19.8 Velocity Measurement

It is well known that when a light beam gets scattered by a moving object, the frequency of the scattered wave is different from that of the incident wave; the shift in the frequency depends on the velocity of the object. Indeed, if ν represents the light frequency and υ represents the velocity of the moving object which is moving at an angle θ with respect to the incident light beam (see Fig. 19.32), then the change in frequency $\Delta\nu$ between the incident and the reflected beams is given as

$$\frac{\Delta\nu}{\nu} = \frac{2\upsilon}{c}\cos\theta \tag{19.20}$$

where c represents the velocity of light in free space. Thus the change in frequency $\Delta\nu$ is directly proportional to the velocity υ of the moving object; this is known as the Doppler shift. Thus, by measuring the change in frequency suffered by a beam when scattered by a moving object, one can determine the velocity of the object. This method has been successfully used for velocity determination of many types of materials from about 10 mm/min to about 150 m/min (Harry 1974). Further, using the above principle, portable velocity-measuring meters have been fabricated which measure speeds in the range of 10–80 miles/h; these have been used by traffic police. Laser Doppler velocimeters have also been used for measuring fluid flow rates.

The basic arrangement for velocity measurements is the following: the beam from a CW laser (usually a helium–neon laser – see Section 9.4) is split by a beam splitter; one of the components is reflected back from a fixed mirror and the other component undergoes scattering from the moving object. The two beams are then combined and made to interfere as shown in Fig. 19.32, and because of the difference in frequency between the two beams, beating occurs. The beat frequency is a direct measure of the velocity of motion of the object.

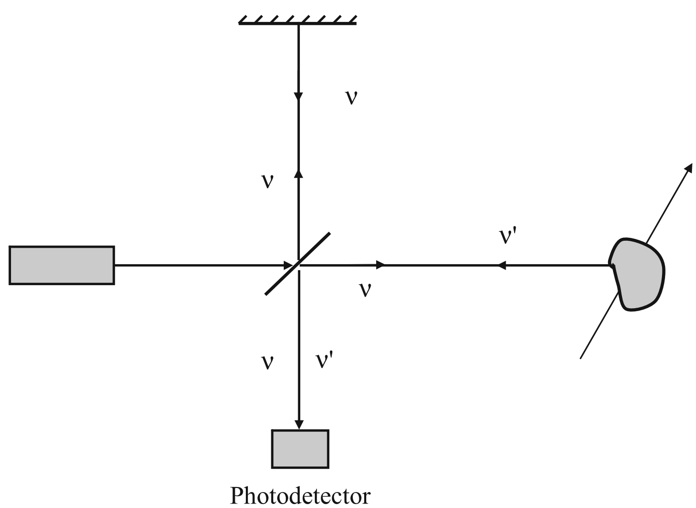

Fig. 19.32 Schematic of an arrangement for measuring the velocity of a moving object using Doppler shift

19.8.1 Lasers in Information Storage

Lasers find widespread applications in the storage, transmission, and processing of information. As we have discussed earlier, combined with optical fibers, they have revolutionized the field of transmission of information. An extremely important application of lasers is in the field of information storage. We are all familiar with compact discs (CDs) storing data, music, pictures, videos, etc. With progress in lasers and materials, the capacity of information storage has been steadily rising and today CDs are used to routinely store gigabytes of information.

Compact discs store information in digital form. Any form of information is first converted into digital form with just a sequence of 1s and 0s. In a CD these 1s and 0s are recorded in the form of pits or depressions along a spiral track on a plastic material with a metal coating (see Fig. 19.33). The total length of the track would be about 6 km! The usual coding is such that any transition from pit to land (flat area) or land to pit is read as 1s, while the duration in the pit or in the land is read as 0s (see Fig. 19.34). In CDs the radial distance between adjacent tracks, which is the track pitch, is 1.6 μm, while the length of data marks is about 0.6 μm. In order to write on the CD, the data stream is used to generate pulses of light corresponding

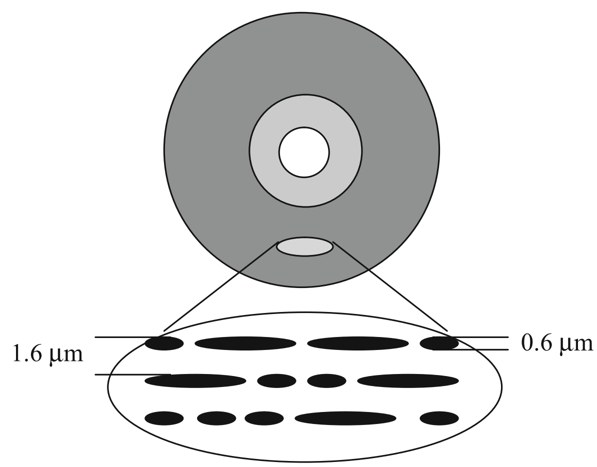

Fig. 19.33 In a compact disc (CD), information is stored in the form of pits along a spiral track

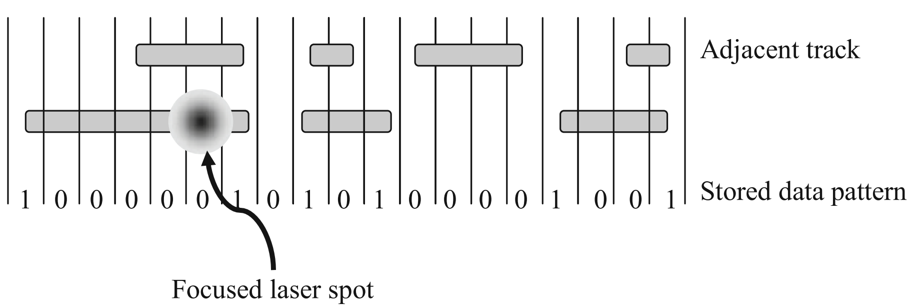

Fig. 19.34 In a CD, transition from land to pit or pit to land is read as "1s," while the duration within the pit or the land is read as "0s"

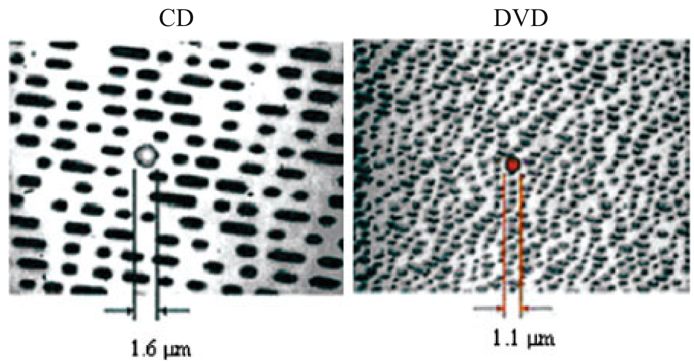

Fig. 19.35 Comparison between the pit sizes in a CD and a DVD

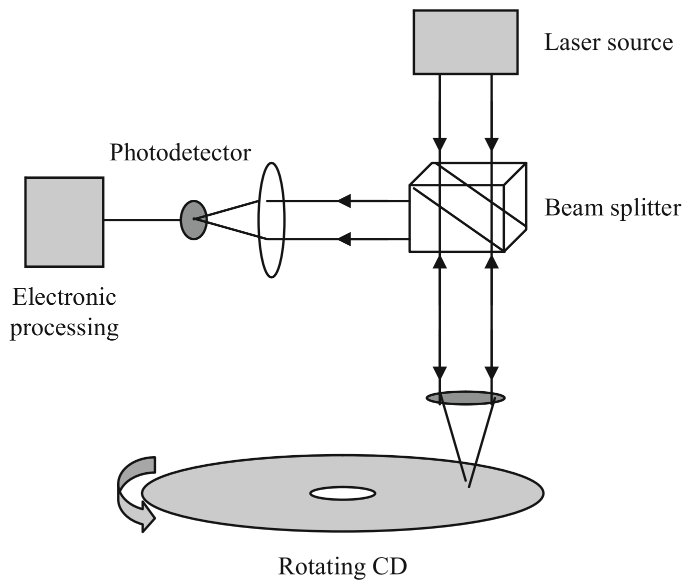

Fig. 19.36 A laser beam is focused on the CD and the reflected intensity is read and converted into the signal

to the data stream. The laser which emits an intense beam of light is focused on the surface of the CD using an objective. As the CD rotates under the laser spot, a small region heats up whenever the laser beam hits and changes the reflectivity of the surface. Digital video discs (DVDs) use the same principle except that the track pitch is about 0.74 μm instead of 1.6 μm and the data marks are narrower and the focused laser spot is also smaller (see Fig. 19.35). The data are written on the CD along a spiral track on the surface. To read the information stored in the CD, a laser beam is focused through a beam splitter on the disc and the spot size of the focused laser is about the track width (see Fig. 19.36). As the CD moves under the focused laser spot, it leads to a modulation of the reflected intensity, which is then directed by the beam splitter to a photodetector which converts the intensity variations to electric current variations for further processing.

It is clear that the smaller the data points and the smaller the track pitch, the larger the amount of data that can be stored per unit area in the disc and hence the larger the capacity of the disc. For writing and reading of the data, we use lasers and the minimum spot to which the laser can be focused will determine the size

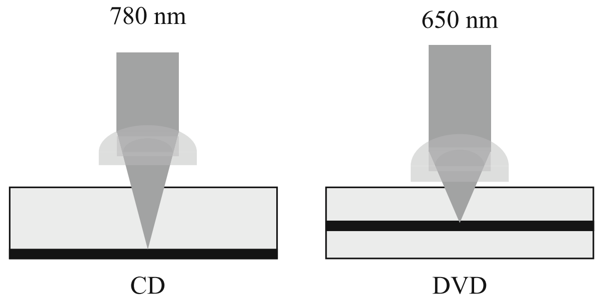

Fig. 19.37 Reading of a CD at a wavelength of 780 nm and a DVD at a wavelength of 650 nm

Table 19.3 Comparison of various parameters of CD, DVD, and Blue Ray DVD

Parameter	CD	DVD	Blue Ray DVD
Laser wavelength (μm)	0.78	0.65	0.405
Track to track spacing (μm)	1.6	0.74	0.32
Spot size of focused spot (μm)	1.6	1.1	0.48
User capacity (Gb)	0.68	9	50

Source: Milster (2005)

of the data points so that the readout can be precise. The fundamental limitation to the size of the focused spot of a laser beam arises due to diffraction. Smaller spot sizes can be achieved using smaller wavelengths and smaller focal length lenses. Since the CD is covered by a protective layer, the focusing needs to be carried out through the protective layer and this determines the smallest focal length that can be used. A CD uses a 1.2-mm clear substrate and data are recorded on the recordable layer through the clear substrate. The substrate also acts as a protective layer for the data. The reading wavelength is typically 780 nm. In contrast, in a DVD, two clear substrates each of 0.6 mm thick are bonded together and data are recorded on the bond side of each substrate. The reading wavelength in DVDs is typically 650 nm (see Fig. 19.37). Thus DVDs can store much more data than do CDs. Recent developments of blue lasers emitting a wavelength of 405 nm have triggered development of DVDs with much higher capacities since they operate with smaller wavelength and hence can be focused to smaller spot sizes. Table 19.3 lists a comparison of CDs, DVDs, and Blue Ray DVDs with regard to some important characteristics.

Further increases in data storage capacity are possible with new technologies such as holographic discs. In holographic storage, information is stored within the entire volume of the recording medium rather than on a surface. Thus holographic storage offers orders of magnitude increase of storage capacity. It is in principle possible to store 1 Tb of information per cubic centimeter of the medium using a wavelength of 500 nm. In holographic data storage, the required data are transferred to and from the storage medium as two-dimensional images composed of thousands of pixels (picture elements). The data which need to be stored are first presented to the recording system as pixels on a device called the spatial light modulator

(SLM). This is a planar device which encodes the data into small checkerboard pattern of light and dark pixels with the data arranged as an array on the page; each pixel is a small shutter which can either stop (corresponding to bit 0) or pass (corresponding to bit 1) a light beam. Commercial devices containing 1000×1000 pixels are available. Light from a laser is split into two parts and one part is used as a reference beam, while the other part illuminates the SLM. Interference occurring between the two beams is recorded in the storage medium as the data pattern. Multiple pages are recorded by recording the holograms with reference waves incident along different directions. Readout is performed by using a laser beam at the appropriate angle when the entire page is read out as a single bit. The reconstructed beam is detected by a detector array and converted into electronic data. By changing the angle of the beam, one can read one entire page at a time. Thus apart from the ability to store large amounts of data, holographic data storage also promises extremely fast readouts of about 1 Gb/s as compared to DVDs, wherein the readouts are about hundred-fold smaller. There is intense research activity to realize efficient recordable media and holographic data storage devices are expected to become commercially available within the next few years.

19.8.2 Bar Code Scanner

The technology associated with identification of all types of products using bar codes is one of the very important developments of the past century. The Universal Product Code (UPC) was introduced in the USA in 1973 and the European Article Numbering (EAN) system was developed in Europe in 1978 and is presently the most widely used bar code scheme used in the world. A special form of the EAN code is the International Standard Book Numbering (ISBN) system and is used for identification of books. A bar code consists of a series of strips of dark and white bands (see Fig. 19.38). Each strip has a width of about 0.3 mm and the total width of the bar code is about 3 cm. Information such as the country of origin, manufacturer of the product, the direction of scan, price, reading error checking, weight of the product, and expiry date can be stored in the pattern of dark and white strips. By a simple scanning, complete information regarding the product can be obtained.

Fig. 19.38 A bar code consisting of series of strips of dark and white bands

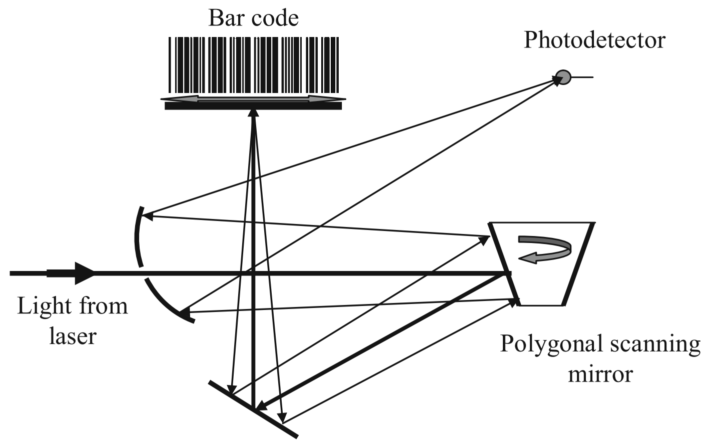

Fig. 19.39 A laser beam is scanned across the bar code and the scattered light is focused on a detector which converts the code into information

The primary purpose of the laser in this application is the optical reading of the bar code. In the bar code scanner, a low-power (~ 0.5 mW) laser beam is deflected by a rotating polygon mirror to scan along a line (see Fig. 19.39). Typical scanning speeds are about 200 m/s. Such high speeds are chosen to ensure that even if the product is moving while it is getting scanned, the scanned object does not move significantly while getting scanned. When the laser beam hits the bars, the amount of scattered light depends on whether the strip is black or white. As the laser beam scans across the black and white strips at a certain speed, the variation of scattering with time contains the information of the bar code. The scattered light is focused on a photodetector which converts the optical signal to an electrical signal for further processing. In order to be able to scan the product in any arbitrary direction for ease of scanning, the laser beam is made to scan in multiple directions by using multiple mirrors with the rotating polygon.

Problems

Problem 19.1 Consider a retroreflector shown in Fig. 19.13. Assuming the rays to be described by vectors, show that the three mirror system reflects any incident wave in exactly the reverse direction.

Problem 19.2 In the Michelson interferometer shown in Fig. 19.20, by what distance would one have to move the mirror for the output on the photodetector to change from one interference maximum to the next one?

Problem 19.3 Calculate the change in frequency of an incident light at 633 nm when it gets scattered by an object moving at the speed of 100 km/h away from it.

Problem 19.4 In the interferometer shown in Fig. 19.20, if the polarization state of the light returning from the object is different from the one reflected by the fixed mirror, what would happen to the signal at the photodetector?