

Description

BACKGROUND OF THE INVENTION.

This invention relates to nonlinear optical devices and more particularly to devices for doubling the frequency of electromagnetic radiation passing therethrough.

Optical digital data storage devices, such as compact discs, have come into widespread use. Typically, such discs are read and written to by means of a light emitted by a semiconductor laser (i.e. a laser diode). However, the light generated by semiconductor laser diodes generally falls within the lower end of the electromagnetic frequency spectrum (i.e. red or infrared). The use of higher frequency light, i.e. at the blue end of the spectrum, to read and write to optical storage medium would result in greatly increased storage density. Unfortunately, however, there are yet no practical blue semiconductor lasers. To date, the only blue lasers are large gas lasers which are obviously unsuitable for use in compact and inexpensive optical storage read/write devices.

Accordingly, a device capable of converting the light emitted by readily available semiconductor laser diodes to blue light is greatly desired. Laser diodes that emit infrared light are inexpensive and widely available. The frequency of blue light is twice that of infrared radiation. Accordingly, a device capable of doubling the frequency of infrared radiation is greatly desired. The present invention is directed to providing an inexpensive frequency doubling device that may be used in conjunction with an infrared semiconductor laser to provide blue light suitable for use in reading and writing optical storage media.

The field of non-linear optics has provided a number of devices used as frequency doublers, generally through the means of second harmonic generation (SHG) of a fundamental frequency. U.S. Patent No. 3,384,433 (Bloembergen) is directed to a non-linear device for converting light from first and second frequencies to a third different frequency. The device includes a series of non-linear crystals or slabs of material possessing specific lattice orientation periodically disposed along the axis of propagation of the two optical beams. Another device is described in the article entitled "Non-linear Optical Effects in Rotationally Twinned Crystals: An Evaluation of CdTe, ZnTe and ZnSe" in Revue De Physique Appliquee February 1977, Vol. 12, pages 405-409 and U.S. Patent 3,988,593 (Dewey) which show devices achieving frequency doubling by passing a beam perpendicularly through a series of slabs of rotationally twinned crystals.

However, the above described approaches have suffered from a number of practical difficulties. These approaches require the frequency doubling device to have a large number (in some cases more than one hundred) of accurately grown slabs of crystals having precisely defined non-linear optical properties. The growth of such crystals is difficult and relatively expensive. GB-A 1,594,387 discloses a similar frequency doubling device wherein in a layer of ferro-electric material alternating domains of opposite polarization directions are realized by providing a periodic structure of electrodes on the layer and applying an electric voltage to said electrodes, such that the polarization direction of the areas under the electrodes is inverted with respect to the initial polarization direction. For a satisfying frequency doubling efficiency a large number of electrodes which should satisfy stringent requirements as to their dimension is required, so that this device is difficult to realize and expensive. Accordingly, a simpler, less expensive device for frequency doubling is desirable.

SUMMARY OF THE INVENTION

An object of the invention is to provide an inexpensive device and method for doubling the frequency of electromagnetic radiation. The device includes a substrate having a waveguide made of a non-linear optical material of a differing refractive index disposed thereon. The waveguide includes an inverted polarization interface at which the direction of polarization of the waveguide abruptly changes from positive to negative. Radiation is directed across the device parallel to the inverted polarization interface and is doubled in frequency by the interface.

The inverted polarization interface may be achieved in a number of ways. A first method is to grow a waveguide of a first polarity followed by the growth of a relatively thin layer of non-polarized material. Finally, a second layer of a polarization opposite to that of the first layer is grown. Another method of providing the inverted polarization interface is to simply grow a first layer of a waveguide polarized in a first direction on a substrate. Thereafter, the waveguide and substrate is cleaved and flipped over upon itself so that the waveguide layers lie in juxtaposed face-to-face relationship. In this relationship the polarization of the waveguide will be inverted along the plane of contact. Another method of providing an inverted polarization interface is through the growth of asymmetric mirror image quantum wells on each side of a plane. The polarity of the growth direction of the quantum wells is reversed at the plane forming the inverted polarization interface.

As can be appreciated, a frequency doubling device constructed in accordance with the present invention is advantageous in that the manufacturing complexity is greatly reduced because only a relatively few layers of crystal have to be grown. Contrast this to the multiple layer approaches of the prior art discussed above. Accordingly, the present invention lends itself to the large scale manufacture of relatively inexpensive frequency doubling devices for use in conjunction with semiconductor laser light sources in optical storage systems.

A device designed in accordance with the present invention is highly effective because the inverted polarization interface leads to the efficient coupling of power into the higher order harmonic mode. As a result, a large index step between the waveguide and the substrate is unnecessary for good frequency conversion efficiency. Accordingly, both the substrate and waveguide may be fabricated of structurally similar materials.

BRIEF DESCRIPTION OF THE DRAWINGS.

For better understanding of the invention, reference is made to the following drawings, to be taken in conjunction with the detailed specification to follow:

Fig. 1 is a sectional view of the non-linear optical frequency doubling device constructed in accordance with the present invention;

Fig. 2 illustrates a method of manufacture of the frequency doubling non-linear optical device; and

Fig. 3 is a schematic diagram of the inverted polarization interface of the present invention as embodied in an asymmetric mirror image quantum well structure.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS.

Figure 1 illustrates a first embodiment of the inventive frequency doubling device 10. The frequency doubling device 10 comprises a substrate 12 which may be any suitable non-linear optical material such as potassium titanate phosphate (KTiOPO_4) known as "KTP", lithium niobate (LiNbO_3) or zinc selenide (ZnSe). On substrate 12 is disposed a waveguide layer 14 of, for example, zinc selenide or zinc sulfur selenide ($\text{ZnS}_x\text{Se}_{1-x}$). As shown in Figure 1 layer 14 has an optical activity dipole facing up and has an index of refraction greater than that of substrate 12 so as to form a waveguide. Because of the construction of the present device, it is not necessary that the difference in indices of refraction of the substrate and waveguide be great. By way of example only, index differences of only 0.13 for the fundamental

frequency and 0.18 for the harmonic frequency have been found effective. Disposed on waveguide layer 14 is a second waveguide layer 16 whose optical activity dipole is opposite that of waveguide layer 14. This orientation of layers having opposed optical activity dipoles provides a "twin plane" or an "inverted polarization interface 18 between the layers.

As shown in Fig. 1 by the arrows, the dipole abruptly changes direction at the interface. Light of a fundamental frequency ω enters the device parallel to the plane of the inverted polarization interface 18. The effect of interface 18 is such that second harmonic generation is caused. The inverted polarization interface 18 causes the positive (or negative) going half of the sinusoidal electromagnetic wave traveling along interface 18 to be inverted causing a doubling in frequency. The thickness of waveguide layers 14 and 16 are adjusted in a known manner (see for example the technique described in P.K. Tien, *Applied Optics*, Vol. 10, p. 2395 (1981)) so that phase matching occurs between the input and output radiation. The light exiting the device is therefore twice the frequency (2ω) of the light entering the device.

Molecular beam epitaxy (MBE) has permitted the growth of crystal structures of great complexity in extremely thin layers. The waveguide layers 14, 16 may be grown by this technique. In order to produce the device of Figure 1 the layer 14 of non-linear optical material such as ZnSe or other material is grown on substrate 12 by MBE and will accordingly have a first polarity. Thereafter, a relatively thin layer of non-polarized material, such as germanium (Ge) is grown on layer 14. Finally, another layer of the zinc selenide is grown on the germanium layer to form the second waveguide layer 16. When this second zinc selenide layer is grown there is a 50% probability that the polarization of the second layer 16 will be opposite to that of the first layer 14 which provides the required inverted polarization interface. If the polarization of the second layer is the same as the first layer, which is also a 50% probability, the inverted polarization interface will not have been achieved and the device will be inoperative and should be discarded. The non-polarized layer of germanium has no effect on the operation of the device since the thickness of this layer is relatively small when compared to the wavelength of light in question.

Figure 2 illustrates a relatively simple method for achieving the inverted polarization interface required. By these means, a waveguide layer 22 is provided on a substrate 20 by proton bombardment or ion exchange. Substrate 20 is thereafter cleaved along a line 24 perpendicular to the waveguide layer 22 and substrate 20. After cleaving, the substrate and waveguide layer is flipped

over upon itself as shown. The physical reversal of the waveguide layer 22 upon itself creates an inverted polarization interface 26 along the plane of contact. The upper portion 28 of the substrate 20 is unnecessary and can be removed.

Figure 3 illustrates yet another means for providing the inverted polarization interface in the waveguide layer by means of asymmetric quantum wells, grown with the polarity of the growth direction inverted to form the interface. As shown in Fig. 3 an inverted polarization plane 40 is formed between a lower portion of quantum wells 42 and an upper portion of quantum wells 44. As shown in Figure 3 the lower 42 and upper 44 asymmetric quantum wells are mirror images of one another along plane 40. Such mirror image asymmetric quantum wells may be readily grown by MBE processes.

The present application is not limited to only the generation of blue light from infrared light. Rather, the frequency doubling device is applicable to doubling the frequency of a fairly wide range of electromagnetic radiation. Devices for different frequencies will utilize active layers of different materials. For example, the infrared to blue conversion is achieved with materials of the II-VI family. Similarly materials in the III-V family such as gallium arsenide (GaAs) may be utilized for the generation of red light from input frequency of half that. As those skilled in the art will appreciate, a selection of materials and film thicknesses can provide frequency doubling for whatever output frequency is desired.

Although the present invention has been described in conjunction with the preferred embodiments, it is to be understood that modifications and variations may be resorted to without departing from the scope of the invention, as those skilled in the art will readily understand. Such modifications and variations are considered to be within the purview and scope of the invention and the appended claims.

Claims

1. A frequency doubling device comprising a substrate, a waveguide made of non-linear optical material disposed on said substrate and means for directing electromagnetic radiation across said waveguide, characterized in that the waveguide has an interface disposed therein, which interface separates two layers having inverted polarization directions, said interface hereinafter being defined as an inverted polarization interface and that the means direct the electromagnetic radiation into the waveguide in a direction parallel to the interface.

2. A frequency doubling device as claimed in Claim 1 comprising two waveguide layers, which waveguide layers are arranged in juxtaposition with their top surfaces facing each other, the two layers in juxtaposition having opposed polarization dipoles and thereby forming said inverted polarization interface.
3. A frequency doubling device as claimed in Claim 1 wherein said inverted polarization interface is formed by growing a waveguide of a first polarity and thereafter growing a waveguide of a second opposite polarity.
4. A frequency doubling device as claimed in Claim 2 or 3 further including a relatively thin layer of neutral polarity material disposed between said first and second polarity waveguides.
5. A frequency doubling device as claimed in Claim 1, wherein said inverted polarization interface is formed between two sets of asymmetric quantum wells, the sets of quantum wells being each others mirror image with respect to said inverted polarization interface.
6. A frequency doubling device as claimed in Claim 1, 2 or 3 wherein said waveguide is formed from zinc selenide.
7. A frequency doubling device as claimed in Claim 1, 2 or 3 wherein said waveguide layer is formed from zinc
8. A frequency doubling device as claimed in any one of the preceding Claims, wherein said substrate comprises KTiOPO_4 (KTP).
9. A method of doubling the frequency of electromagnetic radiation by providing a waveguide made of a non-linear optical material disposed on a substrate, said waveguide having a refractive index differing from that of the substrate, characterized by including an inverted polarization interface separating two layers having inverted polarization directions, said interface extending along said waveguide and by directing the electromagnetic radiation to be doubled in frequency into the waveguide in a direction parallel to said inverted polarization interface.

Patentansprüche

1. Vorrichtung zur Frequenzverdopplung mit einem Substrat, einem auf dem genannten Substrat vorhandenen Wellenleiter aus einem nicht-linearen optischen Material und einem

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2. A frequency doubling device as claimed in Claim 1 comprising two waveguide layers, which waveguide layers are arranged in juxtaposition with their top surfaces facing each other, the two layers in juxtaposition having opposed polarization dipoles and thereby forming said inverted polarization interface.
3. A frequency doubling device as claimed in Claim 1 wherein said inverted polarization interface is formed by growing a waveguide of a first polarity and thereafter growing a waveguide of a second opposite polarity.
4. A frequency doubling device as claimed in Claim 2 or 3 further including a relatively thin layer of neutral polarity material disposed between said first and second polarity waveguides.
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Patentansprüche

1. Vorrichtung zur Frequenzverdopplung mit einem Substrat, einem auf dem genannten Substrat vorhandenen Wellenleiter aus einem nicht-linearen optischen Material und einem



Mittel zur Lenkung elektromagnetischer Strahlung durch den genannten Wellenleiter, dadurch gekennzeichnet, daß in dem Wellenleiter eine Grenzfläche angeordnet ist, die zwei Schichten mit invertierten Polarisationsrichtungen voneinander trennt, wobei die genannte Grenzfläche im folgenden als eine Grenzfläche mit invertierter Polarisation bezeichnet wird, und daß das Mittel die elektromagnetische Strahlung parallel zu der Grenzfläche in den Wellenleiter leitet.

2. Vorrichtung zur Frequenzverdopplung nach Anspruch 1 mit zwei Wellenleiter-Schichten, die so nebeneinanderliegen, daß sich ihre Oberflächen gegenüberliegen, wobei die beiden nebeneinanderliegenden Schichten entgegengesetzte Polarisationsdipole aufweisen und dadurch die genannte Grenzfläche mit invertierter Polarisation bilden.
3. Vorrichtung zur Frequenzverdopplung nach Anspruch 1, wobei die genannte Grenzfläche mit invertierter Polarisation durch das Züchten eines Wellenleiters mit einer ersten Polarität und das anschließende Züchten eines Wellenleiters mit einer zweiten, entgegengesetzten Polarität gebildet wird.
4. Vorrichtung zur Frequenzverdopplung nach Anspruch 2 oder 3, die weiterhin eine relativ dünne Schicht aus einem Material mit neutraler Polarität enthält, die zwischen dem Wellenleiter mit erster Polarität und dem Wellenleiter mit zweiter Polarität angeordnet ist.
5. Vorrichtung zur Frequenzverdopplung nach Anspruch 1, wobei die genannte Grenzfläche mit invertierter Polarisation zwischen zwei Reihen von asymmetrischen Quantum-Wells gebildet wird, wobei die Reihen von Quantum-Wells jeweils an der Grenzfläche mit invertierter Polarisation gespiegelt werden.
6. Vorrichtung zur Frequenzverdopplung nach Anspruch 1, 2 oder 3, wobei der genannte Wellenleiter aus Zinkselenid gebildet wird.
7. Vorrichtung zur Frequenzverdopplung nach Anspruch 1, 2 oder 3, wobei die genannte Wellenleiter-Schicht aus Zinkschwefelselenid der Zusammensetzung $\text{ZnS}_x\text{Se}_{1-x}$ gebildet wird.
8. Vorrichtung zur Frequenzverdopplung nach einem der vorhergehenden Ansprüche, wobei das Substrat KTiOPO_4 (KTP) enthält.

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9. Verfahren zur Verdopplung der Frequenz von elektromagnetischer Strahlung durch Schaffung eines Wellenleiters aus einem nicht-linearen optischen Material, der auf einem Substrat angeordnet wird, wobei der genannte Wellenleiter einen anderen Brechungsindex aufweist als das Substrat, gekennzeichnet durch das in den Wellenleiter Aufnehmen einer die beiden Schichten mit entgegengesetzten Polarisationsrichtungen voneinander trennenden, sich entlang des genannten Wellenleiters erstreckenden Grenzfläche mit invertierter Polarisation sowie durch das Leiten der in der Frequenz zu verdoppelnden elektromagnetischen Strahlung parallel zu der genannten Grenzfläche mit invertierter Polarisation in den Wellenleiter.

Revendications

1. Dispositif doubleur de fréquence comprenant un substrat, un guide d'ondes formé d'une matière optique non linéaire disposée sur le substrat et des moyens pour diriger un rayonnement électromagnétique dans le guide d'ondes, caractérisé en que le guide d'ondes contient une interface qui sépare deux couches présentant des directions de polarisations inverses, l'interface étant définie ci-après comme étant une interface de polarisation inversée et les moyens dirigent le rayonnement électromagnétique dans le guide d'ondes dans une direction parallèle à l'interface.
2. Dispositif doubleur de fréquence suivant la revendication 1, comprenant deux couches de guide d'ondes qui sont juxtaposées avec leurs surfaces supérieures qui se font face, les deux couches juxtaposées comportant des dipôles de polarisation opposés et formant ainsi l'interface de polarisation inversée.
3. Dispositif doubleur de fréquence suivant la revendication 1, dans lequel l'interface de polarisation inversée est formée par croissance d'un guide d'ondes d'une première polarité, puis par croissance d'un guide d'ondes d'une seconde polarité opposée.
4. Dispositif doubleur de fréquence suivant la revendication 2 ou 3, comprenant, en outre, une couche relativement mince de matière de polarité neutre disposée entre les guides d'ondes de la première et de la seconde polarité.
5. Dispositif doubleur de fréquence suivant la revendication 1, dans lequel l'interface de polarisation inversée est formée entre deux jeux de



puits quantiques asymétriques, les jeux de puits quantiques étant énantiomorphes par rapport à l'interface de polarisation inversée.

6. Dispositif doubleur de fréquence suivant la revendication 1, 2 ou 3, dans lequel le guide d'ondes est fait de sélénure de zinc. 5
7. Dispositif doubleur de fréquence suivant la revendication 1, 2 ou 3, dans lequel la couche de guide d'ondes est faite de sélénure de soufre et de zinc. 10
8. Dispositif doubleur de fréquence suivant l'une quelconque des revendications précédentes, dans lequel le substrat comprend du KTiOP_4 - (KTP). 15
9. Procédé pour doubler la fréquence d'un rayonnement électromagnétique en fournissant un guide d'ondes fait d'une matière optique non linéaire disposée sur un substrat, le guide d'ondes ayant un indice de réfraction différent de celui du substrat, caractérisé en ce qu'on prévoit une interface de polarisation inversée séparant deux couches présentant des directions de polarisations inverses, cette interface s'étendant le long du guide d'ondes et on dirige le rayonnement électromagnétique dont la fréquence doit être doublée dans le guide d'ondes dans une direction parallèle à l'interface de polarisation inversée. 20
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