Description

The invention relates to an apparatus for optically scanning a recording track, said apparatus comprising a radiation source for supplying a scanning beam, and an imaging optical system for imaging the radiation source in a scanning spot on the recording track.

The recording track may be a track provided with information, or an optically detectable track in which information is to be written optically. In the first-mentioned case the scanning beam is a read beam and in the second case the scanning beam is constituted by a write beam which is intensity-modulated in accordance with the information to be written.

The recording track may be provided on different types of record carriers such as a tape-shaped or a round disc-shaped record carrier. In the latter case the recording track may be a continuous spiral track comprising a multitude of turns or it may comprise a multitude of separate concentric turns. Examples of the above-mentioned apparatus are a read apparatus for an optical audio or video disc known as "CD" and "Laser-vision" players, respectively, or a combined write and read apparatus for an optical data disc.

In order to achieve that the scanning spot is always correctly positioned with respect to a track portion to be scanned, the optical scanning apparatuses of the type described comprise a tracking servo-system. In such a system the position of the centre of the scanning spot with respect to the centre line of the scanned track portion is detected and the position of the scanning spot is corrected with reference to the tracking error signal obtained.

As described in inter alia United States Patent No. 4,063,287 a tracking error signal may be generated by moving the scanning spot at a given frequency transversely to the track direction. Due to the periodical displacement of the scanning spot the radiation plane in which the recording track is situated is periodically modulated. As a result, the output signal of a radiation-sensitive detector arranged in the path of the radiation has a periodically varying component whose amplitude and phase, related to the movement of the scanning spot, represent the magnitude and the direction of a deviation of the scanning spot position with respect to the scanned track portion.

In the apparatus described in United States Patent No. 4,063,287 the periodical movement of the scanning spot is realized by means of a mirror arranged in the path of the scanning beam, which mirror is periodically pivoted about an axis which is effectively parallel to the direction of the scanned track portion. The average position of the scanning spot can be corrected by setting, for eaxmple, the central or nominal position of this mirror by means of the tracking error signal which has been generated. A tracking servo-system, in which moving elements are used, has a limited bandwidth.

An apparatus as defined in the preamble of claim 1 is known from NL-A-8 602 980. Therein the zero-order beam formed by diffraction of the scanning beam is used to form the scanning spot and the first order beam formed by diffraction of the returned beam is used for detection.

The present invention has for its object to provide a scanning apparatus in which (a) moving element(s) is (are) no longer necessary for correcting the position of the scanning spot with respect to a scanned track portion and/or for generating a tracking error signal.

The apparatus according to the invention is defined in appended claim 1. The diffraction grating is arranged in the radiation path between the radiation source and the recording track in such a way that only the radiation of a beam diffracted by the grating in a higher diffraction order is focused in the scanning spot and in that the radiation source is constituted by a laser whose wavelength is tunable so as to control the position of the spot.

A higher order is understood to mean the first, the second and the further higher diffraction orders of the diffraction grating.

The invention utilizes the fact that the angle at which the diffraction grating diffracts the selected-order beam is a function of the wavelength of the scanning beam. By varying this wavelength, the direction of the selected order beam and hence the position of the scanning spot with respect to the recording track can be varied.

A preferred embodiment of the scanning apparatus is characterized in that the radiation source is constituted by a semiconductor diode operating as a monomode diode laser and an element optically coupled thereto comprising a light-conducting layer operating as a tuning resonant cavity for the laser radiation.

Such a composite semiconductor device, which is also referred to as "Cleaved-Coupled-Cavity Semiconductor Laser", is for use as a radiation source in an optical fibre communication system described in, for example, the Article: "Demonstration of Multilevel Multichannel Optical Frequency Shift Keying with Cleaved-Coupled-Cavity Semiconductor Laser" in "Electronics Letters" (1983), Volume 19, no. 9, pages 341-342.

By varying the electric current passed through the second semiconductor element, the refractive index of the light-conducting layer therein and hence the optical path length of the resonant cavity within this element can be varied, so that the composite radiation source is tuned to a different

wavelength.

The possibility of varying the direction of the scanning beam electro-optically can be utilized in two ways. The first possibility is utilized in an apparatus which is also characterized in that the control signal for the radiation source is a DC signal whose magnitude and sign are proportional to a tracking error signal, the wavelength of the scanning beam being tuned to an optimum value by means of said DC signal.

The optimum wavelength is the tuned wavelength for which the principal axis of the selected-order beam is directed to the centre line of a track portion to be scanned.

For this embodiment the way in which the tracking error signal is generated is not relevant; various known methods may be used.

A second possibility provided by the present invention is the generation of a tracking error signal. A scanning apparatus providing this possibility is characterized in that the radiation source is coupled to an AC signal source for periodically varying the wavelength of the radiation source with a small amplitude about an average value and in that an opto-electronic detection device is provided for the synchronous detection of radiation from the plane of the recording track by means of a reference signal whose frequency is equal to that of the periodical variation of the wavelength.

Due to this variation of the wavelength about an average value, the diffraction grating moves the selected-order beam periodically to and fro. As a result, the scanning spot moves periodically about an average position transversely to the direction of a scanned track portion. This periodical movement of the scanning spot, which is also referred to as the scanning spot wobble, may be used in the same way as described in United States Patent no. 063,287 for generating a tracking error signal.

The apparatus in which the scanning spot is periodically displaced electro-optically may further be characterized in that the imaging optical system is constituted by the diffraction grating which has a lens action.

Such a grating which has curved grating strips with a varying curvature and a varying grating period instead of straight grating strips and a constant grating period may be constituted, for example, by a holographic grating. This grating ensures imaging with sufficiently high quality of the radiation source in the scanning spot. The periodical variation of the wavelength required for the small scanning spot wobble has such a small amplitude that there is no unacceptable deterioration of the scanning spot quality.

A preferred embodiment of the scanning apparatus is further characterized in that the diffraction grating is a reflective grating, the angle of incidence between a normal on the grating and the chief ray of the scanning beam being considerably larger than 45° and smaller than 90°.

By using a reflective grating, the height of the scanning apparatus can be reduced, which is particularly important when reading and/or writing disc-shaped optical record carriers. By suitable choice of the diffraction order in combination with a suitable choice of the grating period it is achieved that the diffraction grating for the selected-order beam behaves as a mirror at an angle of 45°, which mirror reflects this beam at an angle of 90° to the incident beam, although the grating is oriented at an angle which is considerably smaller than 45° with respect to the incident radiation beam. This considerably reduces the mounting height of the apparatus.

A scanning apparatus in which the radiation source comprises a diode laser having an active layer emitting a laser beam whose aperture angle in the lateral plane, through the principle axis of the beam and parallel to the active layer, is smaller than the aperture angle in the transversal plane, through the principal axis of the beam and transversely to the active layer, is preferably further characterized in that the grating strips are transverse to the lateral plane.

In this plane the scanning beam is widened by reflection on the grating and it can be ensured that the lateral width of the beam is equal to the transversal width, so that the scanning spot is round in spite of the non-round cross-section of the beam emitted by the diode laser.

The above-mentioned scanning apparatuses are preferably further characterized in that the diffraction grating is a phase grating. Such a grating has a higher efficiency than an amplitude grating.

In accordance with a further characteristic feature of the scanning apparatuses the phase grating is constituted by a profile grating comprising grating grooves alternating with grating strips. Such a grating may be manufacture in bulk quantities at low cost by means of known pressing or replica techniques starting from a grating mould.

The scanning apparatuses may alternatively be characterized in that the phase grating is a volume grating comprising juxtaposed strips alternately having a first average refractive index and a second average refractive index.

A volume grating is a so-called thick grating in which the grating structure extends across the thickness of the grating plate and is not only provided on the surface, as is the case with a "thin" grating. An example of the volume grating referred to is a so-called volume hologram grating. This is a special type of diffraction grating which is obtained by causing two radiation beams extending at a given angle to each other to be incident on a

thick plate of special photographic material. These beams constitute in the plate a depth interference pattern of strips alternately having a high and a low intensity. The photographic material is chosen to be such that after development the two exposure levels are converted into different refractive indices. A very high efficiency can be achieved with such a volume hologram.

In order to limit as much as possible the radiation loss which is inherent in the use of a diffraction grating and is caused by the distribution of the radiation over the different diffraction orders, the scanning apparatuses are further characterized in that the grating parameters determining the intensity distribution over the different diffraction orders are chosen to be such that a maximum percentage of the incident radiation intensity is comprises in the selected diffraction order.

In the case of a profile grating the said parameters are the ratio between the width of the grating grooves and those of the grating strips, the depth of the grating grooves and the edge steepness of these grooves. A grating which is optimized for a given diffraction order is referred to as a "blazed" grating in the literature. Such a grating often has a sawtooth-shaped profile without portions which are transverse to the direction of incidence.

In the case of a volume hologram the parameters determining the intensity distribution are the ratio between the width of the strips with the first refractive index and those of the strips with the second refractive index, the ratio of the refractive indices, the thickness of the strips and the angle at which these strips extend to the direction of incidence in the plane transversely to the longitudinal direction of the grating strips.

The scanning apparatus may be further characterized in that a sub-beam diffracted in one of the first diffraction orders is focused in the scanning spot. The first-order diffracted sub-beams have of themselves a higher intensity than the higher diffraction orders, without optimization of the grating for this order. Due to the said optimization one of the first-order sub-beams may be intensified at the cost of the sub-beams of the other orders.

The possibility of optimizing the grating for a second or higher diffraction order is advantageously utilized in another embodiment of the scanning apparatus which is characterized in that a second or higher order sub-beam is focused in the scanning spot. If the selected sub-beam has an identical diffraction angle, the period of the diffraction grating can be increased, which facilitates the manufacture of the grating with the required accuracy. If the grating period remains equal, the angle of incidence of the beam can be increased so that the height of the scanning apparatus can be still further reduced.

To facilitate handling and positioning of the diffraction grating, a further embodiment is characterized in that the diffraction grating is arranged on the oblique side of a triangular prism having a straight angle, the other two sides of which are perpendicular to the incident beam and to the beam directed towards the recording track, respectively.

In co-pending EP-A-0 324 518 (published 19.07.89) the use of a sub-beam instead of the main beam diffracted from a diffraction grating is described for correcting the cross-section of the beam and/or reducing the height of the apparatus.

The invention will now be described in greater detail, by way of example, with reference to the accompanying drawings in which

Figure 1 is a diagrammatic perspective view of an embodiment of an apparatus for reading a disc-shaped optical record carrier with a turntable radiation source and a diffraction grating,
Figure 2 shows diagrammatically an embodiment of a tunable radiation source,
Figure 3 shows the principle of generating the tracking error signal according to the invention,
Figures 4, 5 and 6 show embodiments of a phase diffraction grating,
Figure 7 is a perspective view of an embodiment of the scanning apparatus comprising a diffraction grating having a lens action,
Figure 8 is a front elevation of this grating and
Figure 9 is a lateral cross-section of an embodiment of the scanning apparatus comprising a prism having a curved surface and a linear grating.

Figure 1 shows a part of a round disc-shaped record carrier 1. The information structure is indicated by the information tracks 4 located in an information surface 3 and comprising a multitude of information areas 5 alternating with intermediate areas 6 in the track direction t. The information structure is preferably provided in the upper side of the record carrier and is read by a scanning beam b passing through the substrate 2. The scanning beam is supplied by a radiation source 7, for example, a semiconductor diode laser.

The scanning beam b is focused by an objective 9 to form a scanning spot S in the information plane. A collimator lens 8 is arranged between this objective and the diode laser, which lens converts the diverging beam emitted by the diode laser into a parallel beam having such a cross-section that the pupil of the objective is adequately filled so that the scanning spot S is diffraction-limited and has a minimum diameter. The read beam is reflected by the information surface and, if the record carrier is rotated by means of the driving shaft A, it is

modulated in conformity with the information stored in a track 4 to be read.

The radiation path incorporates a beam splitter), for example, in the form of a semi-transparent mirror which passes the beam b emitted by the radiation source 7 to the objective and reflects the modulated beam from the record carrier to a radiation-sensitive detection system 11. This detection system supplies an electric signal which is modulated in conformity with the information stored in a track to be read. The detection system may supply signals representing deviations in the position of the radiation spot with respect to a track to be read and/or it may represent focusing errors as described in, for example, "Philips Technical Review", Volume 40, No . 6, pages 151-155.

As is known, a polarization-sensitive splitting prism may alternatively be used as a beam splitter instead of a semi-transparent mirror. A birefringent plate should then be arranged in the radiation path between this beam splitter and the objective, which plate ensures that the direction of polarization of the beam returning from the record carrier is rotated through 90° with respect to the direction of polarization of the beam emitted by the source.

In order that the information signal read from the record carrier has a sufficiently large modulation depth and that no crosstalk occurs between adjacent track portions, it must be ensured that the scanning spot keeps following the scanned track portion very accurately. To this end the position of the centre of the scanning spot with respect to the centre line of the track portion to be read must be determined at any moment and, if necessary, the position of the scanning spot must be corrected accordingly. According to the invention a linear diffraction grating 14 is arranged in the radiation path for generating a tracking error signal and the wavelength of the radiation source 7 is tunable.

An example of such a tunable radiation source is a semiconductor laser coupled to a resonant cavity ("Cleaved-Coupled-Cavity Semiconductor Laser"). Figure 2 shows the principle of such a radiation source. The radiation source comprises two semiconductor diode structures 31 and 32 on a common cooling block 30. The diode structures comprise a plurality of semiconductor layers alternately of p and n-type and a so-called active strip 33, 34, respectively. Electric currents I_1 and I_2 are passed through these diodes via electrodes (not shown) on the upper and lower sides of the diode structures. The current I_1 is larger than the threshold current of the diode 31 so that laser radiation is generated in the active strip 33 of this diode. This laser radiation crosses the cleavage 35 separating the diodes electrically and enters the strip 34 of the diode 32. The current I_2 through the diode 32 is smaller than the threshold current for this diode so that no laser radiation is generated in the strip 34, but this strip operates as an external resonant cavity for the diode 31.

By varying the current I_2 a variation of the number of charge carriers in the strip 34 occurs so that the refractive index in this strip changes. Consequently, the optical path length of the external resonant cavity for the diode laser 31 changes, so that this laser is tuned to another wavelength. For further details about the radiation source according to Figure 2 reference is made to the afore-cited Article in "Electronics Letters" (1983), Vol. 19, No. 9, pages 341-342 in which the use of this radiation source in an optical fibre communication system has been described.

The tunable radiation source may alternatively be constituted by an assembly of a diode laser and a light-conducting layer integrated therewith and operating as a tuning resonant cavity. Its refractive index can be changed by changing an electric current through this layer. Such a composite radiation source for use in an optical multiplex system or in an optical heterodyne measuring system has been described in the Article "Wavelength Tuning of GaInAsP/InP Integrated Laser with Butt-Jointed Built-in Distributed Bragg Reflector" in "Electronics Letters" (1983), Vol. 19, No. 17, pages 656-657. To realize the invention a laser source may generally be used which is coupled to an external resonant cavity whose optical path length is continuously adjustable.

As is shown in Figure 1, the grating strips 15 and 16 of the diffraction grating 14 are effectively parallel to the direction of a scanned track portion. In the plane XZ transversely to the direction of the grating strips the diffraction grating splits the incident beam b into a non-diffracted zero-order sub-beam, two sub-beams of the +1 order and -1 order, respectively, and a plurality of second and higher order sub-beams. The grating period p_r and the angle of inclination α of the grating and the nominal wavelength of the laser beam are adjusted to one another in such a way that only one of the first or higher order sub-beams passes through the pupil of the objective 9. For the sake of clarity Figure 1 shows only this one sub-beam b_a.

The diode laser itself of the said composite radiation source emits, at stable ambient parameters, a nominal wavelength, which is determined by the construction of the diode laser. A given diffraction angle of the first order, a given diffraction angle of the second order, etc., is associated with this wavelength.

By driving the external resonant cavity with an alternating current I_2, ~ , the wavelength of the laser beam is modulated around the nominal wavelength. The result is that the diffraction angle of the selected diffraction order is modulated ar-

ound the nominal diffraction angle, in other words: the principal axis of the selected beam periodically oscillates around its nominal direction. Consequently, the position of the radiation spot S formed by the objective 9 oscillates around an average position which must coincide with the centre line of the scanned track portion. It is ensured that the amplitude of the periodical spot displacement, or spot wobble, is considerably smaller than the track width, for example, 1/30 of this width. The frequency of the spot wobble is small, for example, several tens of kHz as compared with the frequency of the information to be read, which is, for example, of the order of several MHz.

Due to the periodical displacement of the scanning spot with respect to the scanned track portion which is optically distinguished from its ambiance, for example, because it diffracts the incident radiation, the intensity of the beam reflected by the record carrier is periodically modulated. The output signal S_d of the detector 11 then not only comprises a high-frequency AC component with a relatively large amplitude representing the information which has been read, but also a component of a lower frequency with a small amplitude. This amplitude and the phase of the low-frequency component represent the magnitude and the direction of a deviation between the centre of the scanning spot and the centre line of the track portion which has been read. If the centre of the scanning spot S coincides with the centre line of the track portion, the frequency of the low-frequency component in the detector system S_d is equal to twice the frequency with which the scanning spot is oscillated. In the case of a deviation of this position the frequency of the low-frequency component is equal to that of the scanning spot wobble, whilst the phase of this component is equal to or is shifted 180° with respect to the phase of the signal with which the scanning spot wobble is realized, dependent on whether the centre of the radiation spot is situated to the left or to the right of the centre line of the scanned track portion.

Figure 3 illustrates the principle of generating the tracking error signal. The elements corresponding to those of Figure 1 have the same reference numerals. The diode laser 31 is controlled by a DC source 36 supplying a current I_1 which is larger than the threshold current. The resonant cavity 32 is connected to an AC source 37 and possibly to a DC source 38. The alternating current I_2~ ensures that the direction of the selected-order beam b_a changes periodically, as is diagrammatically indicated by means of the broken lines b_a' and b_a''. The scanning spot wobble produced thereby is diagrammatically shown in the inset in Figure 3.

The output signal S_d of the detector 11 not only comprises the high-frequency information signal S_i, which is passed by a high-pass filter 40 and is subsequently processed in known manner, but also a low-frequency component. This component passes a bandpass filter 41 and possibly an amplifier 42. Subsequently this component is synchronously detected by means of a reference signal S_{ref} which has the same phase as the scanning spot wobble and is taken from, for example, the source 37. This detection implies that the low-frequency component is multiplied in element 43 by the reference signal and that the resultant signal is passed through a low-pass filter 44. The tracking error signal S_{rad} with which the position of the radiation spot S can be corrected via a control member 45 is then produced at the output of this filter.

This correction may be effected in a conventional manner, for example, by tilting or displacing an element which is already present in the radiation path or which has been especially arranged for this purpose.

The signal S_{rad} is preferably split into a high-frequency fine control component $S_{rad,f}$ with which a fast control over a smalle range can be realized and a low-frequency component $S_{rad,c}$ with which a slower control over a larger range can be realized and which may compensate, for example, for a possible eccentricity of the track turns. The last-mentioned control may be, for example, a displacement in the radial direction of a sledge on which the optical components of the read apparatus have been arranged. The fine-control may be, for example, a tilting of the diffraction grating through a small angle.

According to one aspect of the present invention the fine positioning of the scanning spot can be realized electro-optically without using moving elements, as is shown in Figure 3. For example, the control current $I_{2\sim}$ is set to a new value by means of the signal $S_{rad,f}$ so that the tuned wavelength of the laser beam acquires a different value. The result is that the position of the scanning spot, the central position s_m in the inset in Figure 3, is shifted in such a way that the centre of this spot coincides again with the centre line of the scanned track portion if the spot had previously been off-centre with respect to this track portion.

The tracking error signal for electro-optically correcting the spot position may alternatively be obtained in a manner which differs from that described with reference to Figure 3. For example, the method described in United States Patent No. 3,876,842 may be used. With the aid of extra radiation sources or with a beam splitter, two extra radiation spots are generated which are projected on the two edges of the scanned track portion. A

separate detector has been added to each of these radiation spots and the difference between the output signals of these detectors represents the tracking error signal. This signal may alternatively be generated with the scanning beam itself by arranging two radiation-sensitive detectors in the path of this beam from the record carrier, the bounding line between these detectors being parallel to the track direction, and by comparing the output signals of these detectors as described, for example, in United States Patent No. 4,423,496.

The wavelength of the radiation source may not only be tuned or modulated in the manner described above, but also in other manners. If the tuning need not be very fast, the wavelength may be tuned to a different value, for example, by variation of the temperature of a diode laser by means of, for example, a Peltier element.

The diffraction grating may be a radiation transmitting grating. However, as is shown in Figure 1, this grating is preferably a reflection grating reflecting the beam b at an angle of 90°. The greater part of the radiation path then extends horizontally so that the mounting height of the read apparatus is small. The advantage of the use of a grating as a reflector is that the angle of inclination α of the grating is smaller than 45° because one of the higher order beams is used as a scanning beam, so that this grating only requires little space in the vertical direction. Consequently, the mounting height of the scanning apparatus can be further reduced. This is particularly important for scanning apparatus which are intended to be built into optical disc players for consumer use, which players are portable or which must be built into motor cars. A small mounting height is also very desirable when using the scanning apparatuses as scanning heads for an optical disc memory which, analogously as a magnetic disc memory, has a plurality of optical memory discs each of which are scanned with one or two separate scanning head(s).

A diode laser is preferably used as a radiation source in read and/or write apparatus for disc-shaped optical record carriers. As is known, the beam emerging from the front side 23 of a diode laser 7 is not symmetrical. The aperture angle of this beam in the lateral plane, the plane XZ parallel to the active strip, is considerably smaller than the angle of aperture in the transversal plane, the plane XY transversely to the active strip, as is shown in Figure 1. In this Figure the boundary rays of the beam in the lateral plane are denoted by solid lines and the boundary rays of the beam in the transversal plane are denoted by broken lines. At the area of the collimator lens 8 the beam b has an elliptical cross-section. To obtain a round radiation spot S on the information surface 3, the beam has to be reshaped into a beam having a round cross-section.

As is shown in Figure 1, the desired beam shaping can be realized by means of the diffraction grating 14 at a small angle of inclination α or a large angle of incidence γ. Since the chief ray h of the beam b in the lateral plane extends at a small angle α to the reflective surface 14, whereas the beam b_a is reflected substantially in the vertical direction, the last-mentioned beam in the lateral plane is considerably widened with respect to the incident beam b. While adapting the period P_r of the grating, the angle of inclination α may be chosen to be such that the lateral width of the beam, after reflection on the grating, is equal to the transversal width which is not changed by the grating.

In the apparatus according to Figure 1 the mounting height is simultaneously reduced by means of the grating 14 and the beam in the lateral plane is widened. However, it is alternatively possible to use the diffraction grating for fulfilling only one of these requirements.

Hitherto, the invention has been described with reference to a read apparatus. However, the invention may alternatively be used in an apparatus for writing a record carrier with optical radiation, which carrier is provided with a previously arranged and optical detectable servo track used to cause a write radiation spot to follow an accurately determined path. Such a write apparatus principally has the same structure as the read apparatus. However, the scanning beam must then be modulated with the information to be written. This can be realized by means of an optical modulator arranged in the radiation path or by controlling the diode laser by means of a control signal which is modulated in conformity with the information to be written.

The diffraction grating is preferably arranged on a triangular prism the other two surfaces of which are denoted by 17 and 18 in Figure 1. The angle β between the surfaces 17 and 18 is preferably 90°, which facilitates alignment and mounting of the grating.

The diffraction grating may be an amplitude grating and may comprise reflective strips 15 and absorbing or radiation-transmitting strips 16. However, the diffraction grating is preferably a phase grating. Such a grating yields a higher diffraction efficiency than an amplitude grating. The phase grating may be in the form of a so-called profile grating comprising, for example, grating grooves 15 and higher located grating strips 16, as is shown in Figure 4. Such a grating has the advantage that it can be manufactured in bulk quantities at low cost by means of known pressing and replica techniques if a mould in which the grating structure is provided is available. Such a

mould need only be manufactured once.

The phase grating may alternatively be constituted by a structure of juxtaposed strips alternately having a first and a second refractive index. This structure may have the shape of a so-called volume hologram or thick hologram having a thickness of the order of several mm:s. Such a hologram is obtained by causing two beams to be incident on a thick plate of special photographic material. Dependent on whether a reflection or volume hologram is to be obtained, the beams must be incident on different sides or on the same side of the plate. Within this plate the beams interfere with one another so that a structure of juxtaposed strips alternatively having a high and low intensity is produced. By developing the plate the intensity pattern is converted into a pattern of strips having higher and lower refractive indices. Figure 5 shows such a volume hologram 14' in a diagrammatic cross-section.

The difference Δn between the refractive index n_1 of the strips 15' and the refractive index n_2 of the strips 16' is, for example, 0.02 and n and n_2 have values of, for example, 1.52 and 1.54, respectively. In most cases the strips will extend at an angle ϕ deviating from 90° to the two sides 25 and 26 of the plate 14'.

Moreover, the transitions between the areas having different refractive indices will generally not be so abrupt in practice as is shown in Figure 5, but the refractive index has a more gradual variation as is shown in Figure 5a. In this Figure the position e on the plate, transversely to the strips of Figure 5, is plotted horizontally and the refractive index n is plotted vertically.

The beam b_a passing through the objective may be one of the first-order sub-beams. These sub-beams have of themselves a higher intensity than the higher order sub-beams. For a sub-beam of the order m diffracted by a diffraction grating it holds that the sine of the diffraction angle δ is proportional to

$$\frac{\lambda \cdot m}{p_r} .$$

If a sub-beam of, for example, the second order is chosen for the sub-beam b_a, the period p_r of the grating 14 is twice as large at the same diffraction angle δ than when choosing a sub-beam of the first order. Under circumstances it is therefore preferable to choose a second or higher order sub-beam because the diffraction grating can then be manufactured more easily with the required accuracy.

In the case of selecting a second or higher diffraction order sub-beam as well as in the case of selecting a first-order sub-beam, the efficiency of the grating for the selected sub-beam can be enhanced by adapting the grating parameters. The efficiency is herein understood to mean that part of the radiation intensity incident on the grating which is diffracted in the selected order. In the case of a profile grating the said parameters are the depth of the grating grooves 15, the wall steepness of these grooves and the ratio between the width of the grooves 15 and those of the intermediate grooves 16. Optimizing the grating parameters of a profile grating is known as "blazing". Figure 6 shows a small part of an embodiment of such a "blazed" grating 14" in a simplified form. It has been ensured, inter alia, that the parts of the incident radiation beam b_a are incident as much as possible on areas 16" reflecting the radiation in the desired direction.

Also for a refractive index grating, like a volume hologram according to Figures 5 and 5a, the efficiency for the selected diffraction order can be maximized by an optimum choice of the difference Δn in refractive index, the angle of inclination ϕ of the strips and the ratio between the widths of the strips 15' and 16'. Although the beam is diffracted, it can be assumed in a first approximation that the optimization of the diffraction grating implies, inter alia, that the grating areas on which the beam parts are incident have such a direction that they reflect the radiation in the desired direction.

If the wavelength-tunable radiation source and the diffraction grating are only used for generating the scanning spot wobble with a small amplitude, at which the wavelength variation is also very small, and if it is not used for correcting the average scanning spot position, the scanning apparatus may be considerably simplified. In fact, it is then possible to use a diffraction grating with a built-in lens power so that a separate collimator lens and an objective are no longer necessary. Such a grating has curved grating lines and a varying grating period.

Figure 7 shows the simplified scanning apparatus in a diagrammatical form. Figure 8 shows the diffraction grating in a front elevation. The radius of curvature of the grating strips 15 uniformly increases in one direction. The grating period P_r uniformly decreases in the same direction. In Figure 8 only one grating strip 15 is shown each time over a number of (q) grating periods. The distance between the curved strips 15 in Figure 8 is thus equal to qxP_r. The grating according to Figure 8 may be manufactured, for example, holographically by exposing a plate of holographic material at the position of the grating with a diverging beam from a point source at the position of a scanning spot S and a beam corresponding to the beam b, and by developing this plate. This grating is therefore also

referred to as a holographic (grating) objective.

Due to the absence of an objective, the embodiment of a scanning apparatus as shown in Figure 7 has a very low mounting height. Moreover, this apparatus may be very light. The positioning of the scanning spot may therefore be established with the desired speed and accuracy by displacing a holder in which the elements 7 and 14 are arranged.

Also when using a linear grating, that is to say, a grating having straight grating strips and a constant grating period the apparatus can be simplified and its height can be reduced by integrating the objective with the prism in which the grating is arranged.

Figure 9 shows a first embodiment of such an integrated element. This Figure shows in a lateral cross-section a triangular prism having a straight angle, with the diffraction grating 14 being arranged at its oblique side. The prism is differently oriented in Figure 9 than the prism in Figure 1, namely in such a way that the beam b_a enters the prism via the surface 17 and leaves the prism via the surface 18' after reflection by the grating. This exit face is not a flat face like surface 18 of Figure 1 but a curved face which has a lens action due to its curvature and may therefore replace the objective 9 of Figure 1.

As described in, inter alia, United States Patent No. 4,668,066 the objective in a scanning apparatus for disc-shaped record carriers may comprise a single lens element. However, this element must have at least one aspherical surface in order to be able to form a scanning spot which is free from aberration. Such a correction will also have to be introduced in the objective diffraction grating element of Figure 6. This can be realized by giving the curved surface an aspherical shape 18", as denoted by the broken-line curve, instead of a spherical shape 18'.

Claims

1. An apparatus for optically scanning a recording track (5), said apparatus comprising a radiation source (7) for supplying a scanning beam (6), an imaging optical system (8-11) for imaging the radiation source in a scanning spot on the recording track, a diffraction grating (14) arranged in the radiation path between the radiation source (17) and the recording track and means (41-45, 33, 37) for controlling the position of the scanning spot with respect to the track, characterized in that the diffraction grating is arranged in such a way that only the radiation of a beam (ba) diffracted by the grating in a higher diffraction order is focused in the scanning spot, that the radiation source (7) is constituted by a laser (31, 32) whose wavelength is tunable and that the means for controlling the position of the scanning spot generate a control signal (S_{rad}) for the radiation source for tuning the laser so as to control the wavelength.

2. An apparatus as claimed in Claim 1, characterized in that the radiation source is constituted by a semiconductor diode operating as a monomode diode laser and an element optically coupled thereto comprising a light-conducting layer operating as a tuning resonant cavity for the laser radiation.

3. An apparatus as claimed in Claim 1 or 2, characterized in that the control signal for the radiation source is a DC signal whose magnitude and sign are proportional to a tracking error signal, the wavelength of the scanning beam being tuned to an optimum value by means of said DC signal.

4. An apparatus as claimed in Claim 1, 2 or 3, characterized in that the radiation source is coupled to an AC signal source for periodically varying the wavelength of the radiation source with a small amplitude about an average value and in that an opto-electronic detection device is provided for the synchronous detection of radiation from the plane of the recording track by means of a reference signal whose frequency is equal to that of the periodical variation of the wavelength.

5. An apparatus as claimed in Claim 4, characterized in that the imaging optical system is constituted by the diffraction grating which has a lens action.

6. An apparatus as claimed in Claim 1, 2, 3, 4 or 5, characterized in that the diffraction grating is a reflective grating, the angle of incidence between a normal on the grating and the chief ray of the scanning beam being considerably larger than 45° and smaller than 90°.

7. An apparatus as claimed in Claim 6 in which the radiation source comprises a diode laser having an active layer emitting a laser beam whose aperture angle in the lateral plane, through the principal axis of the beam and parallel to the active layer, is smaller than the aperture angle in the transversal plane, through the principal axis of the beam and transversely to the active layer, characterized in that the grating strips are transverse to the lateral plane.

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referred to as a holographic (grating) objective.

Due to the absence of an objective, the embodiment of a scanning apparatus as shown in Figure 7 has a very low mounting height. Moreover, this apparatus may be very light. The positioning of the scanning spot may therefore be established with the desired speed and accuracy by displacing a holder in which the elements 7 and 14 are arranged.

Also when using a linear grating, that is to say, a grating having straight grating strips and a constant grating period the apparatus can be simplified and its height can be reduced by integrating the objective with the prism in which the grating is arranged.

Figure 9 shows a first embodiment of such an integrated element. This Figure shows in a lateral cross-section a triangular prism having a straight angle, with the diffraction grating 14 being arranged on its oblique side. The prism is differently oriented in Figure 9 than the prism in Figure 1, namely in such a way that the beam b_a enters the prism via the surface 17 and leaves the prism via the surface 18' after reflection by the grating. This exit face is not a flat face like surface 18 of Figure 1 but a curved face which has a lens action due to its curvature and may therefore replace the objective 9 of Figure 1.

As described in, inter alia, United States Patent No. 4,668,066 the objective in a scanning apparatus for disc-shaped record carriers may comprise a single lens element. However, this element must have at least one aspherical surface in order to be able to form a scanning spot which is free from aberration. Such a correction will also have to be introduced in the objective diffraction grating element of Figure 6. This can be realized by giving the curved surface an aspherical shape 18", as denoted by the broken-line curve, instead of a spherical shape 18'.

Claims

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2. An apparatus as claimed in Claim 1, characterized in that the radiation source is constituted by a semiconductor diode operating as a monomode diode laser and an element optically coupled thereto comprising a light-conducting layer operating as a tuning resonant cavity for the laser radiation.

3. An apparatus as claimed in Claim 1 or 2, characterized in that the control signal for the radiation source is a DC signal whose magnitude and sign are proportional to a tracking error signal, the wavelength of the scanning beam being tuned to an optimum value by means of said DC signal.

4. An apparatus as claimed in Claim 1, 2 or 3, characterized in that the radiation source is coupled to an AC signal source for periodically varying the wavelength of the radiation source with a small amplitude about an average value and in that an opto-electronic detection device is provided for the synchronous detection of radiation from the plane of the recording track by means of a reference signal whose frequency is equal to that of the periodical variation of the wavelength.

5. An apparatus as claimed in Claim 4, characterized in that the imaging optical system is constituted by the diffraction grating which has a lens action.

6. An apparatus as claimed in Claim 1, 2, 3, 4 or 5, characterized in that the diffraction grating is a reflective grating, the angle of incidence between a normal on the grating and the chief ray of the scanning beam being considerably larger than 45° and smaller than 90°.

7. An apparatus as claimed in Claim 6 in which the radiation source comprises a diode laser having an active layer emitting a laser beam whose aperture angle in the lateral plane, through the principal axis of the beam and parallel to the active layer, is smaller than the aperture angle in the transversal plane, through the principal axis of the beam and transversely to the active layer, characterized in that the grating strips are transverse to the lateral plane.

8. An apparatus as claimed in any one of the preceding Claims, characterized in that the diffraction grating is a phase grating.

9. An apparatus as claimed in Claim 8, characterized in that the phase grating is constituted by a profile grating.

10. An apparatus as claimed in Claim 8, characterized in that the phase grating is a volume grating comprising a plurality of juxtaposed strips alternately having a first average refractive index and a second average refractive index.

11. An apparatus as claimed in Claim 1, characterized in that the grating parameters determining the intensity distribution over the different diffraction orders are chosen to be such that a maximum percentage of the incident radiation intensity is comprised in the selected diffraction order.

12. An apparatus as claimed in Claim 1 or 11, characterized in that a sub-beam diffracted in one of the first diffraction orders is focused in the scanning spot.

13. An apparatus as claimed in Claim 1 or 11, characterized in that a second or higher order sub-beam is focused in the scanning spot.

14. An apparatus as claimed in Claim 1, characterized in that the diffraction grating is arranged on the oblique side of a triangular prism having a straight angle, the other two sides of which are perpendicular to the incident beam and to the beam directed towards the recording track, respectively.

15. An apparatus as claimed in Claim 14, characterized in that the surface of the prism which faces the diffraction grating and through which the beam reflected by the diffraction grating emerges is curved.

16. An apparatus as claimed in Claim 15, characterized in that the curved surface is an aspherical surface and in that the diffraction grating is a linear grating.

17. An apparatus as claimed in Claim 15, characterized in that the curved surface is spherical and in that the grating has an aberration-correcting asphericity.

Patentansprüche

1. Vorrichtung zum optischen Abtasten einer Aufzeichnungsspur (5), wobei die Vorrichtung eine Strahlungsquelle (7) zur Lieferung eines Abtaststrahlenbündels (6), ein abbildendes optisches System (8-11) zur Abbildung der Strahlungsquelle in einen Abtastfleck auf der Aufzeichnungsspur, ein in dem Strahlengang zwischen der Strahlungsquelle (17) und der Aufzeichnungsspur angeordnetes Beugungsgitter (14) und Mittel (41-45, 33, 37) zur Steuerung der Lage des Abtastflecks in bezug auf die Spur enthalt, dadurch gekennzeichnet, daß das Beugungsgitter so angeordnet ist, daß nur die Strahlung eines von dem Gitter in eine höhere Beugungsordnung gebeugten Strahlenbündels (ba) in den Abtastfleck fokussiert wird, daß die Strahlungsquelle (7) von einem Laser (31, 32) gebildet wird, dessen Wellenlänge abstimmbar ist, und daß die Mittel zur Steuerung der Lage des Abtastflecks ein Steuersignal (S_{rad}) für die Strahlungsquelle erzeugen, um den Laser so abzustimmen, daß die Wellenlänge gesteuert wird.

2. Vorrichtung nach Anspruch 1, dadurch gekennzeichnet, daß die Strahlungsquelle von einer als Einmodendiodenlaser arbeitenden Halbleiterdiode und einem damit optisch gekoppelten Element mit einer lichtleitenden Schicht gebildet wird, die als abstimmbarer Resonator für die Laserstrahlung wirkt.

3. Vorrichtung nach Anspruch 1 oder 2, dadurch gekennzeichnet, daß das Steuersignal für die Strahlungsquelle ein Gleichstromsignal ist, dessen Größe und Vorzeichen proportional zu einem Spurfolgefehlersignal sind, wobei die Wellenlänge des Abtaststrahlenbündels mit Hilfe des Gleichstromsignals auf einen optimalen Wert abgestimmt wird.

4. Vorrichtung nach Anspruch 1, 2 oder 3, dadurch gezeichnet, daß die Strahlungsquelle mit einer Wechselstromsignalquelle gekoppelt ist, um die Wellenlänge der Strahlungsquelle mit einer kleinen Amplitude um einen Mittelwert periodisch zu verändern und daß eine optoelektronische Detektionsanordnung vorhanden ist, um aus der Ebene der Aufzeichnungsspur stammende Strahlung mit Hilfe eines Bezugssignals, dessen Frequenz gleich der periodischen Veränderung der Wellenlänge ist, synchron zu detektieren.

5. Vorrichtung nach Anspruch 4, dadurch gekennzeichnet, daß das abbildende optische

System von dem Beugungsgitter gebildet wird, das eine Linsenwirkung aufweist.

6. Vorrichtung nach Anspruch 1, 2, 3, 4 oder 5, dadurch gezeichnet, daß das Beugungsgitter ein Reflexionsgitter ist, wobei der Einfallswinkel zwischen einer Gitternormalen und dem Hauptstrahl des Abtaststrahlenbündels bedeutend größer als 45° und kleiner als 90° ist.

7. Vorrichtung nach Anspruch 6, in der die Strahlungsquelle einen Diodenlaser mit einer aktiven Schicht enthält, der ein Laserstrahlenbündel emittiert, dessen Öffnungswinkel in der lateralen Ebene, durch die Hauptachse des Strahlenbündels und parallel zur aktiven Schicht, kleiner ist als der Öffnungswinkel in der transversalen Ebene, durch die Hauptachse des Strahlenbündels und quer zur aktiven Schicht, dadurch gekennzeichnet, daß die Gitterstreifen quer zu der lateralen Ebene liegen.

8. Vorrichtung nach einem der vorhergehenden Ansprüche, dadurch gekennzeichnet, daß das Beugungsgitter ein Phasengitter ist.

9. Vorrichtung nach Anspruch 8, dadurch gekennzeichnet, daß das Beugungsgitter von einem Profilgitter gebildet wird.

10. Vorrichtung nach Anspruch 8, dadurch gekennzeichnet, daß das Phasengitter ein Volumengitter mit mehreren nebeneinanderliegenden Streifen ist, die abwechselnd eine erste mittlere Brechzahl und eine zweite mittlere Brechzahl haben.

11. Vorrichtung nach Anspruch 1, dadurch gekennzeichnet, daß die die Intensitätsverteilung über die verschiedenen Beugungsordnungen bestimmenden Gitterparameter so gewählt sind, daß ein maximaler Prozentsatz der einfallenden Strahlungsstärke in der gewählten Beugungsordnung enthalten ist.

12. Vorrichtung nach Anspruch 1 oder 11, dadurch gekennzeichnet, daß ein in eine der ersten Beugungsordnungen gebeugtes Teilbündel in den Abtastfleck fokussiert wird.

13. Vorrichtung nach Anspruch 1 oder 11, dadurch gekennzeichnet, daß ein in eine zweite oder höhere Beugungsordnung gebeugtes Teilbündel in den Abtastfleck fokussiert wird.

14. Vorrichtung nach Anspruch 1, dadurch gekennzeichnet, daß das Beugungsgitter an der schrägen Seite eines dreieckigen Prismas angeordnet ist, das einen rechten Winkel hat, und dessen beide andere Seiten senkrecht zum Einfallsstrahlenbündel bzw. dem zur Aufzeichnungsspur gerichteten Strahlenbündel stehen.

15. Vorrichtung nach Anspruch 14, dadurch gekennzeichnet, daß die Oberfläche des Prismas, die dem Beugungsgitter zugewandt ist und durch die das von dem Beugungsgitter reflektierte Strahlenbündel austritt, gekrümmt ist.

16. Vorrichtung nach Anspruch 15, dadurch gekennzeichnet, daß die gekrümmte Fläche eine asphärische Fläche ist und daß das Beugungsgitter ein lineares Gitter ist.

17. Vorrichtung nach Anspruch 15, dadurch gekennzeichnet, daß die gekrümmte Fläche sphärisch ist und daß das Gitter eine aberrationskorrigierende Asphärizität hat.

Revendications

1. Dispositif pour l'exploration optique d'une piste d'enregistrement (5), ledit dispositif comportant une source de rayonnement (7) pour fournir un faisceau d'exploration (6), un système optique de formation d'image (8-11) pour former une image de la source de rayonnement dans un spot d'exploration sur la piste d'enregistrement, un réseau de diffraction (14) disposé dans le trajet de rayonnement entre la source de rayonnement (17) et la piste d'enregistrement et des moyens (41-45, 33, 37) pour commander la position du spot d'exploration par rapport à la piste, caractérisé en ce que le réseau de diffraction est disposé de manière que seul le rayonnement d'un faisceau (b_a) diffracté par le réseau dans un ordre de diffraction plus élevé est focalisé dans le spot d'exploration, en ce que la source de rayonnement (7) est constituée d'un laser (31, 32) dont la longueur d'onde est ajustable et en ce que les moyens pour commander la position du spot d'exploration engendrent un signal de commande (S_{rad}) destiné pour la source de rayonnement pour ajuster le laser de manière à mettre au point la longueur d'onde.

2. Dispositif selon la revendication 1, caractérisé en ce que la source de rayonnement est constituée d'une diode semi-conductrice fonctionnant comme une diode laser monomode, ainsi que d'un élément couplé optiquement à ladite diode, comportant une couche conductrice de lumière faisant fonction de ca-

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vité résonante pour le rayonnement laser.

3. Dispositif selon la revendication 1 ou 2, caractérisé en ce que le signal de commande pour la source de rayonnement est constitué d'un signal de courant continu dont la valeur et le signe sont proportionnels à un signal d'erreur de suivi de piste, la longueur d'onde du faisceau d'exploration étant ajustée sur une valeur optimale à l'aide dudit signal de courant continu.

4. Dispositif selon la revendication 1, 2 ou 3, caractérisé en ce que la source de rayonnement est couplée à une source de signaux de courant alternatif, qui fait varier périodiquement la longueur d'onde de la source de rayonnement d'une faible amplitude autour d'une valeur moyenne et en ce qu'il est prévu un dispositif de détection optoélectronique pour la détection synchrone de rayonnement sortant du plan de la piste d'enregistrement à l'aide d'un signal de référence dont la fréquence est égale à celle de la variation périodique de la longueur d'onde.

5. Dispositif selon la revendication 4, caractérisé en ce que le système de formation d'image optique est constitué du réseau de diffraction présentant un effet de lentille.

6. Dispositif selon la revendication 1, 2, 3, 4 ou 5, caractérisé en ce que le réseau de diffraction constitue un réseau réfléchissant, l'angle d'incidence fait entre une normale au réseau et le rayon principal du faisceau d'exploration étant sensiblement supérieur à 45° et inférieur à 90°.

7. Dispositif selon la revendication 6, dans lequel la source de rayonnement comporte une diode laser munie d'une couche active qui émet un faisceau laser dont l'angle d'ouverture dans le plan latéral, à travers l'axe principal du faisceau et parallèlement à la couche active, est inférieur à l'angle d'ouverture dans le plan transversal, à travers l'axe principal du faisceau et transversalement à la couche active, caractérisé en ce que les bandes de réseau sont situées transversalement au plan latéral.

8. Dispositif selon l'une quelconque des revendications précédentes, caractérisé en ce que le réseau de diffraction est constitué d'un réseau de phase.

9. Dispositif selon la revendication 8, caractérisé en ce que le réseau de phase est constitué d'un réseau de profile.

10. Dispositif selon la revendication 8, caractérisé en ce que le réseau de phase constitue un réseau de volume comportant une pluralité de bandes juxtaposées présentant alternativement un premier indice de réfraction et un deuxième indice de réfraction moyens.

11. Dispositif selon la revendication 1, caractérisé en ce que les paramètres de réseau déterminant la distribution d'intensité sur les différents ordres de diffraction sont choisis de manière qu'un pourcentage maximal de l'intensité de rayonnement incident est compris dans l'ordre de diffraction choisi.

12. Dispositif selon la revendication 1 ou 11, caractérisé en ce qu'un sous-faisceau diffracté dans l'un des premiers ordres de diffraction est focalisé dans le spot d'exploration.

13. Dispositif selon la revendication 1 ou 11, caractérisé en ce qu'un sous-faisceau d'un deuxième ordre ou d'un ordre plus élevé est focalisé dans le spot d'exploration.

14. Dispositif selon la revendication 1, caractérisé en ce que le réseau de diffraction est disposé sur le côté oblique d'un prisme triangulaire présentant un angle droit, dont les deux autres côtés sont perpendiculaires au faisceau incident ou au faisceau dirigé vers la piste d'enregistrement.

15. Dispositif selon la revendication 14, caractérisé en ce que la surface du prisme située à l'opposé du réseau de diffraction et par laquelle sort le faisceau réfléchi par le réseau de diffraction est courbée.

16. Dispositif selon la revendication 15, caractérisé en ce que la surface courbée constitue une surface asphérique et en ce que le réseau de diffraction constitue un réseau linéaire.

17. Dispositif selon la revendication 15, caractérisé en ce que la surface courbée est sphérique et en ce que le réseau présente une asphéricité de correction d'aberrations.