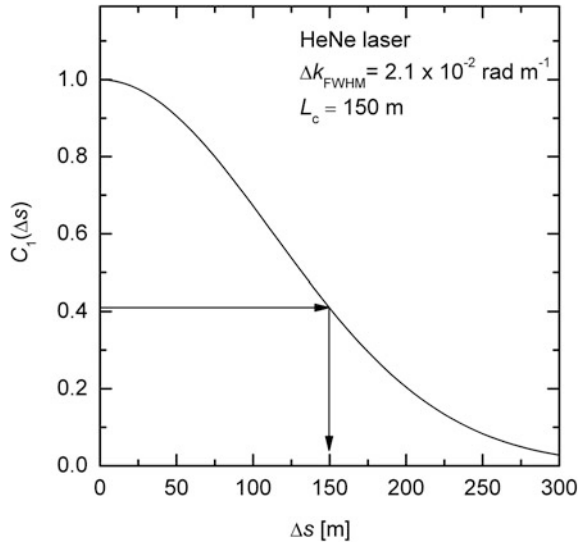
Figure A.2 shows this contrast function. The key point is that the quantity  $\sigma$  appears in the denominator of the exponent of the spectrum (A.1.17) whereas in the contrast function  $\sigma$  occurs in the numerator of the exponent. From this follows that a broader spectrum, i.e. greater values of  $\sigma$ , lead to a contrast function decreasing faster with increasing  $\Delta s$ . The behaviour of the two functions—spectrum and contrast—is inverted. The broader the first one becomes, the narrower is the second, and vice versa. We have discussed already a similar feature while introducing the temporal coherence, see Sect. 2.4.2, where the coherence time is increasing, if the spectrum of a light source becomes narrower.

Let us now take the relations (2.28) and (2.29) from Chap. 2 describing the dependence of the coherence length  $L_c$  and the angular frequency width of the light source  $\Delta\omega$ :

$$\Delta\omega \frac{L_c}{c} = \pi. \quad (\text{A.1.21})$$

We assume that  $\Delta\omega$  refers to the full width of the spectrum of the light source at half maximum. With  $\omega = kc$  and the differential thereof, we can rewrite (A.1.21):

**Fig. A.2** Contrast function belonging to the spectrum shown in Fig. A.1



$$\Delta k_{\text{FWHM}} L_c = \pi. \tag{A.1.22}$$

With (A.1.20a) and (A.1.20b) we can calculate the contrast if the path difference  $\Delta s$  is chosen to be just equal to the coherence length  $L_c$ :

$$C_1(\Delta s = L_c) = e^{-\frac{L_c^2 \sigma^2}{2}} = e^{-\frac{\pi^2}{16 \ln^2}} \approx 0.41. \tag{A.1.23}$$

The coherence length defined with relation (A.1.22) corresponds to a decrease of the contrast to about 0.41. This is a way to measure the coherence length by successively increasing the path difference  $\Delta s$  caused by the two interferometer arms of different lengths until the contrast function reaches the limit given in (A.1.23), then we have  $L_c = \Delta s$ . For the chosen example, Fig. A.2 indicates the resulting coherence length of about 150 m. For a laser with this coherence length the frequency full width at half maximum is calculated with (A.1.21) and  $\Delta\omega = 2\pi\Delta f$ :  $\Delta f = 1$  MHz. This frequency width divided by the frequency at the maximum of the spectrum amounts to  $2.1 \times 10^{-9}$ . This illustrates the extremely high spectral resolution achievable with a Michelson interferometer.

Instead of taking the right-hand side of (A.1.21) equal to  $\pi$  another value could be chosen, so that e.g. the contrast function yields 0.5 for  $\Delta s = L_c$ :

$$\Delta\omega \frac{L_c}{c} = 4 \ln 2. \tag{A.1.24}$$

This is just a question of definition. With the analogous calculation steps as above, we find with (A.1.20b) and (A.1.24):

$$C_1(\Delta s = L_c) = e^{-\frac{L_c^2 \sigma^2}{2}} = e^{-\frac{8(\ln 2)^2 \sigma^2}{\Delta k_{\text{FWHM}}^2}} = e^{-\ln^2} = 0.5. \tag{A.1.25}$$

For the chosen example of Fig. A.1 and the right-hand side of (A.1.24) we obtain for the coherence length  $L_c = 132$  m.

(b) Contrast function (A.1.18):

The contrast function (A.1.16) for the spectrum (A.1.18) is calculated with (A.1.9), (A.1.10) as follows:

$$C_2(\Delta s) = \frac{1}{2\sqrt{2\pi\sigma}} \left| \int_{-\infty}^{\infty} e^{-\frac{(k'+k_0-k_1)^2}{2\sigma^2}} e^{ik'\Delta s} dk' + \int_{-\infty}^{\infty} e^{-\frac{(k'+k_0-k_2)^2}{2\sigma^2}} e^{ik'\Delta s} dk' \right|. \quad (\text{A.1.26})$$

The first integral can be solved with the help of the substitution  $\tilde{k} = k' + k_0 - k_1$ :

$$\int_{-\infty}^{\infty} e^{-\frac{(k'+k_0-k_1)^2}{2\sigma^2}} e^{ik'\Delta s} dk' = e^{-i(k_0-k_1)\Delta s} \int_{-\infty}^{\infty} e^{-\frac{\tilde{k}^2}{2\sigma^2}} e^{i\tilde{k}\Delta s} d\tilde{k} = e^{-i(k_0-k_1)\Delta s} \sqrt{2\pi\sigma} e^{-\frac{\Delta s^2\sigma^2}{2}}. \quad (\text{A.1.27})$$

In an analogous way we have for the second integral of (A.1.26):

$$\int_{-\infty}^{\infty} e^{-\frac{(k'+k_0-k_2)^2}{2\sigma^2}} e^{ik'\Delta s} dk' = e^{-i(k_0-k_2)\Delta s} \sqrt{2\pi\sigma} e^{-\frac{\Delta s^2\sigma^2}{2}}. \quad (\text{A.1.28})$$

Inserting (A.1.27) and (A.1.28) into (A.1.26) then yields:

$$\begin{aligned} C_2(\Delta s) &= \frac{1}{2} e^{-\frac{\Delta s^2\sigma^2}{2}} \left| e^{-i(k_0-k_1)\Delta s} + e^{-i(k_0-k_2)\Delta s} \right| \\ &= \frac{1}{2} e^{-\frac{\Delta s^2\sigma^2}{2}} \left| e^{-ik_0\Delta s} \left| \sqrt{(e^{ik_1\Delta s} + e^{ik_2\Delta s})(e^{-ik_1\Delta s} + e^{-ik_2\Delta s})} \right| \dots \right. \\ &= \frac{1}{2} e^{-\frac{\Delta s^2\sigma^2}{2}} \sqrt{2(1 + \cos((k_2 - k_1)\Delta s))} = \frac{1}{2} e^{-\frac{\Delta s^2\sigma^2}{2}} \sqrt{2 \cdot 2 \cos^2\left(\frac{(k_2 - k_1)}{2}\Delta s\right)}. \end{aligned} \quad (\text{A.1.29})$$

So we have finally for the contrast function belonging to (A.1.18):

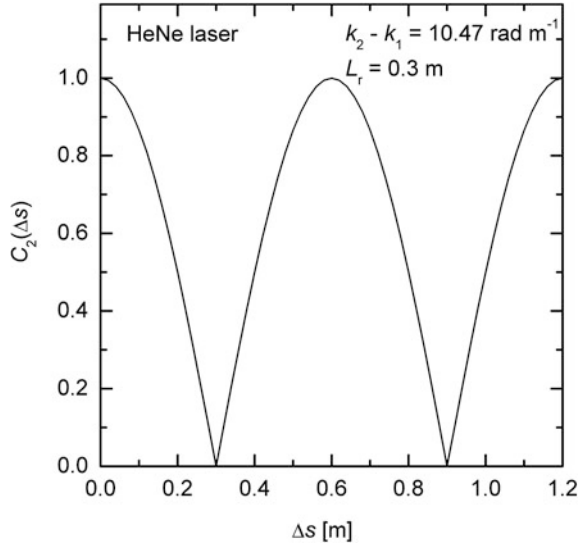
$$C_2(\Delta s) = e^{-\frac{\Delta s^2\sigma^2}{2}} \left| \cos\left(\frac{(k_2 - k_1)}{2}\Delta s\right) \right|. \quad (\text{A.1.30})$$

Let us consider a HeNe laser with a resonator length of  $L_r$ , then the frequency spacing between two neighboring longitudinal modes of this laser is given by:

$$\Delta\nu = \frac{c}{2L_r}, \quad (\text{A.1.31})$$

with  $c$  speed of light and  $L_r$  distance between the two resonator mirrors, cf. Sect. 2.5. As numerical example we take  $L_r = 30$  cm and with (A.1.31) we obtain

**Fig. A.3** Contrast function belonging to the spectrum (A.1.18) of two neighboring axial modes of a HeNe laser



$\Delta\nu = 5 \cdot 10^8$  Hz. The distance of the two longitudinal modes expressed with the angular wave numbers according to the definition chosen in (A.1.18) is then:

$$k_2 - k_1 = \frac{2\pi}{c} \Delta\nu = 10.47 \text{ rad m}^{-1}. \tag{A.1.32}$$

The resulting contrast function according to (A.1.30) is shown in Fig. A.3. The contrast varies periodically, a series of minima occur at odd integer multiples of the resonator length  $L_r$ . Starting with  $\Delta s = 0$  and stepwise increasing  $\Delta s$  the first drop to  $C_2(\Delta s) = 0.5$  appears for the following path difference:

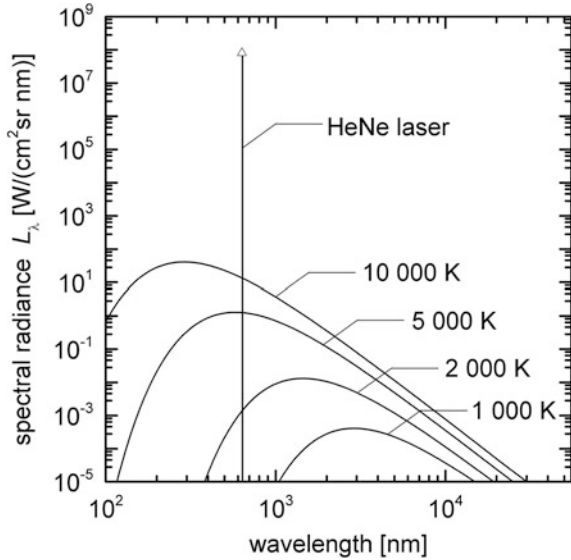
$$\Delta s_{0.5} = \frac{2\pi}{3(k_2 - k_1)}. \tag{A.1.33}$$

## A.2 Comparison of Spectral Radiance of the Emission of a Black Body and a Laser Source

The idea of this appendix is to provide the reader a numerical example of the significant differences of the spectral radiance emitted of a black body at thermal equilibrium and a laser source. The spectral radiance  $L_\lambda$  describes the emitted radiant flux divided by the unit area, the unit solid angle and the unit wavelength interval. Therefore, the unit of  $L_\lambda$  is  $W/(m^2 \text{ sr m})$ . The spectral radiance of a black body is described by Planck’s law [2]:

$$L_\lambda = \frac{2hc^2}{\lambda^5} \frac{1}{e^{hc/\lambda kT} - 1}, \tag{A.2.1}$$

**Fig. A.4** Spectral radiance of the radiation of a black body described by Planck’s law for temperatures up to 10,000 K and spectral radiance of a HeNe laser with a flux of 1 mW, see text



with  $h$  Planck constant,  $c$  speed of light,  $\lambda$  wavelength,  $k$  Boltzmann constant and  $T$  temperature. Figure A.4 shows the spectral radiance of a black body for temperatures ranging from 1,000 to 10,000 K.

For comparison with a laser source we consider a HeNe laser emitting at  $\lambda = 633$  nm taking the following exemplary data: flux  $\phi = 1$  mW, full divergence angle  $\Theta = 1$  mrad, beam diameter  $d = 1$  mm, spectral line width  $\Delta\nu = 1.5$  GHz. The latter can be transformed to a corresponding wavelength width with the help of the relation  $c = \lambda\nu$ :

$$|\Delta\lambda| = \frac{\lambda^2}{c} |\Delta\nu|. \tag{A.2.2}$$

Relation (A.2.2) yields then  $\Delta\lambda = 2$  pm. The solid angle of the laser beam in the far field for a given divergence angle  $\Theta$  is described by:

$$\Delta\Omega = 2\pi(1 - \cos(\Theta/2)). \tag{A.2.3}$$

This relation follows from the integral:

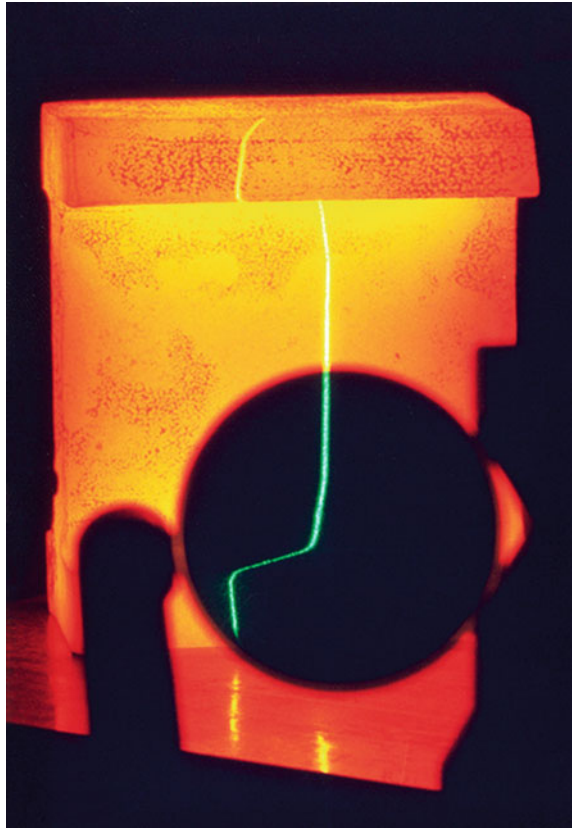
$$\Delta\Omega = \int_0^{2\pi} \int_0^{\Theta/2} \sin\theta \, d\theta \, d\varphi, \tag{A.2.4}$$

where  $\varphi$  is the azimuth angle,  $\theta$  the polar angle. We can check whether (A.2.3) is plausible by inserting  $\Theta = 2\pi$  in (A.2.3) which yields  $\Delta\Omega = 4\pi$  sr, i.e. the full solid angle of a sphere.

With the given divergence angle of the laser beam we obtain  $\Delta\Omega = 7.85 \times 10^{-7}$  sr. The spectral radiance of the laser source is given by:



**Fig. A.5** Photograph of a hot T-beam section illuminated by a laser light section. The dark black circle is a band-pass interference filter centered at the laser wavelength. The light passing the filter reveals a very high contrast which allows to follow the shape of the laser line even in the case of a strong luminous object



$$L_{\lambda}^{\text{laser}} = \frac{\phi}{\pi \left(\frac{d}{2}\right)^2 \Delta\Omega \Delta\lambda}. \tag{A.2.5}$$

Finally we obtain  $L_{\lambda}^{\text{laser}} = 8.1 \times 10^7 \text{W}/(\text{cm}^2 \text{sr nm})$ , see data point shown as open triangle in Fig. A.4. This demonstrates that the spectral radiance of even a moderate laser with a flux of 1 mW only is by many orders of magnitude higher than the black body radiation calculated for temperatures up to 10,000 K.

Figure A.5 gives an experimental evidence of this significant difference in the spectral radiances. A laser light section, cf. Chap. 10, is projected onto a T-beam section. The scattered light is observed via a bandpass interference filter (black circular disk in Fig. A.5) with a width of about 10 nm centered at the laser wavelength. Behind this filter a very high contrast between the laser light and the black body radiation is observed which mirrors the above stated differences between the spectral radiances of a coherent and an incoherent light source. This unique feature is utilized to measure e.g. the flatness of hot heavy plates with laser triangulation, see Sect. 10.4, Figs. 10.24, 10.25 and 10.26.

### A.3 Derivation of Equation (9.23)

We insert the spectrum of the light source (9.21) in (9.18) and integrate over the angular wave numbers to gain the quantity  $I$ , which we need to describe the signal for time-domain OCT, cf. (9.19):

$$I(z_r) = \int_0^\infty \left( 1 + \sum_{j=1}^N R_{m,j} \right) \frac{I_0}{\sqrt{\pi}\Delta k} e^{-\left[\frac{k-k_0}{\Delta k}\right]^2} dk + \dots \\ \dots + \int_0^\infty 2 \sum_{j=1}^N \sqrt{R_{m,j}} \frac{I_0}{\sqrt{\pi}\Delta k} e^{-\left[\frac{k-k_0}{\Delta k}\right]^2} \cos(2k(z_r - z_{m,j})) dk. \quad (\text{A.3.1})$$

The autocorrelation term is neglected, cf. third term with double sum in (9.18). The first integral in (A.3.1) is easily evaluated by use of (9.22):

$$A = \left( 1 + \sum_{j=1}^N R_{m,j} \right) I_0. \quad (\text{A.3.2})$$

As abbreviation for the second integral to be solved we use:

$$B = \int_0^\infty \frac{I_0}{\sqrt{\pi}\Delta k} e^{-\left[\frac{k-k_0}{\Delta k}\right]^2} \cos(2k(z_r - z_{m,j})) dk. \quad (\text{A.3.3})$$

With the substitution  $k' = k - k_0$ , and the abbreviation  $\delta z_j = z_r - z_{m,j}$  we obtain:

$$B = \int_{-k_0}^\infty \frac{I_0}{\sqrt{\pi}\Delta k} e^{-\left[\frac{k'}{\Delta k}\right]^2} \cos((k' + k_0)2\delta z_j) dk'. \quad (\text{A.3.4})$$

Assuming  $k_0 > 0$  and  $k_0 \gg \Delta k$  the integrand of (A.3.4) has only significant positive values close to the origin of the  $k'$  axis. Since we assume that the width of this Gaussian function is small compared to  $k_0$ , we can approximate the integral of (A.3.4) by extending the lower integration limit from “ $-k_0$ ” to minus infinity:

$$B \approx \int_{-\infty}^\infty \frac{I_0}{\sqrt{\pi}\Delta k} e^{-\left[\frac{k'}{\Delta k}\right]^2} \cos((k' + k_0)2\delta z_j) dk'. \quad (\text{A.3.5})$$

With the trigonometric addition theorem  $\cos(x + y) = \cos x \cos y - \sin x \sin y$ , we have:

$$B \approx \frac{I_0}{\sqrt{\pi}\Delta k} \int_{-\infty}^\infty e^{-\left[\frac{k'}{\Delta k}\right]^2} [\cos(k'2\delta z_j) \cos(k_0 2\delta z_j) - \sin(k'2\delta z_j) \sin(k_0 2\delta z_j)] dk'. \quad (\text{A.3.6})$$

The second summand is a point symmetric function with respect to  $k'$ , whereas the Gaussian function is a symmetric function with respect to  $k'$  and the ordinate. Therefore, the integral of the product of the second summand and the Gaussian function becomes zero. So from (A.3.6) we come to:

$$B \approx \frac{I_0 \cos(k_0 2\delta z_j)}{\sqrt{\pi}\Delta k} \int_{-\infty}^{\infty} e^{-\left[\frac{k'}{\Delta k}\right]^2} \cos(k' 2\delta z_j) dk'. \quad (\text{A.3.7})$$

From [1] the following definite integral is known:

$$\int_{-\infty}^{\infty} e^{-a^2 x^2} \cos bx \, dx = \frac{\sqrt{\pi}}{a} e^{-\frac{b^2}{4a^2}}. \quad (\text{A.3.8})$$

With  $a = 1/\Delta k$ ,  $b = 2\delta z_j$  and  $x = k'$ , we see that (A.3.8) is equivalent to (A.3.7) and finally get for (A.3.7):

$$B \approx \frac{I_0 \cos(k_0 2\delta z_j)}{\sqrt{\pi}\Delta k} \sqrt{\pi}\Delta k e^{-\delta z_j^2 \Delta k^2} = I_0 \cos(k_0 2\delta z_j) e^{-\delta z_j^2 \Delta k^2}. \quad (\text{A.3.9})$$

Taking this result (A.3.9), we have now solved (A.3.1) and can write with resubstitution of the used abbreviations:

$$I(z_r) = I_0 \left( 1 + \sum_{j=1}^N R_{m,j} \right) + 2I_0 \sum_{j=1}^N \sqrt{R_{m,j}} \cos(2k_0(z_r - z_{m,j})) e^{-(z_r - z_{m,j})^2 \Delta k^2}. \quad (\text{A.3.10})$$

Relation (A.3.10) is identical to (9.23).

### A.4 Derivation of Equation (9.26)

To solve the integral (9.26) we introduce a substitution  $k' = k - k_0$ :

$$\tilde{f} = \frac{\eta}{2\pi} \int_{-\infty}^{+\infty} \frac{I_0}{\sqrt{\pi}\Delta k} e^{-\left[\frac{(k-k_0)}{\Delta k}\right]^2} e^{ikz} dk = \frac{\eta I_0 e^{ik_0 z}}{2\pi\sqrt{\pi}\Delta k} \int_{-\infty}^{+\infty} e^{-\left[\frac{k'}{\Delta k}\right]^2} e^{ik'z} dk'. \quad (\text{A.4.1})$$

Euler's formula says:

$$e^{ik'z} = \cos(k'z) + i \sin(k'z). \quad (\text{A.4.2})$$

With the help of (A.4.2) the definite integral in (A.4.1) can be decomposed as follows:

$$\int_{-\infty}^{+\infty} e^{-\left[\frac{k'}{\Delta k}\right]^2} e^{ik'z} dk' = \int_{-\infty}^{+\infty} e^{-\left[\frac{k'}{\Delta k}\right]^2} \cos(k'z) dk' + i \int_{-\infty}^{+\infty} e^{-\left[\frac{k'}{\Delta k}\right]^2} \sin(k'z) dk'. \quad (\text{A.4.3})$$

The first term on the right handside of (A.4.3) is a symmetric function of  $z$  (symmetric about the  $y$ -axis), whereas the second term is a point symmetric function with respect to  $z$  (symmetric about the origin). Hence, the second term on the right handside of (A.4.3) is zero. The first term is a known definite integral [1]:

$$\int_{-\infty}^{+\infty} e^{-\left[\frac{k'}{\Delta k}\right]^2} \cos(k'z) dk' = 2 \int_0^{+\infty} e^{-\left[\frac{k'}{\Delta k}\right]^2} \cos(k'z) dk' = \sqrt{\pi} \Delta k e^{-\frac{z^2 \Delta k^2}{4}} \quad (\text{A.4.4})$$

for  $\Delta k > 0$ . Inserting (A.4.4) in (A.4.1) then yields:

$$\tilde{f}(z) = \frac{\eta I_0 e^{ik_0 z}}{2\pi \sqrt{\pi} \Delta k} \sqrt{\pi} \Delta k e^{-\frac{z^2 \Delta k^2}{4}} = \frac{\eta I_0 e^{ik_0 z}}{2\pi} e^{-\frac{z^2 \Delta k^2}{4}} \quad (\text{A.4.5})$$

Relation (A.4.5) is identical to (9.26).

## A.5 Derivation of Equation (9.27)

We start with (9.25), insert (9.20) and for  $I_k$  (9.18):

$$\tilde{S}(z) = \frac{\eta}{2\pi} \left\{ \int_{-\infty}^{\infty} I_{0,k} \left( 1 + \sum_{j=1}^N R_{m,j} \right) e^{ikz} dk + \int_{-\infty}^{\infty} I_{0,k} 2 \sum_{j=1}^N \sqrt{R_{m,j}} \cos(k2(z_r - z_{m,j})) e^{ikz} dk \right\}. \quad (\text{A.5.1})$$

Relation (A.5.1) is decomposed in two summands. For the first summand we have with (9.21) and (9.26):

$$\tilde{S}_1(z) = \frac{\eta}{2\pi} \left( 1 + \sum_{j=1}^N R_{m,j} \right) I_0 e^{ik_0 z} e^{-\frac{z^2 \Delta k^2}{4}} = \left( 1 + \sum_{j=1}^N R_{m,j} \right) \tilde{f}(z). \quad (\text{A.5.2})$$

For the second summand we obtain after insertion of (9.21) and the abbreviation  $\Delta z_j = 2(z_r - z_{m,j})$ :

$$\tilde{S}_2(z) = \frac{2\eta}{2\pi} \sum_{j=1}^N \sqrt{R_{m,j}} \frac{I_0}{\sqrt{\pi} \Delta k} \int_{-\infty}^{\infty} e^{-\frac{(k-k_0)^2}{\Delta k^2}} \cos(k \Delta z_j) e^{ikz} dk. \quad (\text{A.5.3})$$

We abbreviate the definite integral with the letter  $B$ :

$$B = \int_{-\infty}^{\infty} e^{-\frac{(k-k_0)^2}{\Delta k^2}} \cos(k \Delta z_j) e^{ikz} dk. \quad (\text{A.5.4})$$

With the substitution  $k' = k - k_0$  follows from (A.5.4):

$$B = \int_{-\infty}^{\infty} e^{-\frac{k'^2}{\Delta k^2}} e^{ik'z} e^{ik_0 z} \cos[(k' + k_0) \Delta z_j] dk'. \quad (\text{A.5.5})$$

With Euler's formula (A.4.2) this can be rewritten and decomposed in two summands:

$$B = \frac{e^{ik_0z}}{2} \int_{-\infty}^{\infty} e^{-\frac{k'^2}{\Delta k^2}} e^{ik'z} \left[ e^{i(k'+k_0)\Delta z_j} + e^{-i(k'+k_0)\Delta z_j} \right] dk', \quad (\text{A.5.6})$$

$$B = \frac{e^{ik_0z}}{2} (b_1 + b_2). \quad (\text{A.5.7})$$

The summand  $b_1$  can be converted as follows:

$$b_1 = e^{ik_0\Delta z_j} \int_{-\infty}^{\infty} e^{-\frac{k'^2}{\Delta k^2}} e^{ik'(z+\Delta z_j)} dk'. \quad (\text{A.5.8})$$

With Euler's formula (A.4.2) we see, that the integrand is again a sum of a symmetric and a point symmetric function, hence the integral over the second summand vanishes and we obtain:

$$b_1 = e^{ik_0\Delta z_j} \int_{-\infty}^{\infty} e^{-\frac{k'^2}{\Delta k^2}} \cos(k'(z+\Delta z_j)) dk'. \quad (\text{A.5.9})$$

This integral is known, cf. (A.3.8) and (A.4.4):

$$b_1 = e^{ik_0\Delta z_j} \sqrt{\pi} \Delta k e^{-\frac{(z+\Delta z_j)^2 \Delta k^2}{4}}. \quad (\text{A.5.10})$$

Analogously we have for the second summand:

$$b_2 = e^{-ik_0\Delta z_j} \sqrt{\pi} \Delta k e^{-\frac{(z-\Delta z_j)^2 \Delta k^2}{4}}. \quad (\text{A.5.11})$$

Now we insert these summands into relation (A.5.7):

$$B = \frac{e^{ik_0z}}{2} \sqrt{\pi} \Delta k \left[ e^{ik_0\Delta z_j} e^{-\frac{(z+\Delta z_j)^2 \Delta k^2}{4}} + e^{-ik_0\Delta z_j} e^{-\frac{(z-\Delta z_j)^2 \Delta k^2}{4}} \right]. \quad (\text{A.5.12})$$

This can be rewritten with (A.4.5):

$$B = \frac{\sqrt{\pi} \Delta k}{2} \left[ \frac{2\pi \tilde{f}(z+\Delta z_j)}{\eta I_0} + \frac{2\pi \tilde{f}(z-\Delta z_j)}{\eta I_0} \right]. \quad (\text{A.5.13})$$

Going back to (A.5.3) and cancelling some terms we get:

$$\tilde{S}_2(z) = \sum_{j=1}^N \sqrt{R_{m,j}} (\tilde{f}(z+\Delta z_j) + \tilde{f}(z-\Delta z_j)). \quad (\text{A.5.14})$$

Inserting (A.5.2) and (A.5.14) into (A.5.1) then finally yields:

$$\tilde{S}(z) = \tilde{f}(z) \left( 1 + \sum_j R_{m,j} \right) + \left( \sum_j \sqrt{R_{m,j}} (\tilde{f}(z + \Delta z_j) + \tilde{f}(z - \Delta z_j)) \right). \quad (\text{A.5.15})$$

The expression (A.5.15) is identical to (9.27).

## References

1. I. Bronstein, K. Semendjajew, *Taschenbuch der Mathematik*, 19. Aufl. (Verlag Harri Deutsch, Thun Frankfurt, 1980), p. 118
2. A. Anders, *A Formulary for Plasma Physics* (Akademie-Verlag, Berlin, 1990)

## Abbreviations

Abbreviation	Explanation	Chapter(s), Figure(s), Table(s)	Page numbers
A-, B-, C-scan	Depth scan, 2D scan, 3D scan	9.1, Fig. 9.2	228
ADC	Analog digital converter	14.6	382
BD	Blu-ray disc	12.3.1	315
BOXCARS	Variant of CARS, cf. Fig. 13.31	13.3.2	362
CD	Compact disc	12.3.1	314
DC term	Undiffracted reference wave	7.4.1	185
CARS	Coherent anti-Stokes Raman spectroscopy	13.3	355
CLSM	Confocal laser scanning microscope	12	305
CCD	Charge-coupled device	5.4.5, 10.2.4, Table 10.1, Fig. 5.38	135, 260, 261
CMOS	Complementary metal oxide semiconductor	10.2.4, Table 10.1	260, 261
CRM	Certified reference material	13.1.6	336
DON	Deoxynivalenol	14.7	388
DVD	Digital versatile disc	12.3.1	314
E-CARS	CARS in backward direction	13.3.4	368
ESPI	Electronic speckle interferometry	8.3.3, Fig. 8.11	213, 214
F-CARS	CARS in forward direction	13.3.4	367
FD-OCT	Fourier domain OCT	9.1.2, Fig. 9.19	235, 244
FLIM	Fluorescence lifetime imaging	14.6	382
FPS	Fluorescence polarization spectroscopy	14.5, Fig. 14.7	380, 381
FWHM	Full width at half maximum	12.1.2	307
IR	Infrared	5.4.3	131
LAM	Laser additive manufacturing	1	2
LDA	Laser Doppler anemometer	11.3, Fig. 11.3	292
LIDAR	Light detection and ranging	13.2, Fig. 13.17	343, 344
LIBS	Laser-induced breakdown spectroscopy	13.1, Fig. 13.1	324

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Abbreviation	Explanation	Chapter(s), Figure(s), Table(s)	Page numbers
MEMS	Microelectromechanical systems	9.3	243
MESF	Molecules of equivalent soluble fluorophore	14.7	389
MOS	Metal-oxide-semiconductor	5.4.5, Fig. 5.37	134
MOSFET	Metal-oxide-semiconductor field effect transistor	5.4.5	134
NA	Numerical aperture	12.1.1, (12.1), 12.1.2, Table 12.1	306, 308, 315
OCT	Optical coherence tomography	9, Fig. 9.1	227
OPO	Optical parametric oscillator	13.3.1	360
PDA	Photodiode array	5.4.5	135
PET	Polyethylene terephthalate	9.3, Fig. 9.19	244
PIN	Positive-intrinsic-negative photodiode	5.3.2	121
PSF	Point-spread function	12.1.2	307
ROI	Region of interest	10.2.4	262
ptv	Peak-to-valley	7.5.2, Fig. 7.22	193
SEM	Scanning electron microscopy	12.3.1	315
TCSPC	Time correlated single photon counting	14.6, Fig. 14.8	382
TD-OCT	Time-domain optical coherence tomography	9.1.1, Fig. 9.3	229
UV	Ultraviolet	5.4.3, 9.3	131, 244
VCO	Voltage controlled oscillator	11.3.2, Fig. 11.16	296
VIS	Visible	5.4.3	131
2-D	Two dimensional	10.1, Fig. 10.2	249
3-D	Three dimensional	10.1, Fig. 10.2	249

## Notations and list of symbols

The following notation rules are used in this book:

- physical quantities are written with italic characters to visualize that these quantities have a unit, example:  $P$ , radiant flux; unit: Watt,
- mathematical variables are also written with italic characters to clearly distinguish these from units or numbers, example:  $j = 1, 2, \dots$ ,
- numbers including the imaginary unit  $i = \sqrt{-1}$ , and the Euler number  $e$  are set with non-italic characters; mathematical functions are also set with non-italic characters, example  $J_0$ , zeroth order Bessel function,
- units are set with non-italic characters to clearly distinguish these from the cases a), b); example: m, meter,
- abbreviations for objects or denominations of points are set with non-italic characters, examples:  $r$ , stands for reference beam or  $P$ , denotes a point,
- differentials are written with non-italic characters followed by a physical quantity written with italic character, example:  $dx$ .

Symbol	Description	Unit	Chapter(s), Figure(s), Formula(s)
$a$	Typical dimension of diffracting aperture	m	2.3, (2.16)
$A(\tau)$	Autocorrelation function	$[s(t)]^2$	11.3.2, (11.38)
$A$	Absorptance	1	5.1, (5.1), 13.1.3, (13.8),
$A$	Resolution	1	6.2.4
$A_{ji}$	Einstein coefficient for spontaneous emission for the transition from the upper level $j$ to the lower level $i$	$s^{-1}$	13.1.3, (13.8)
$\alpha$	Absorption coefficient	$m^{-1}$	3.3.1, (3.12), (7.7)
$\alpha$	Angle of incident laser beam	rad	2.2.3, (2.10), 10.2.1, (10.9)
$\alpha$	Temperature coefficient	1/K	5.1.2, (5.18)
$\alpha_x$	Angle of deflection in the $x$ -direction	rad	10.2.5, (10.35)
$(\alpha)$	Specific rotation	rad/m	4.1.2, (4.6)
$b$	Image distance	m	8.2.1, (8.3)
$b_\lambda$	spectral intensity of the background radiation	W/m	13.1.5, (13.12)
$B$	Size of the image	m	8.2.1, (8.4), 10.1.1
$B_\omega$	Angular spectrum bandwidth	rad $s^{-1}$	11.2.2, (11.18)
$\beta$	Opening angle of the objective	rad	10.2.4, (10.31)
$\beta(r, t)$	Scattering coefficient per solid angle per path length	$m^{-1}sr^{-1}$	13.2.1, (13.17)
$c$	Speed of light	m/s	2.1, 3.2, (2.4), (3.4)
$c$	Specific heat capacity	J/(kg K)	13.1.2, (13.3)
$C_Q$	Heat capacity	J/K	5.1, (5.1)
$\chi^{(1)}$	Electrical susceptibility of first order	As/(Vm)	13.3.1
$d_{fp}$	Displacement in the film plane	m	8.2.1, (8.5)
$d_{op}$	Displacement in the object plane	m	8.2.1, (8.6)
$d_{plasma}$	Plasma diameter	M	13.1.4, (13.10)
$d_{sp}$	Speckle size	m	8.2.1, (8.7)
$d_x$	Object translation within the object surface	m	8.3.2, Table 8.1
$d_z$	Object translation perpendicular to the object surface	m	8.3.2, Table 8.1
$\vec{d}$	Displacement vector	m	8.3.2, (8.26), (8.28)
$d\Omega_{det}$	Solid angle of receiving optic	sr	13.2.1, (13.18)
$D$	Thickness of hologram, diameter of aperture	m	7.1, (7.7), 8.1, (8.2), Fig. 8.6, 10.2.4, (10.11)
$D$	Optical density	1	5.4.1, (5.55)
$D_c$	Diameter of circle enclosing the interference pattern in the observation plane	m	8.2.1, Fig. 8.4
$D_{ph}$	Pinhole diameter	m	12.1.2, (12.8)

(continued)



(continued)

Symbol	Description	Unit	Chapter(s), Figure(s), Formula(s)
$\delta_h$	Heat penetration depth	m	13.1.1
$\delta_{opt}$	Optical penetration depth	m	13.1.1
$\delta(z_m - z_{m,j})$	Dirac function	$m^{-1}$	9.1.1, (9.11)
$\vartheta_{m,r}(x, y)$	Phase of scattered waves in the observation plane	rad	8.3, (8.21)
$\Delta$	Path difference	m	2.3.1, (2.19)
$\Delta\phi$	Phase difference	rad	8.2.2, (8.17)
$\Delta\Omega_c$	Solid coherence angle	sr	2.4.3, (2.33)
$\Delta N_{sp}$	Fluctuation of number of speckles per pixel	1	10.2.4
$\Delta p$	Width of pixel	m	10.2.4, Fig. 10.15
$\Delta r_{min}$	Lateral resolution	m	12.1.2, (12.5)
$\Delta t$	Temporal width	s	9.1.1, (9.1)
$\Delta y$	Height of pixel	m	10.2.4, Fig. 10.15
$\Delta z$	Uncertainty in the determination of the light spot on the $z$ -axis	m	10.2.1, (10.9), Fig. 10.7, 10.2.4, (10.32)
$\Delta z'_{cg}$	Measuring uncertainty in the determination of the position of the light spot in the detector plane	m	10.2.4, (10.25), (10.29)
$e$	elementary charge	C	5.1.3, (5.50)
$\vec{e}_i$	Unit vector describing the direction of the incident wave	1	11.1
$\vec{e}_o$	Unit vector describing the direction of the scattered wave	1	11.1
$\vec{E}$	Electric field strength vector	V/m	2.1, (2.1a)
$\vec{E}_0$	Electric field strength amplitude	V/m	2.1, (2.1a)
$E_{m,k}, E_{r,k}$	Complex spectral field strength in the measuring arm, reference arm	V/rad	9.1.1, (9.10)
$E_o$	Complex amplitude of the electric field of the object wave	V/m	7, (7.1)
$E_o^d$	Complex amplitude of the electric field of the object wave of the displaced object	V/m	Fig. 7.5, (7.8)
$E_r$	Complex amplitude of the electric field of the reference wave	V/m	7, (7.1), 9.1.1, (9.5)
$\varepsilon$	Slope of the linear part of an amplitude transmission curve	$m^2/(Ws)$	7, (7.2)
$\varepsilon_{AB}$	Seebeck coefficient	V/K	5.1.1, (5.16)
$\varepsilon_0$	Permittivity of free space	$AsV^{-1}m^{-1}$	3.4.3, (3.20a)
$\varepsilon_{ji}^{v,d\Omega}(t)$	Line emission coefficient of the transition $j \rightarrow i$	$W/(m^3 sr Hz)$	13.1.4, (13.9)
$\eta$	Modulation index	1	11.2.2, (11.7)

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Symbol	Description	Unit	Chapter(s), Figure(s), Formula(s)
$\eta$	Quantum efficiency	1	5.3.1, (5.43)
$F$	Area	m <sup>2</sup>	5.1.3, (5.25)
$f, f_F$	Focal length	m	7.1, Fig. 7.3, 8.2.1, (8.3), 10.1.1, (10.2), 10.2.1, (10.6)
$f$	Frequency	1/s	2.1, (2.4), 5.1.3, (5.50)
$\varphi_0$	Phase angle	rad	2.1 (2.1)
$\phi$	Phase of the object wave	rad	7.1, (7.8)
$\phi_i$	Phase shifts	rad	7.3.3, (7.19)
$\phi_{sp}$	Size of speckles	m	10.2.4, (10.11)
$g$	Object distance	m	8.2.1, (8.3)
$G$	Size of the object	m	8.2.1, (8.4), 10.1.1
$\Gamma(v)$	Line profile as a function of the frequency	1/Hz	13.1.4, (13.9)
$h$	Planck constant	Js	3.1, 13.1.4, (13.9)
$H$	Brightness on the monitor	a.u.	8.3.3, (8.50)
$H$	Radiant exposure	J/m <sup>2</sup>	5.4.1, (5.56)
$\vec{H}$	Magnetic field strength vector	A/m	2.1, (2.1b)
$\vec{H}_0$	Magnetic field strength amplitude	A/m	2.1, (2.1b)
$i_{cg}$	Center of gravity of the counter variable $i$	1	10.2.4, (10.12)
$I$	Intensity, irradiance	W/m <sup>2</sup>	2.1, (2.6), 6.1.1, (6.5b)
$I$	Current	A	5.1.3, (5.29)
$I_j$	Intensity of an element line of an analyte $j$	a.u.	13.1.1
$I_{ph}$	Photovoltaic current	A	5.3.2, (5.50)
$I_r$	Intensity of a reference line	a.u.	13.1.1
$I(r)$	Intensity profile	W/m <sup>2</sup>	10.2.2
$I(x, y)$	Irradiance as function of the coordinates $x, y$	W/m <sup>2</sup>	7, (7.1)
$I'(z')$	Intensity distribution of the imaged light spot in the plane of detection	W/m <sup>2</sup>	10.2.2
$I_k$	Spectral irradiance	W/(m rad)	9.1.1, (9.16a)
$J_0$	Zeroth order Bessel function	1	8.3.4, (8.57)
$J_k$	Line intensity of species $k$	a.u.	13.1.5, (13.13)
$k$	Angular wave number	rad m <sup>-1</sup>	2.1, (2.3)
$\vec{k}_1, \vec{k}_2; \vec{k}, \vec{k}'$	Angular wave vectors of incident and scattered light	rad m <sup>-1</sup>	7.1, (7.16), 8.3.2, (8.26)
$K$	Number of beam quality	1	2.6.3, (2.39)
$K$	Kerr's constant	m/V <sup>2</sup>	3.2.4, (3.10)
$\kappa$	Constant	1	10.2.4, (10.29)
$\kappa$	Thermal diffusivity	m <sup>2</sup> /s	13.1.2
$\vec{l}$	Displacement vector	m	7.1, (7.16)
$L$	Distance between mirrors	m	2.5, (2.34)

(continued)

(continued)

Symbol	Description	Unit	Chapter(s), Figure(s), Formula(s)
$L$	Distance between scattering surface and observation screen	m	2.3, (2.16), 8.1, (8.1)
$L_c$	Coherence length	m	2.4 (2.28), 9.1.1, (9.1)
$\lambda$	Wavelength	m	2.1, (2.3), 8.1, (8.1)
$\Lambda$	Wavelength	m	4.1.1, (4.4)
$m_L$	Slope	1	10.1.1, (10.1), Fig. 10.4
$M_\varphi$	Angle enlargement	1	7.1
$M_z$	Enlargement in the $z$ -direction	1	7.1
$M_z$	Measuring range in $z$ -direction	m	10.2.1, (10.8)
$M$	Ray transfer matrix	N/A	4.2.1, (4.22)
$M$	Number of modes	1	4.3.1, (4.64)
$M^2$	Beam propagation ratio	1	2.6.3, (2.42)
$\mu(\lambda, R)$	Spatial dependent extinction coefficient	$m^{-1}$	13.2.1, (13.15)
$n$	Integer	1	7.1, (7.11)
$n$	Refractive index	1	3.2.2, 7.1, (7.7), 10.2.5, (10.35)
$N$	Resolving power	1	10.2.1, (10.10)
$NA$	Numerical aperture	1	12.1.2, (12.4)
$N_a^z$	Density of species $a$ with charge $z$	$m^{-3}$	13.1.4, (13.9)
$N_{sp}$	Number of speckles per pixel	1	10.2.4
$\nu_{ji}$	Frequency of the transition from $j \rightarrow i$	Hz	13.1.4, (13.9)
$\omega$	Angular frequency of oscillation	$rad\ s^{-1}$	2.1, (2.1), 8.3.4, (8.53)
$p$	Momentum	$kg\ m\ s^{-1}$	3.1, (3.2)
$p$	Pyroelectric coefficient	$C\ m^{-2}\ K^{-1}$	5.1.3, (5.28)
$\bar{P}$	Electrical polarization	$As/(m^2)$	3.5, (3.20a), 13.3.1, (13.32)
$P$	Power	W	5.1, (5.1)
$P$	Radiant flux	W	5.3.2, (5.50)
$q$	Natural number	1	2.5, (2.34)
$q$	Complex beam Parameter	m	4.2.1, (4.18)
$Q$	Charge	C	5.2.1, (5.36)
$Q_i$	Radiant energy received by pixel element $i$	J	10.2.4, (10.12)
$r$	Electro-optical coefficient	$m/V$	3.2.4, (3.11)
$r_m$	Reflection coefficient of the measuring object	1	9.1.1, (9.6)
$R$	Distance between light source and diffracting aperture	m	2.3, (2.16)
$R$	Reflectivity, reflectance	1	3.2.2, (3.6), 4.1.1, (4.2) 13.1.2, (13.4)
$R$	Resistance	$\Omega$	5.1.2, (5.18)

(continued)

(continued)

Symbol	Description	Unit	Chapter(s), Figure(s), Formula(s)
$R_{m,j}$	Reflectivity in the measurement path at location $j$	1	9.1.1, (9.17)
$R_Q$	Thermal resistance	K/(Wm <sup>2</sup> )	5.1, (5.2a)
$r_b$	Beam radius	m	13.1.2, (13.2)
$r_{m,z_m}(z_m)$	Reflection coefficient in the measurement path per unit length	m <sup>-1</sup>	9.1.1, (9.11)
$\rho$	Radius of curvature of the phase surfaces	m	2.6, (2.40)
$\rho$	Density	kg/m <sup>3</sup>	13.1.2, (13.3)
$s(t)$	Local elongation	m	8.3.4, (8.53)
$s_{cg}$	Standard deviation of $i_{cg}$	1	10.2.4, (10.19)
$s_i$	Distance between objective and image plane	m	10.2.4, (10.11)
$s_{opt}$	Optical path length	m	4.1.4, (4.15)
$S$	Spin	Js	3.1, (3.3)
$S_k$	Signal of Fourier-domain OCT depending on the angular wavenumber at constant position of the reference mirror	a.u.	9.1.1, (9.20), 9.1.2
$S_\lambda$	Spectral intensity	W/m	13.1.5, (13.11)
$S(z_r)$	Signal of time-domain OCT as a function of the position of the reference mirror	a.u.	9.1.1, (9.19)
$\tilde{S}(z)$	Inverse Fourier transform of $S_k$	a.u.	9.1.2, (9.25), (9.27)
$\vec{S}$	Poynting vector	W/m <sup>2</sup>	6.1.1
$\sigma_i(\lambda)$	Absorption cross-section of the gas $i$ at the wavelength $\lambda$	m <sup>2</sup>	13.2.1, (13.28)
$\Sigma$	Sensitivity	K/W	5.1, (5.7)
$t$	Complex amplitude transmission	1	(7.7)
$t$	Time	s	
$T$	Transmittance	1	3.3.2, (3.15)
$T$	Integration time of the video camera	s	8.3.4, (8.56)
$T$	Temperature	K	5.1, (5.1), 13.1.2, (13.3)
$T_0$	Transmittance at low intensities	1	3.3.2, (3.15)
$T_b$	Beat period	s	2.2, (2.13), 11.2.1, (11.12)
$T_c$	Coherence time	s	2.4.1, (2.28), 9.1.1, (9.2a)
$\tau$	Exposure time	s	5.4.1, (5.56), 7, (7.2)
$\tau_D$	Time constant of the detector	s	13.2.1, (13.21)
$\tau_L$	Duration of the laser pulse	s	13.2.1, (13.21)
$\theta_0$	Opening angle of Gaussian beam	rad	2.6.1, (2.39)
$\theta_B$	Brewster angle	rad	3.2.2, (3.7)
$\theta_t$	Critical angle of total reflection	rad	3.2.2, (3.8)

(continued)

(continued)

Symbol	Description	Unit	Chapter(s), Figure(s), Formula(s)
$u, v$	Coordinates	m	10.1.1, (10.1)
$u_a^z(T)$	Partition function of species $a$ with charge $z$	1	(13.1.4), (13.9)
$U$	Voltage of video signal	V	8.3.3, (8.48)
$U_{\lambda/2}$	Half-wave voltage	V	4.1.3, (4.10)
$v_R$	Velocity of the reference mirror	m/s	9.1.1, (9.1)
$v_{th}$	Average thermal speed of the atoms and ions in the plasma	m/s	13.1.4, (13.10)
$\vec{v}$	Velocity vector	m/s	11.1, (11.5)
$V$	Verdets's constant	rad/A	4.1.2, (4.7)
$w, w_0$	Waist radius of laser beam	m	2.6.1, (2.37a), 4.2.1, (4.19), 10.2.1
$W$	Photon energy	J	3.1, (3.1)
$W_W$	Work function	J	5.1.3, (5.33)
$z_m$	Position of measuring object	M	9.1.1, (9.6)
$z_r$	Position of reference mirror	m	9.1.1, (9.5)

(continued)

# Index

## A

Abbe, 268  
Aberration, spherical, 259  
ABCD Law, 80  
Absorbance, 99  
Absorbed laser intensity, 330  
Absorptance, 328  
Absorption, 51  
Absorption coefficient, 171  
Absorption cross-section, 348  
Absorption, non-linear, 53  
Absorption spectroscopy, 376  
Acoustic vibrations, 290  
Acousto-optic modulator, 67, 76, 283  
Aerosol particles, 353  
Aging effect, 113  
Airy disk, 16, 197  
Alkali metals in the atmosphere, 354  
Aluminum scrap metal, 338  
Amplitude, 5  
Amplitude hologram, 171  
Angle measurements, 156  
Angle of acceptance, 91  
Angle of deflection, 268  
Anthracene, 374  
Antibodies, 378  
Anti-Stokes frequency, 58  
Anti-Stokes wave, 357  
A-, B- and C- scans, 222  
Astigmatism, 259  
Atmosphere research, 352  
Atmospheric influences, 268  
Atmospheric optical quantities, 346  
Autocorrelation, 379  
Autocorrelation function, 299  
Autocorrelation term, 233  
Avalanche photodiode, 124  
Averaging, spatial, 215

## B

Babinet's phase shifter, 78  
Background radiation, 334  
Bandwidth, 235, 285  
Basicity of liquid slag, 340  
Beam deflection, 269  
Beam expansion, 87  
Beam quality number, 32  
Beam radius, 28  
Beam scanner, 310  
Beam splitter, 66  
Beam waist, 28  
Bearings, 290  
Beat frequency, angular, 284  
Beat period, 11, 283  
Beat signals, 153  
Bessel function, 217  
Birefringence, 49  
Blood vessels, 243  
Blu-ray disc, 315  
Bolometer, 106  
Boltzmann constant, 102  
BOXCARS, 361  
Bragg cell, 68  
Brewster angle, 45  
Brightness, 215  
Broadband CARS, 363  
Broadband Stokes source, 360  
Brownian motion, 379  
Built-in voltage, 121

## C

Calibration, 220  
Calibration curve, 324  
Calibration measurements, 335  
Car body, 292  
Car door handle, 220

- Carrier angular frequency, 288
  - Cat's eye, 66
  - CCD image sensor, 135
  - CCD line array, 251, 260
  - Center of gravity determination, 257
  - Center of gravity of the light spot, 264
  - Channel electron multiplier, 117
  - Characteristic curve of a triangulation sensor, 251
  - Chopper, 74
  - Circular aperture, 16
  - Circularly polarized light, 12, 70
  - Classification of pattern features, 275
  - Cloud formations, 353
  - CMOS image sensor, 137
  - CMOS-line arrays, 260
  - CO<sub>2</sub> laser, 365
  - Coaxial cable, 138
  - Coherence, 18
  - Coherence area, 21
  - Coherence function, 235
  - Coherence length, 155, 214, 228
  - Coherence length, longitudinal, 21
  - Coherence length, transverse, 22
  - Coherence, spatial, 23
  - Coherence time, 21
  - Coherent anti-Stokes Raman spectroscopy, 355
  - Coherent molecular vibrations, 358
  - Collision of second kind, 52
  - Coma, 259
  - Combustion chamber, 301, 387
  - Combustion processes, 363
  - Compact disc, 314
  - Complex beam parameters, 81
  - Complex notation, 146
  - Complex spectral field strengths, 231
  - Component vibrations, 290
  - Computer hard drives, 290
  - Concentration, 323
  - Confocal, 306
  - Confocal laser scanning microscope, 305
  - Confocal microscopy, 305
  - Conjugate object wave, 167, 183
  - Conservation laws for energy and momentum in the photon model, 357
  - Conservation of frequency, 58
  - Continuously casted steel bar, 301
  - Continuous spectrum, 333
  - Continuous wave mode, 186
  - Contour, 248
  - Contour measurement, 270
  - Contrast of the interference, 282
  - Coordinate-measuring machine, 275
  - Core, 90
  - Correlation, 210
  - Correlation fringes, 207, 211, 218
  - Counter, 296
  - Cross correlation term, 233
  - Cross-section of rails, 277
  - Current-voltage conversion, 140
  - Cutoff frequencies, 102, 296
  - Cutoff wavelength, 111
- D**
- Dark current, 121
  - Dashboards, 218
  - Debondings, material delaminations, cracks, impacts, indents, material inclusions, 223
  - Defect types, 275
  - Demodulator, 286
  - Depth concentration profiles, 340
  - Depth of modulation, 294
  - Depth resolution, 342
  - Derivation of object displacements, 211
  - Detection of organic molecules, 376
  - Detection sensitivities, 336
  - Detector aperture, 351
  - Diagnostics of coronary atherosclerosis, 241
  - Differential, 293
  - Differential absorption LIDAR, 348
  - Diffraction, 13
  - Diffraction angle, 15, 23
  - Diffraction efficiencies, 172
  - Diffraction order, 182, 202
  - Diffuse reflection, 49
  - Digital holography, 182
  - Digital holographic interferometry, 185
  - Digital signal processors, 287
  - Digital versatile disc, 314
  - Dirac function, 231
  - Direction of polarization, 12
  - Dispersion, 60
  - Dispersion relation, 6
  - Displacement field, 216, 218
  - Displacement gradients, 204, 211
  - Displacement vector, 176, 207, 210
  - Doppler effect, 60, 153, 279
  - Doppler LIDAR, 355
  - Doppler shift, 281
  - Double slit, 16
  - Double-exposure method, 173, 186
  - Double-exposure recording, 180
  - Dual-frequency interferometer, 152
  - Dynamic range, 350
  - Dynodes, 116

**E**

E-CARS, 368  
 Electric field strength, 5  
 Electric polarization, 108  
 Electrical gas discharges, 363  
 Electrical polarization, 355  
 Electrical susceptibility, 58, 355  
 Electron densities, 331  
 Electronic speckle interferometry, 213  
 Electron multiplier, 115  
 Electro-optic shutter, 333  
 Element, 323  
 Elementary bundle, 20  
 Elementary charge, 113  
 Elliptically polarized light, 12  
 Emission spectrum, 324  
 Emission, spontaneous, 25  
 Emission, stimulated, 25  
 Energy balance, 331  
 Enlargement, 170  
 Environmental protection, 352  
 ESPI, 213  
 Extinction coefficient, 344  
 Extraordinary beam, 49  
 Eye, 241

**F**

Faraday effect, 71  
 Faraday rotator, 71  
 Far-field divergence, 28  
 Fatigue effect, 113  
 F-CARS, 367  
 FET amplifiers, 140  
 Fiber-based Fourier-domain OCT, 239  
 Fiber lasers, 343  
 Fiber stretchers, 239  
 Field strength, electrical, 5  
 Field strength, magnetic, 5  
 Filtering, spatial, 24  
 Filtering, temporal, 22  
 First spatial momentum of the intensity distribution, 261  
 Flatness of rolled heavy plates, 273  
 Flatness topologies, 275  
 Flow-cytometry, 378  
 Flow fields, spatial, 301  
 Fluorescence confocal laser scanning microscopy, 306  
 Fluorescence correlation spectroscopy, 379  
 Fluorescence emission spectrum, 376  
 Fluorescence excitation, 373  
 Fluorescence excitation spectrum, 376  
 Fluorescence LIDAR, 353

Fluorescence life time, 380, 382  
 Fluorescence marker, 378  
 Fluorescence microscopy, 387  
 Fluorescence polarization spectroscopy, 380  
 Fluorescence spectroscopy, 376  
 FM-discriminator, 287  
 Foam parts, 218  
 Folded-BOXCARS, 362  
 Fourier-domain OCT, 233, 235  
 Fourier transformation, inverse, 235  
 Franck-Condon factors, 374  
 Fraunhofer diffraction, 13  
 Frequency, angular, 284  
 Frequency doubling, 58  
 Frequency-modulated detector signal, 284  
 Frequency shift, 279  
 Fresnel's formulas, 45  
 Fresnel-Kirchhoff integral, 184  
 Fresnel zone plate, 168  
 Fringe spacing, 209  
 Fuel distribution, 386

**G**

Gabor, 165  
 Galvo-scanner, 291  
 Gas discharges, electrical, 363  
 Gaussian beam, 27, 253  
 Gaussian function, 265  
 Generation-recombination noise, 119  
 Glan-Taylor prism, 72  
 Glaucoma, 241  
 Gradient fibers, 89  
 Graphite furnace, 364  
 Grating, 18  
 Grating constant, 18

**H**

Half-wave plate, 74  
 Handheld measuring probe, 343  
 Heat conduction equation, 328  
 Heat penetration depth, 327  
 Hertzian dipole, 46, 56  
 High-alloy pipe fittings, 336  
 High-alloy steel grades, 336  
 Hologram, 166, 182  
 Holographic interferometry, 165, 172  
 Holographic recording, 166  
 Hot sheet metal, 275  
 Human eye, 35  
 Human cornea, 241  
 Huygens-Fresnel principle, 13  
 Hydraulic bulging, 383



**I**

I and Q signals, 289  
 Identification testing, 336  
 IEC standard, 337  
 Illumination aperture, 197  
 Image converter, 132  
 Image shear, 213  
 Imaged light spot, 257  
 Imaging aberrations, 259  
 Imaging equation, 198  
 Imaging speckle pattern photography, 198  
 Impedance conversion, 140  
 In vitro diagnostics, 387  
 Inclination factor, 13  
 Inclusions, 218, 341  
 Inline analysis, 338  
 Inline control, 336  
 In-plane, 209  
 Inspection equipment monitoring, 337  
 Inspection of tires, 223  
 Intensity, 8  
 Intensity of the CARS signal, 359  
 Interference fringes, 200  
 Interference fringe spacing, 200  
 Interference term, 233  
 Interferometry, 145  
 Intermediate frequency carrier, 289  
 Intermittence effect, 127  
 Irradiance, 7, 147

**J**

Jablonski term scheme, 374

**K**

Kasha's rule, 374  
 KDP, 79  
 Kepler's telescope, 87  
 Kerr cell, 75  
 Kerr effect, 50

**L**

Labeled antigen, 381  
 Lacquer industry, 300  
 Lambert-Beer law, 344  
 Lambert's cosine law, 48  
 Lambert's emission law, 258  
 Lambert's law of absorption, 51  
 Laser classification, 39  
 Laser Doppler anemometer (LDA), 292  
 Laser Doppler anemometry, 279  
 Laser Doppler methods, 279

Laser-induced plasma, 324  
 Laser-induced breakdown spectroscopy (LIBS), 324  
 Laser interferometry, 145  
 Laser light section, 270  
 Laser light section technique, 247  
 Laser material analysis, 324  
 Laser measurement technology, 2  
 Laser mirror, 218  
 Laser protection, 34  
 Laser radiant flux, 219  
 Laser sorting system, 338  
 Laser-specific risks, 35  
 Laser spectroscopy, 323  
 Laser triangulation, 247  
 Laser vibrometer, 188, 281  
 Laser vibrometry, 279  
 Latent image, 125  
 Lateral effect diode, 137, 260  
 LIDAR equation, 345  
 Lifetime of the plasma, 332  
 Light detection and ranging, 343  
 Light scattering, 55  
 Light spot, 251  
 Limits of detection, 376  
 Linear absorption coefficient, 51  
 Linearity error, 243  
 Linearly polarized wave, 12  
 Line emission coefficient, 332  
 Liquid slag, 338  
 Local strain determination, 383  
 Longitudinal, 20  
 Loudspeaker, 189  
 Lower limit of the measuring uncertainty for laser triangulation sensors, 267  
 Low pressure discharge, 365  
 Luminous exposure, 126

**M**

Machine tools, 290  
 Magnetic tapes, 291  
 Magnification, 198  
 Maiman  
   Theodore, 2  
 Mass ablation, 331  
 Master oscillator, 287  
 Matching resistor, 138  
 Material composition, 323  
 Material dispersion, 95  
 Measurement frequencies, 261  
 Measurement rate, 336  
 Measuring range of laser vibrometers, 290  
 Measuring range of triangulation sensor, 254

Measuring resistor, 135  
 Measuring uncertainty, 266  
 Medical imaging technique, 227  
 Membrane of a loudspeaker, 291  
 Metal and dielectric mirrors, 63  
 Metallic coatings, 342  
 Michelson, A. A., 148  
 Michelson interferometer, 21, 205  
 Micro beads, 389  
 Microchannel plates, 133  
 Microtiter plates, 388  
 Microtopology of weld seams, 278  
 Mie scattering, 56, 296  
 Mirrors, 63  
 Mixing stage, 286  
 Mobile laser material analyzing systems, 343  
 Mode dispersion, 95  
 Modulation index, 285  
 Molecular partial density, 361  
 MOS capacitors, 134  
 MOSFET readout, 135  
 Multi-layer PET preform, 243  
 Multi-mode fiber, 93  
 Multi-photon process, 359  
 Multiple scattering, 260  
 Multi point scanners, 310  
 Mycotoxins, 388

## N

N<sub>2</sub> distributions, 353  
 Net line intensity, 334  
 Nitrogen gas, 359  
 Non-destructive testing, 165  
 Non-linear absorption, 53  
 Non-linear polarization, 357  
 N<sub>2</sub> temperature, 367  
 Number  $M$  of modes, 93  
 Number of particles, 335  
 Numerical aperture, 91, 267, 306  
 Numerical reconstruction, 185

## O

Object displacements in the object surface, 209  
 Object displacements perpendicular to the object surface, 207  
 Objective scanners, 310  
 Object rotation, 176  
 Object scanners, 310  
 Object translation, 176  
 Object wave, 167

OCT, 227  
 OCT sensors, 237  
 Operational amplifiers, 140  
 Ophthalmology, 241  
 Optical amplifier, 25  
 Optical axis, 49  
 Optical coherence tomography, 227  
 Optical density, 126  
 Optical disc scanning systems, 314  
 Optical-feedback amplifier, 25  
 Optical fibers, 89, 95  
 Optical measurement methods, 1  
 Optical parametric oscillator, 360  
 Optical penetration depth, 327  
 Optical pick-up systems, 317  
 Optical resonator, 25  
 Optical scanning system, 316  
 Optical signal compression, 351  
 Ordinary ray, 49  
 Organic material, 227  
 Organic pollution in sea water, 354  
 Organic tissue, 227  
 Ortho chromatic, 127  
 Oscillating engine bonnet, 190  
 Oscillating object, 188  
 Oscillation, harmonic, 285, 289  
 Oscillator, local, 286  
 Ozone distribution, 353  
 Ozone in the stratosphere, 352

## P

Pan chromatic films, 127  
 Parallel fluorescence sensors, 389  
 Particle concept, 42  
 Pentaprism, 65  
 Phase angle, 8  
 Phase change, 210  
 Phase difference, 204, 206  
 Phase grating, 67  
 Phase hologram, 171  
 Phase information, 166  
 Phase-modulating material, 129  
 Phase shifter, 77  
 Phase-shifting method, 180  
 Phase velocity, 6, 42  
 Phosphorescence, 373  
 Phosphor screen, 132  
 Photocathode, 115  
 Photocurrent, 121  
 Photodiode, 119  
 Photodiode arrays, 135  
 Photoelectric cell, 112

Photoelectric detectors, 111  
 Photoelectric effect, 111  
 Photo fragments, 378  
 Photographic films, 125  
 Photographic plate, 182  
 Photomultiplier, 115  
 Photon correlation, 299  
 Photon-correlator, 296  
 Photons, 41  
 Photoresistor, 118  
 Photovoltaic element, 121  
 Piezoelectric transducers, 239  
 PIN photodiode, 124  
 Pixels, 134  
 Planar laser-induced fluorescence, 386  
 Planck's constant, 42  
 Plane hologram, 170  
 Plasma phenomena, 189  
 Plastics, 330  
 P-n junction, 121  
 Pockels cell, 79, 187  
 Pockels effect, 51  
 Poisson distribution, 262  
 Polarization, 58  
 Polarization degree, 381  
 Polarization, electrical, 106, 344  
 Polarization interferometer, 149  
 Polarization, non-linear, 357  
 Polarization-sensitive beam splitters, 67  
 Polygon mirror, 271  
 Polyurethane foam, 220  
 Population numbers, 359  
 Position-sensitive detector, 248  
 Preamplifier, 140  
 Pre-exposure, 128  
 Principle of superposition, 8  
 Principal plane, 49  
 Production flaws, 218  
 Profile, 273  
 Profilometer, 313  
 Protein-protein interactions, 379  
 Pseudoscopic distortion, 184  
 Pure rotation, 178, 179  
 Pure translation, 178  
 Pyroelectric coefficient, 108  
 Pyroelectric detectors, 108

## Q

Quadrature signals, 287  
 Quantum efficiency, 112  
 Quarter-wave plate, 69

## R

Radial error, 317  
 Radiant energy, 186, 263  
 Radiation transport equation, 332  
 Radicals, 378  
 Radius of cladding, 90  
 Raman scattering, 57  
 Rayleigh length, 28, 253  
 Rayleigh scattering, 56, 295  
 Ray transfer matrix, 81  
 Real image, 167  
 Real-time method, 174  
 Reconstruction of the hologram, 166  
 Reconstruction wavelength, 169  
 Recycling, 338  
 Reference samples, 324  
 Reference wave, 167  
 Reflectance, 45, 64  
 Reflection, 44  
 Reflection coefficient per unit length, 231  
 Reflection hologram, 172  
 Refractive index, 43  
 Refractive index ellipsoid, 50  
 Refractive index gradient, 268  
 Refractometer, 155  
 Regions of interest, 262  
 Relative measurement, 349  
 Residues of organic substances, 385  
 Resolution, 128, 307  
 Resolution in the z-direction, 255  
 Resolution, lateral, 185, 307, 335  
 Resolvable object displacement, 200  
 Resolving power, 102  
 Retina, 35  
 Retinal tissue, 241  
 Retroreflectors, 66, 148  
 Reverse current, 121  
 Rise time, 101, 117, 123  
 Rolled sheet metal, 258  
 Rolling mill, 275  
 Rotational CARS, 361  
 Rotational levels, 361  
 Rotation diffusion time, 380  
 Roughness, 196  
 Ruby laser, 186

## S

Saturation current, 113  
 Scanners, 310  
 Scanning CARS, 363  
 Scanning microanalysis, 340

- Scanning sensor, 270
  - Scan rate, 243
  - Scattering characteristics, 258
  - Scattering coefficient, 345
  - Scattering of light, 41
  - Scattering particle types, 300
  - Scheimpflug condition, 249
  - Schottky diodes, 125
  - Schwarzschild effect, 127
  - Secondary emission, 115
  - Seebeck coefficient, 104
  - Semiconductor detectors, 118
  - Semiconductor laser, 32
  - Sensitivity, 104, 110, 113, 120, 127, 139, 167, 252
  - Sensitivity vector, 175
  - Shape, 249
  - Shearing interferometry, 211
  - Shearing speckle interferometer, 223
  - Shearography, 211
  - Signal evaluation, 262
  - Single-beam system, 316
  - Single cell, 389
  - Single point scanners, 302
  - Single slit, 14
  - Singlet states, 373
  - Sinusoidal transmission, 168
  - Slit scanners, 310
  - Solid coherence angle, 24
  - Solid-state image sensors, 134
  - Sorting fractions, 338
  - Space-resolving detectors, 125
  - Spatial averaging, 215
  - Spatial coherence, 20, 23
  - Spatial filtering, 21
  - Spatial flow fields, 301
  - Speckle effect, 195
  - Speckle interferometer, 207
  - Speckle interferometry, 204
  - Speckle metrology, 195
  - Speckle noise, 263
  - Speckle pattern photography, 198
  - Speckles, 262
  - Speckle size, 263
  - Spectral amplitude, 231
  - Spectral intensity, 334
  - Spectral line intensity, 324
  - Spectrometer, 326
  - Spectroscopy, time-resolved, 332
  - Spectrum of angular wave numbers, 231
  - Step-index fiber, 89, 93
  - Stokes, 357
  - Stokes frequency, 57
  - Straightness measurements, 158
  - Straightness of rails, 273
  - Stress, 218
  - SO<sub>2</sub>, 353
  - Superluminescent diode, 239
  - Superposition, 146, 197
  - Superposition, incoherent, 228
  - Surface absorption, 328
  - Susceptibility, electrical, 58, 355
  - Susceptibility tensor, 356
- T**
- Telescope, 350
  - TEM<sub>00</sub>-mode, 31
  - TEM<sub>u,v</sub>-modes, 31
  - Temperature measurements with CARS, 364
  - Temperature scale, 363
  - Temporal, 20
  - Thermal detectors, 99
  - Thermal diffusivity, 328
  - Thermal noise, 103
  - Thermal resistance, 100
  - Thermocouple, 104
  - Thermoelectric effect, 104
  - Thermoelectric voltage, 104
  - Thermopiles, 104
  - Thermoplastic photographic plates, 129
  - Thickness of rolled sheet metal, 273
  - Thicknesses of multi-layer polymer films, 243
  - Three-dimensional displacement vector, 191
  - Three-dimensional oscillation elongation, 291
  - Three-dimensional point-spread function, 307
  - Time-averaged spectral intensity, 232
  - Time-averaged vibration electronic speckle interferometry, 216, 225
  - Time correlated single photon counting, 382
  - Time-domain OCT, 229, 233
  - Time-resolved fluorescence analytics, 382
  - Titanium dioxide particles, 301
  - Total reflection, 93
  - Tracker, 296
  - Translation parallel and perpendicular to the object surface, 179
  - Transmission hologram, 172
  - Transmittance, 53, 126
  - Triangulation resolving power, 255
  - Triple-beam system, 318
  - Tumor, 388
  - Tuneable lasers, 349
  - Turbine housing, 192

Two-beam interference, 293  
Two-photon absorption, 54  
Twyman-Green interferometer, 160

## U

Uncertainty in the determination  
of the position of the light  
spot, 255  
Undistorted real image, 184  
Unfocused speckle pattern photography, 203

## V

Vacuum chamber, 223  
 $\gamma$ -value, 128  
Vaporization, 327  
Vaporized material, 331  
Vapor densities, 331  
Velocity of an object point, 279  
Verdet's constant, 72  
Vibrational CARS, 361  
Vibrational frequencies, 378  
Vibrational levels, 361  
Vibration of a membrane, 225  
Vibrations of component parts, 281  
Vibronic levels, 361  
Video signal, 214  
Virtual hologram, 183  
Virtual image, 167, 182  
Virtual intermediate level, 54  
Virtual lens, 183

Visibility, 353  
Void, 220  
Voltage controlled oscillator, 296  
Volume absorption, 330  
Volume hologram, 170  
Volumetric flows, 300

## W

Waist diameter, 253  
Waist radius, 28  
Wave concept, 42  
Wave equation, 26  
Wave impedance of the vacuum, 147, 138, 167  
Wave number, angular, 5  
Wedge plate, 186  
Wheatstone bridge, 107  
Whole-body translations, 211  
Wind tunnel, 301  
Wollaston prism, 78, 158

## Y

Young interference fringes, 199

## Z

Zeeman effect, 152  
Zeroth order, 202  
Zinc layers, 342  
Zirconium tetra fluoride, 301