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(19)

(54) INFORMATION RECORD AND READING APPARATUS THEREFOR

(71) We PHILIPS ELECTRONIC AND ASSOCIATED INDUSTRIES LIMITED, of Abacus House, 33 Gutter Lane, London, E.C.2., a British Company, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to apparatus for reading records provided with parallel tracks in which signals are recorded in optically readable form. (The term "parallel tracks" is to be understood to mean a number of tracks constituting the successive turns of a spiral or a number of separate circular concentric tracks). The signals may represent video and/or audio information, and the apparatus comprises a source of radiation and a radiation-sensitive detection system for converting a read beam emitted by the radiation source and modulated by an optical (i.e. optically readable) structure in the record into an electric signal. It has already been proposed to build up the optical structure containing the information in a track as a succession of marks of differing lengths separated by spaces. The marks and spaces may be recorded in the form of a phase structure i.e. a structure such that the phase of a wavefront of the read beam incident on a mark is changed with respect to the phase of another part of the same wavefront incident on a space. Alternatively, the marks and spaces may form an amplitude structure i.e. one wherein a mark produces a change of wavefront amplitude with respect to the amplitude produced by a space.

The marks and spaces will hereinafter be referred to as blocks and areas respectively and reference may be made to various prior Specifications describing such records and optical reading apparatus therefor. Notable examples are Patent Specifications No. 1,391,541, No: 1,391,335, No. 1,428,731 No. 1,429,882, No: 1,435,922 (co-pending Application 21902/73) and No: 1,434,834 (co-pending Application 21901/73).

Taking these cases as a group, "blocks" and "areas" (or "spaces") are used as terms to indicate the two distinctive states impressed on a record when a stream of information is recorded on a track in a pulse modulated form. The start of a pulse is indicated by the change from the "area" state to the "block" state, the end of the pulse by the reverse change. In addition to differing from one another, the block and area states may differ from a background state of the record medium, but in most cases it is sufficient for the area state to be the same as the background state. For example, the area and background states may be transparency of the record medium, the block state being opacity therein, or differing optical path lengths or diffraction effects may be used e.g. as described in various examples in the above cases. Optical methods of reading such pulse modulated records produce radiation changes which alternate between two distinctive amplitudes corresponding to the two states. The recorded information is contained in the relative times of transition between these two amplitudes and not in the values of these amplitudes, which require only to be distinctive.

It has also been proposed, for example in the aforesaid Patent Specification 1,391,541 (co-pending Patent Application No. 9487/72), that the reading of such an information structure be carried out by imaging onto the detection system parts thereof having dimensions smaller than the smallest detail of the structure. This may be achieved by projecting a very small spot of radiation onto the structure and imaging the irradiated part of the optical structure on the detection system. As an alternative, a larger spot of radiation may be projected onto the structure, only a very small portion of the irradiated part of this structure being imaged on the detection system. Because it is desirable for the amount of information stored on the record to be large, the dimensions of the blocks and areas may be required to be very small. For example, if a video program or a

duration of 45 minutes is to be recorded on a circular record or disc having an outer diameter of 30 cm, the blocks and areas may be required to have dimensions of the order of 1 μm. This means that for the two aforementioned reading methods a lens having a large numerical aperture has to be used, because the smallest detail which a lens can image is proportional to the wavelength of the radiation used divided by the numerical aperture of the lens. The numerical aperture (N.A.) of a lens having a circular entrance pupil is given by:

$$N.A. = \sin u,$$

where u is one half of the angle subtended by the entrance pupil diameter at the object.

A lens having a large numerical aperture is expensive. In addition, because the depth of focus of a lens is proportional to the wavelength of the light employed divided by the square of the numerical aperture, such a lens will have a small depth of focus.

It is an object of the invention to provide optical record playback apparatus which does not require the use of a lens having a large numerical aperture. Apparatus according to the invention moreover is eminently suitable for reading a record in which the information is stored in the form of a phase structure. In addition, the apparatus may be relatively simple and cheap and does not require the expensive and complicated phase contrast arrangements or interferometric arrangements used in some known apparatus.

According to a first aspect, the invention provides apparatus for reading a record on which information is recorded in parallel tracks (as herein defined) in optically readable form which apparatus is combined with such a record and comprises a source of optical radiation and radiation-sensitive detection system for converting a read beam emitted by the radiation source and modulated by the record into an electric signal, wherein the dimension of the cross-sectional area (as herein defined) of the read beam in the direction of width of a track at the location of recorded information is greater than the width of the track and smaller than the sum of the track width plus twice the width of informationless lands between the tracks, and wherein the path of the radiation from the record to the detection system has inserted in it a limiting aperture arranged to cause a variable part of the radiation diffracted by, and in accordance with, the information on the record to fall outside said limiting aperture and hence outside the detection system.

The energy in the beam will, in general, be distributed non-uniformly and the said area of the read beam is to be understood to be defined in relation to points in the cross-sectional area at which the radiation intensity has decreased to the (e^{-2})th part of the intensity at the centre of the beam. In the case of a circular read beam the dimension of the cross-sectional area of the read beam in the direction of width of the track is equal to the diameter of the read beam.

According to a second aspect, the invention provides apparatus for reading a record on which information is recorded in parallel tracks (as herein defined) in optically readable form as a succession of blocks separated by areas which apparatus is combined with such a record and comprises a source of optical radiation and a radiation-sensitive detection system for converting a read beam emitted by the radiation source and modulated by the record into an electric signal, wherein the dimension of the cross-sectional area (as herein defined) of the read beam in the direction of width of a track at the location of the recorded information is greater than the width of the track and smaller than the sum of the track width plus twice the width of informationless lands between the tracks, the said beam dimension being chosen in relation to the width of the track so that approximately half of the energy of the read beam falls on a block when the read beam is centred on the block, and wherein the path of the radiation from the record to the detection system has inserted in it a limiting aperture arranged to cause a part of the radiation diffracted by a block on the record to fall outside said limiting aperture and hence outside the detection system so that said detection system receives differing amounts of beam radiation depending on the presence or absence of a block.

In apparatus according to the invention the imaging system is used in a manner different from that commonly used hitherto. Whereas in known read apparatus a lens having the highest possible resolving power is used, in apparatus according to the invention a lens of lower resolving power can intentionally be chosen.

Apparatus according to the invention may advantageously be used for reading a reflecting record. For this purpose such apparatus preferably has its limiting aperture also arranged in the path of the radiation from the radiation source to the record. The term "reflecting record" is to be understood to mean a record in which the information is recorded in a reflecting structure, e.g. as described in the said Patent Specification 1,391,541 (co-pending Patent Application No. 9487/72) and in (co-pending Application: 41114/73).

An embodiment of the invention will now be described, by way of example, with reference to the accompanying diagrammatic drawings, in which:

Figure 1 illustrates the principle of the invention,

Figure 2 shows part of the optical structure of a record to be read, and

Figure 3 shows apparatus according to the invention for reading a reflecting record.

As is shown in Figure 1, a lens L1 when irradiated by a parallel beam B will concentrate this beam into a small spot of radiation V1 in the back focal plane of the lens. The minimum, diffraction-limited, dimension of the spot of radiation is determined by the wavelength of the radiation employed and by the lens itself. When the beam B fills the entire entrance pupil of the lens, the minimum dimension of the spot of radiation is given by

$$V1_{min} = C\frac{\lambda}{N.A.}$$

where λ is the wavelength of the radiation employed and N.A. is the numerical aperture of the lens, whilst C is a constant of the order of 1 which is determined by the intensity distribution across the read beam.

Conversely, a lens L2 having a N.A. equal to that of the lens L1 is capable of imaging a detail the dimensions of which are equal to those of V1. A detail V2 situated at the location of V1 and having dimensions smaller than those of V1, however, cannot be imaged by the lens L2. This is due to the wave nature of the radiation. Irradiation of a small detail V2 gives rise to diffraction radiation. The lens L2 can only form a faithful image of this detail if this diffraction radiation is transmitted through the entrance pupil of the lens. If, as shown in Figure 1, the detail V2 is so small that the diffracted radiation largely falls outside the entrance pupil of the lens (see beams B′ in Figure 1), the lens can no longer form a faithful image of the detail V2. A detector D then receives only very little radiation from V2.

In accordance with the invention an arrangement as shown in Figure 1 may be used for reading a record by transmission of the beam. For this purpose the record is positioned so that the track to be read lies in the plane of the detail V2. The record is moved so that the successive parts of the track sequentially appear at the location of V2.

Figure 2 shows part of the optical structure of a record to be read, in this case a circular record or disc 1. A plurality of blocks *b* are arranged on tracks 2 on the record. A beam of radiation incident on the record is influenced by the blocks in a manner differing from the influence of the remainder of the record i.e. the plane surface combining the areas *g* (situated between the blocks) and the informationless intermediate stripes or lands 3. The tracks may be arranged so as to be concentric about the centre of the record. Alternatively they may be the turns of a continuous spiral provided on the record. The lengths of the blocks and of the areas between the blocks are determined by the information stored in the tracks.

A beam of radiation (for example the beam B of Figure 1) forms a spot of radiation V1 on the optical structure. Movement of the record in the direction indicated by an arrow 4 causes the radiation beam to be modulated in accordance with the sequence of blocks and areas in a track. The diameter *d* of the spot of light V1 is greater than the width of the tracks 2, but smaller than the sum of the track width plus twice the width of the informationless intermediate stripes 3.

The numerical aperture of the lens which is to form an image of the record on the detection system is chosen so that this lens can no longer image the narrow blocks *b*. Thus the detector D (Figure 1) will receive radiation as long as the spot of radiation is projected onto an area of the record lying outside any block *b*. When a radiation spot is projected onto a block *b*, a finer structure is involved and a comparatively large amount of radiation is deflected or diffracted outside the entrance pupil of the lens L2. In this case little radiation impinges on the detector, and the output signal from said detector is low or substantially zero.

As will be explained later in greater detail, the information may be stored in the record in the form of an amplitude structure, the blocks being coplanar with the surface of the record. In this embodiment the blocks may be radiation-absorbing while the remainder of the record is either radiation-transmitting or radiation-reflecting. Alternatively, the plane of the blocks may be slightly spaced from the surface of the remainder of the record. An example of such a phase structure is a reflecting record in which pits have been pressed at the locations of the blocks, which pits lie at a distance of $\lambda/4$ beneath the surface of the record. The pits need not have straight walls i.e. walls normal to the face of the record. In fact a record in which the surface merges gradually into the bottom of each pit can also be read by means of apparatus according to the invention.

Figure 3 shows apparatus in accordance with the invention for reading a reflecting information structure. A beam of radiation B incident on lens L is focussed into a spot of radiation V1 on a circular record which can rotate about an axis 7. The record reflects the radiation back to the lens L. As long as the spot of radiation V1 is not projected onto a pit, the reflected radiation will pass through the lens L and be reflected by a beam-splitting prism 8 to a radiation-sensitive detector D. This will cause a signal to

appear at the output of this detector. As soon as the radiation spot is projected onto a pit, reflected radiation will be diffracted so as to fall outside the pupil of the lens L. In this case the detector D receives little radiation and only a very small signal appears at the output of this detector. In this apparatus the functions of the lenses L1 and L2 shown in Figure 1 are fulfilled by a single lens L.

Apparatus according to the invention is particularly suited for reading a phase structure as mentioned hereinbefore. As explained in the aforesaid Patent Specification 1,391,541, a phase structure can be made to introduce in various ways a difference in beam path length as between a block and any other part of the record said difference being substantially $\lambda/2$ or an odd multiple of $\lambda/2$. In a preferred example applied to a reflective record this is achieved by spacing the bottoms of the pits by a distance of $\lambda/4$ below the reflective surface of the record. Applying this in conjunction with a suitable choice of the diameter of the read beam relative to the width of the blocks enables destructive interference to occur between the amount of radiation returned by the bottom of the pit and that returned by the surrounding areas. If the energies of these two amounts are comparable radiation returning towards the limiting aperture will be reduced. However, in the preferred case the said energies are substantially equal and this permits substantially the elimination of radiation returning to the limiting aperture and a consequent increase in signal amplitude at the detector D.

The read beam B is supplied by a laser source 5. To prevent radiation reflected at the record from entering the laser cavity, the beam-splitting prim 8 may be constructed as a polarization-splitting prism. For example, it may transmit only radiation having a plane of polarization parallel to the plane of the drawing whilst reflecting radiation having a plane of polarization at right angles to the plane of the drawing. A $\lambda/4$ plate 6 is arranged in diagonal orientation between the lens L and the record 1. This ensures that the plane of polarization of the radiation reflected to the prism is rotated through 90° so that this radiation is reflected by the prism.

Hereinbefore a lens having a limited numerical aperture has been considered. Obviously, as an alternative the lens may be preceded by a separate aperture stop and have a larger numerical aperture if this is desired.

In a practical embodiment of the invention a lens having a focal distance of 8 mm and a N.A. of 0.4 was irradiated by a laser beam emitted by a helium-neon laser (λ=6328 Å.U.) which has a Gaussian distribution with a diameter of 2.1 μm. The track pitch of the optical structure of the record in the radial direction was 1.8 μm, and the smallest dimension in the track was 0.9 μm.

Although the embodiment has been described with reference to a circular disc-shaped record, apparatus according to the invention is not only suitable for reading such records. Other records, for example records of tape form, can also be read by means of the apparatus described.

WHAT WE CLAIM IS:—

1. Apparatus for reading a record on which information is recorded in parallel tracks (as herein defined) in optically readable form which apparatus is combined with such a record and comprises a source of optical radiation and a radiation-sensitive detection system for converting a read beam emitted by the radiation source and modulated by the record into an electric signal, wherein the dimension of the cross-sectional area (as herein defined) of the read beam in the direction of width of a track at the location of the recorded information is greater than the width of the track and smaller than the sum of the track width plus twice the width of informationless lands between the tracks, and wherein the path of the radiation from the record to the detection system has inserted in it a limiting aperture arranged to cause a variable part of the radiation diffracted by, and in accordance with, the information on the record to fall outside said limiting aperture and hence outside the detection system.

2. Apparatus as claimed in Claim 1 wherein the record is reflective and the limiting aperture is also inserted in the path of the radiation from the radiation source to the record.

3. Apparatus for reading a record on which information is recorded in parallel tracks (as herein defined) in optically readable form as a succession of blocks separated by areas which apparatus is combined with such a record and comprises a source of optical radiation and a radiation-sensitive detection system for converting a read beam emitted by the radiation source and modulated by the record into an electric signal, wherein the dimension of the cross-sectional area (as herein defined) of the read beam in the direction of width of a track at the location of recorded information is greater than the width of the track and smaller than the sum of the track width plus twice the width of information lands between the tracks, the said beam dimension being chosen in relation to the width of the track so that approximately half of the energy of the read beam falls on a block when the read beam is centred on the block, and wherein the path of the radiation from the record to the detection system has inserted in it a limiting aperture

appear at the output of this detector. As soon as the radiation spot is projected onto a pit, reflected radiation will be diffracted so as to fall outside the pupil of the lens L. In this case the detector D receives little radiation and only a very small signal appears at the output of this detector. In this apparatus the functions of the lenses L1 and L2 shown in Figure 1 are fulfilled by a single lens L.

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2. Apparatus as claimed in Claim 1 wherein the record is reflective and the limiting aperture is also inserted in the path of the radiation from the radiation source to the record.

3. Apparatus for reading a record on which information is recorded in parallel tracks (as herein defined) in optically readable form as a succession of blocks separated by areas which apparatus is combined with such a record and comprises a source of optical radiation and a radiation-sensitive detection system for converting a read beam emitted by the radiation source and modulated by the record into an electric signal, wherein the dimension of the cross-sectional area (as herein defined) of the read beam in the direction of width of a track at the location of recorded information is greater than the width of the track and smaller than the sum of the track width plus twice the width of information lands between the tracks, the said beam dimension being chosen in relation to the width of the track so that approximately half of the energy of the read beam falls on a block when the read beam is centred on the block, and wherein the path of the radiation from the record to the detection system has inserted in it a limiting aperture

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arranged to cause a part of the radiation diffracted by a block on the record to fall outside said limiting aperture and hence outside the detection system so that said detection system receives differing amounts of beam radiation depending on the presence or absence of a block.

4. Apparatus as claimed in Claim 3 wherein the optical path length imposed on part of the read beam by the block differs from the optical path length imposed on the remainder of the read beam by adjacent areas by an odd number of half wavelengths of the read beam radiation.

5. Apparatus as claimed in Claim 3 or Claim 4 wherein the record is reflective.

6. Apparatus as claimed in any of Claims 3 to 5 wherein the limiting aperture is also inserted in the path of the radiation from the radiation source to the record.

7. Apparatus as claimed in any of the preceding claims wherein the axis of the read beam is normal to the record.

8. Apparatus as claimed in any preceding claim wherein the record is a disc.

9. Apparatus substantially as described with reference to the accompanying drawings.

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