

Description

Background of the Invention

1. Field of the Invention

The invention pertains generally to optical systems, e.g., optical communication systems and optical computers.

2. Art Background

Optical systems, e.g., optical communication systems and optical computers, are in use, or are being developed, because such systems are capable, or offer the possibility, of transmitting and/or processing much larger amounts of information, much more quickly, than is possible using purely electronic systems.

The optical systems, referred to above, typically include one or more sources of electromagnetic radiation, e.g., one or more semiconductor lasers, a device (or devices) for processing the electromagnetic radiation emitted by the sources, and one or more detectors for detecting the processed electromagnetic radiation. The electromagnetic radiation emitted by the sources is communicated to the processing device (or devices), and then to the detectors through, for example, the air, a vacuum, or through waveguides such as optical fibers.

The processing devices employed in the optical systems include, for example, switches (devices for switching electromagnetic radiation from one waveguide to another waveguide of the system), amplitude modulators (devices for altering the intensity of the electromagnetic radiation), and multiplexers/demultiplexers (devices which serve, for example, to redirect the electromagnetic radiation carried by a plurality of waveguides onto a single waveguide and vice versa). At present, these devices are typically fabricated in electro-optic materials, such as lithium niobate, and the processing is performed electronically. For example, a switch, containing two or more planar waveguides (typically in optical communication with other waveguides, e.g., optical fibers, of the system) is formed in a lithium niobate substrate by depositing a dopant, such as titanium, onto the surface of the substrate in the pattern desired for the planar waveguides. The substrate is then heated to diffuse the dopant into the substrate, thus forming the planar waveguides. In addition, electrodes are formed on opposite sides of one or more of the planar waveguides. To produce switching, a voltage is applied across the electrodes, thus inducing a local change in the optical polarizability of the lithium niobate, which locally changes the refractive

index and, in turn, alters the path of the light from one planar waveguide to the other planar waveguide. Significantly, switching speed depends upon the configuration of the electrodes. For example, when applying a voltage to electrodes having a lumped electrode configuration, the time required to achieve switching is limited by the RC time constant of the electrodes, which is typically several nanoseconds (ns). (Removing the applied voltage results in the induced changes in optical polarizability and refractive index disappearing essentially instantaneously.) As a consequence, the cycle time (the time interval between successive switching operations) is limited to (is no smaller than) several nanoseconds (ns), and thus the repetition rate (the number of switching operations per unit time, equal to the inverse of the cycle time) is limited to no more than about 3×10^8 Hertz (Hz). On the other hand, when using a traveling wave (transmission line) electrode configuration, a switching time, and a cycle time, equal to several hundreds of picoseconds (ps) is readily achieved, yielding a repetition rate as high as 3×10^9 Hz.

To achieve even shorter cycle times and higher repetition rates, devices have been sought, and proposed, in which the processing is achieved by purely optical means. That is, these proposed devices typically include a region of material which serves as a transmission medium for a beam of electromagnetic radiation (hereafter the signal beam) to be processed. Significantly, the transmission medium is chosen to exhibit a nonlinear optical response (a change in refractive index and/or optical absorption) when impinged by a second beam of electromagnetic radiation (hereafter the control beam), with the nonlinear optical response serving to effect the processing of the signal beam.

One device which is exemplary of the devices employing purely optical processing is disclosed in J. L. Jewell et al., "Parallel Operation and Crosstalk Measurements in GaAs Etalon Optical Logic Devices," *Applied Physics Letters*, Vol. 48, No. 20, 19 May 1986, pp. 1342-1344. This device is a gallium arsenide (GaAs) etalon which includes a layer of GaAs (an inorganic semiconductor material), having a thickness less than about 1 micrometer (μm), sandwiched between two dielectric mirrors. The mirrors are designed to exhibit relatively high reflectivity to electromagnetic radiation having a wavelength of about 890 nanometers (nm), and relatively low reflectivity to electromagnetic radiation having a wavelength of about 800 nm. Moreover, the etalon is designed so that a peak in the transmission curve of the etalon occurs at the former wavelength. In operation, and in the absence of a control beam, a signal beam, having a wavelength of 890 nm, impinging upon the GaAs, suffers relatively little absorption, and is thus large-

ly transmitted. On the other hand, by impinging a control beam, having a wavelength of 800 nm, upon the GaAs, valence band electrons in the GaAs are promoted into the conduction band, which alters the refractive index of the GaAs and, as a consequence, (essentially instantaneously) shifts the etalon transmission peak away from 890 nm. As a result, the signal beam (having a wavelength of 890 nm) suffers relatively low transmission. Depending upon the thickness of the GaAs, this decrease in etalon transmission exhibits a characteristic decay time, τ (the time interval over which the decrease in transmission decays to 1/e of its original value, after the control beam is turned off), ranging from about 200 ps to about 15 ps. Significantly, it is this decay time which limits device speed. That is, the control beam cannot be turned on a second time to produce a significantly decreased etalon transmission until the first transmission decrease has largely disappeared, which typically takes about 2τ . Thus, and depending upon the thickness of the GaAs, the cycle time of this device (the time interval between successive, low transmission states) ranges from about 400 ps to about 30 ps, and therefore the repetition rate ranges from about 2.5×10^9 Hz to about 3.3×10^{10} Hz.

Rather than employing inorganic semiconductor materials, such as GaAs, processing devices have also been proposed which employ organic materials, such as polydiacetylene (PDA). In this regard, it is known that one particular crystalline form of PDA, known as poly-2,4-hexadiyn-1,6-diol bis (p-toluene sulfonate) (PDA-PTS), exhibits the absorption spectrum depicted in FIG. 1, which includes a wavelength region of relatively high absorption (a region where the absorption coefficient, α , is greater than or equal to about 2×10^4 cm⁻¹), extending from about 640 nm to shorter wavelengths. It is also known that this relatively high absorption region is associated with electrons being promoted from a relatively low energy electronic state (the ground state) to a higher energy electronic state as a result of photon absorption. Significantly, it has long been known that PDA exhibits a relatively large (compared to that in other materials) nonlinear optical response at wavelengths associated with relatively low absorption, i.e., wavelengths at which α is less than about 2×10^4 cm⁻¹. This response is believed to decay essentially instantaneously, i.e., within 10^{-15} seconds. Unfortunately, the magnitude of this response (though relatively large compared to that in other materials) is generally too small to be useful for device applications. On the other hand, it has long been believed that the (much larger) nonlinear optical response at wavelengths exhibiting relatively high absorption (α is greater than or equal to about

2×10^4 cm⁻¹) would have a much longer decay time.

An experimental investigation into the decay times associated with the nonlinear optical responses produced in PDA-PTS at wavelengths ranging from about 651.5 nm (which is at the long-wavelength edge of the relatively high absorption region extending from about 640 nm to shorter wavelengths) to about 701.5 nm has been carried out and is described in G. M. Carter et al, "Time and Wavelength Resolved Nonlinear Optical Spectroscopy of a Polydiacetylene in the Solid State Using Picosecond Dye Laser Pulses", *Applied Physics Letters*, Vol. 47, No. 5 (September 1, 1985), pp. 457-459. This investigation involved the use of conventional, degenerate four-wave mixing. That is, two pulses of electromagnetic radiation, of identical wavelength, were interfered within a volume region of the PDA-PTS to produce a periodic intensity variation which resulted in a periodic variation in refractive index (the nonlinear optical response) and thus, in effect, a volume diffraction grating. These pulses had durations of about 6 ps and had peak intensities of about 2.5×10^7 watts per square centimeter (W/cm²). A third pulse of electromagnetic radiation, of identical wavelength, duration and intensity was impinged upon the PDA-PTS and diffracted by the diffraction grating to produce a fourth beam of electromagnetic radiation which traversed the thickness of the PDA-PTS and was then detected by a detector. By varying the arrival time of the third pulse relative to the first two pulses, it was determined that the duration of the nonlinear optical response at the edge of the PDA-PTS relatively high absorption region was less than the pulse duration, and thus less than about 6 ps. Based upon this experimental data, and by making a number of (implicit) assumptions, it was then inferred that the nonlinear optical response at relatively high absorption wavelengths, e.g., at 625 nm, would also have a decay time less than about 6 ps. One of the (implicit) assumptions underlying this conclusion is that the absorption in PDA-PTS is attributable to the existence of only a single electronic excited state, and it was this state that was accessed (populated) by the two interfering pulses.

To date, there has been no reported experimental verification that PDA truly exhibits a nonlinear optical response at relatively high absorption wavelengths having a decay time less than about 6 ps. In the absence of such verification, the utility of PDA in fast optical processing devices is still in question.

Thus, those engaged in the development of optical processing devices have sought, and continue to seek, fast devices capable of achieving relatively high repetition rates.

Summary of the Invention

According to the invention there is provided an optical system as set out in claim 1. We have found that a plurality of states are readily populated in materials, e.g., organic materials such as PDA, via resonant optical (control beam) excitations, i.e., optical excitations at wavelengths where α is greater than or equal to about $2 \times 10^4 \text{ cm}^{-1}$, and that these states include both relatively short-lived and relatively long-lived states. Moreover, the wavelength, duration and intensity of the control beam radiation determine which state or states are accessed. For example, in the case of PDA-PTS, it has been found that only a first electronic energy level (herein denoted S_1), having a decay time of about 2 ps, is populated provided the incident control beam is in the form of a pulse having a wavelength of about 625 nm, a duration of about 2 ps or longer (full-width-at-half maximum), and an intensity (the ratio of pulse energy to pulse width, per unit area) equal to or less than about $4 \times 10^6 \text{ W/cm}^2$. If the corresponding nonlinear optical response is to have a decay time equal to that of S_1 , then the duration of the control beam pulse should be less than or equal to 2 ps (to avoid repopulating S_1 , and thus producing a longer nonlinear optical response). As a consequence, a cycle time (in the nonlinear optical response) as small as about 4 ps (twice the decay time of the nonlinear optical response), and a corresponding repetition rate as high as about $2.5 \times 10^{11} \text{ Hz}$, is readily achieved.

By contrast, it has also been found that a control beam pulse of wavelength equal to 625 nm, duration equal to or greater than about 2 ps, and intensity greater than about $4 \times 10^6 \text{ W/cm}^2$ results in the population of a triplet state (herein denoted T_1), as well as S_1 . Significantly, this triplet state exhibits a decay time equal to about forty microseconds (μs). Thus, if a control beam pulse (of wavelength equal to 625 nm) had a duration of, for example, 2 ps, and the intensity of the control beam were equal to $2.5 \times 10^7 \text{ W/cm}^2$ (the intensity employed in Carter et al), then the resulting nonlinear optical response would contain both a component exhibiting a 2 ps decay time as well as a component exhibiting a decay time equal to about 40 μs . Successive repetitions of such control beam pulses, separated by time intervals less than about 40 μs , would necessarily result in an ever-increasing population in T_1 (until a steady-state population is established), which would be manifested by a corresponding nonlinear optical response, i.e., the response would include (a relatively slow) component exhibiting a decay time equal to about 40 μs . As a result, at cycle times less than about $2\tau = 80 \mu\text{s}$, and thus repetition rates greater than about

$1.25 \times 10^4 \text{ Hz}$, the form of the nonlinear optical response would be dependent upon the repetition rate, i.e.; the relative amplitude of the relatively slow component would increase with increasing repetition rate.

It has further been found that even at relatively low intensities, the use of relatively short wavelength (high frequency) control beam radiation, e.g., control beam radiation of wavelength equal to 488 nm, also results in the population of T_1 in PDA-PTS, and thus results in the relatively slow, nonlinear optical responses discussed above.

Brief Description of the Drawings

The invention is described with reference to the accompanying drawings, wherein:

FIG. 1 is a graph of absorption coefficient, α , as a function of photon energy and wavelength, λ , for PDA-PTS;

FIG. 2 depicts the inventive optical system;

FIGS. 3 and 5-9 depict embodiments of the inventive optical processing device;

FIG. 4 depicts the structure of PDA;

FIG. 10 depicts the nonlinear optical response induced in PDA-PTS using a single control beam pulse of wavelength equal to 625 nm, of duration equal to 70 femtoseconds, and of intensity equal to about $10^{10} \text{ watts/cm}^2$;

FIGS. 11-12 depict the resonant nonlinear optical responses induced in PDA-PTS using control beam pulses having identical wavelengths and durations but different intensities;

FIG. 13 depicts yet another embodiment of the inventive optical processing device; and

FIG. 14 depicts the results of a transient-absorption spectroscopy experiment performed on an optical processing device of the type depicted in Fig. 13.

Detailed Description

The invention involves an optical system, e.g., an optical communication system or an optical computer, which includes one or more optical processing devices, at least one of these devices employing, at least in part, purely optical processing. Significantly, this device includes a material, e.g., an organic material, exhibiting a nonlinear optical response at one or more resonant wavelengths. In addition, the device includes at least one source of electromagnetic radiation which emits a control beam whose wavelength, duration and intensity are chosen to produce a resonant, nonlinear optical response within the material of sufficiently short duration so as to be essentially free of any relatively slow component even at repetition rates higher than about $1.25 \times 10^4 \text{ Hz}$ (i.e.,

at repetition rates which yield relatively slow components when using the durations and intensities taught in Carter et al.), or higher than about 3.3×10^{10} Hz (higher than is achievable with the GaAs etalon), or even as high as about 2.5×10^{11} Hz (readily achieved in PDA, provided the appropriate wavelength, duration and intensity is employed).

With reference to FIG. 2, the inventive optical system 10 includes at least one source 20 of (signal) electromagnetic radiation, e.g., at least one semiconductor laser, which is in optical communication with one or more devices which process the (signal) electromagnetic radiation emitted by the source (or sources) 20. At least one of these processing devices is a processing device 40 which employs (at least in part) purely optical processing. The system 10 also includes at least one detector 60 of electromagnetic radiation, in optical communication with the processing device 40. In one embodiment of the invention, the source 20 communicates with the processing device 40, which in turn communicates with the detector 60, through waveguides 30 and 50, such as optical fibers (as shown in FIG. 2). Alternatively, the optical communication is achieved by transmitting the unprocessed and processed electromagnetic radiation through, for example, the air or a vacuum.

In accordance with the invention, the processing device 40 includes a region of material 42 (see FIG. 3) which exhibits one or more resonant wavelengths, i.e., the material 42 exhibits an absorption coefficient, α , greater than or equal to about $2 \times 10^4 \text{ cm}^{-1}$ at each such wavelength. (For purposes of the invention, the resonances produced at these wavelengths are associated with one or more of a variety of material excitations, e.g., electronic excitation, vibrational excitation, etc.) In addition, the device 40 includes one (or more) sources 44 of electromagnetic radiation to provide one (or more) control beams at a resonant wavelength or wavelengths. Significantly, both the material 42 as well as the duration, intensity and resonant wavelength or wavelengths of the control beam radiation are chosen so as to only populate an energy state or states of the material 42 having decay times less than about 40 μs , or less than about 15 ps, or even as small as about 2 ps or less. (Here, the decay time of an energy state denotes the time interval over which the excited state population decays to 1/e of its original size.)

If the duration of the control beam radiation is longer than the decay time of an excited state of the material 42, then the excited state will necessarily be repopulated, resulting in a corresponding, nonlinear optical response having a duration equal to or longer than that of the radiation. Thus, to achieve a nonlinear optical response having a decay time, τ , as short as the decay time of the

excited state, the duration of the radiation should be equal to or less than the decay time of the excited state. (Here τ denotes the time interval over which the magnitude of the nonlinear optical response decreases to 1/e of its original value.)

By employing a cycle time (the time interval between applications of the control beam radiation) equal to (or longer than) about 2τ , it has been found that the resulting resonant, nonlinear optical responses within the material 42 are essentially free of any relatively slow components even at relatively high repetition rates (the frequency of application of control beam radiation, equal to the inverse of the cycle time). For example, for the materials described below, this has been found to be true for repetition rates higher than about 1.25×10^4 Hz ($\tau = 40 \mu\text{s}$), or higher than about 3.3×10^{10} Hz ($\tau = 15 \text{ ps}$), or even as high or higher than about 2.5×10^{11} Hz ($\tau = 2 \text{ ps}$). (For purposes of the invention, a nonlinear optical response in the material 42 is essentially free of any relatively slow component, at a particular repetition rate, provided that after subjecting the initially unactivated material 42 to 100 pulses of control beam radiation at that repetition rate, the nonlinear optical response produced by the last pulse meets a specific criterion. This criterion is that the ratio of the magnitude of the response maximum (relative to a zero defined by the unactivated material) to the magnitude of the response after a time interval (subsequent to the one-hundredth pulse) equal to the cycle time, is equal to or greater than about 10.)

Materials exhibiting the relatively short (excited state) decay times, discussed above, are readily found, in accordance with the invention, by employing a two-step procedure. The first step of this procedure is to find condensed phase materials, e.g., solid or liquid materials, having absorption spectra which include resonant wavelengths, as defined above. In this regard, the absorption spectra of many materials are to be found in a wide variety of references (see, e.g., CRC Handbook of Chemistry Physics, edited by R. C. Weast (CRC Press, Inc., Boca Raton, Fla.), 80th edition, 1980), or can readily be measured using conventional techniques (regarding these techniques see, e.g., P. Laszlo and P. Stang, Organic Spectroscopy - (Harper & Row Publishers, N. Y.), 1971). The second step is to vary the resonant wavelength, intensity and duration of the control beam radiation until a wavelength-intensity-duration regime (or regimes) is found which yields an excited state (or states) having the desired decay time. The presence, and duration, of such excited states is readily detected using conventional techniques such as time-resolved absorption spectroscopy or time-resolved luminescence (regarding these techniques, see,

e.g., "An Apparatus for Obtaining Accurate Transient Absorption Spectra on the Picosecond Time Scale," by R. B. Weisman and B. I. Greene in *Multichannel Image Detectors*, edited by Y. Talmi [American Chemical Society, Washington, D. C., 1979]).

Materials which exhibit resonant wavelengths are typically, although not exclusively, organic materials. As discussed, one such material is PDA. For purposes of the invention, PDA is a polymer having the structure shown in FIG. 4. Here, R denotes any one of a variety of side groups. One such side group is, for example, paratoluene sulfonate (PTS). Other useful side groups are described in "Structural Aspects of the Topochemical Polymerization of Diacetylenes," by V. Enkelmann in *Advances in Polymer Science* 63 (Springer-Verlag, Berlin, Heidelberg, 1984). Significantly, the side groups play only a minor role in defining the optical properties of PDA, typically serving only to shift the long-wavelength absorption peak of PDA, which is typically located at about 630 nm (see, e.g., FIG. 1 which is the absorption curve for PDA-PTS).

If, for example, R is PTS, then it has been found, using the procedure described above, that PDA exhibits both a relatively short-lived electronic energy state, here denoted S_1 , and a relatively long-lived electronic triplet state, here denoted T_1 . That is, by using 2 ps-long pulses of control beam radiation, it has been found that S_1 has a decay time of about 2 ps, and that it alone is populated at an excitation wavelength of, for example, 625 nm, provided the control beam intensity is equal to or less than about 4×10^6 W/cm². On the other hand, at higher intensities, it has been found that both S_1 and T_1 are populated, and that T_1 has a decay time of about 40 μ s.

Not only does S_1 exhibit a relatively short decay time but, equally surprisingly, it has been found that the corresponding nonlinear optical response is much larger in magnitude than previously imagined. For example, when populating S_1 (using the control beam resonant wavelength, duration and intensity, discussed above), signal beam radiation, at the corresponding, resonant wavelength (of 625 nm), will see (what is considered to be) a relatively large change in refractive index from about 6.0 to about 5.95. Similarly, such signal beam radiation will also see a change in absorption coefficient from about 8×10^5 cm⁻¹ to about 7.96×10^5 cm⁻¹, which is correspondingly large.

It has been found that populating S_1 not only produces a relatively large change in refractive index or absorption coefficient in relation to a resonant signal beam but, quite unexpectedly, produces a relatively large change in refractive index

and absorption coefficient in relation to signal beam radiation having nonresonant wavelengths. (The particular nonresonant wavelengths so affected must generally be determined empirically.)

A variety of optical processing devices 40, capable of operating at relatively high repetition rates (by virtue of the relatively short decay times of the material 42), have been developed and are depicted in FIGS. 5-9. For example, the device 40 depicted in FIG. 5 is an amplitude modulator. In operation, a resonant control beam 46 (emitted by the source 44) is used to populate a relatively short-lived energy state, to produce a change in absorption. Simultaneously, a resonant or nonresonant signal beam 22 (emitted by the source 20) is impinged upon the material 42 to suffer absorption, and thus modulation, i.e., a change in intensity.

The embodiment of the device 40 depicted in FIG. 6 is useful, for example, as a demultiplexer. In operation, two resonant control beams 46 and 48 (emitted, for example, by two control beam sources) are interfered on a surface of the material 42 (in contrast to a volume region of the material 42), to produce a periodic intensity variation resulting in a periodic variation in refractive index, and thus a diffraction grating, on the surface of the material 42. Coincidentally with the formation of the diffraction grating, a resonant or nonresonant signal beam 22 is impinged upon the surface of the material 42, and reflectively diffracted from the surface of the material 42. If the signal beam radiation 22 consists of a plurality of optical pulses which have been multiplexed onto a waveguide, e.g., an optical fiber, used to communicate these pulses to the device 40, then selected pulses are readily diffracted, to achieve demultiplexing, by selectively forming the diffraction grating on the surface of the material 42. To avoid diffracting non-selected pulses, the time interval between the pulses should be greater than or equal to the decay time of the diffraction grating.

A third embodiment of the device 40 is depicted in FIG. 7 and is useful as a switch. This embodiment includes two intersecting, planar waveguides 47 and 49. Such waveguides are, for example, thin layers 42 of PDA formed in a monomeric crystal by subjecting selected surface regions of the crystal to a beam of energy, e.g., a heat beam or a beam of electrons. (Regarding this technique for polymerizing PDA from monomeric crystals see, e.g., J. Berrehar, C. Lapersonne-Meyer and M. Schott, "Polydiacetylene Single Crystal Thin Films," *Applied Physics Letters*, Vol. 48, No. 10, 1986, pp. 630-631.) In operation, two resonant control beams 46 and 48 are interfered on a surface region of the monomeric crystal common to the two planar waveguides to produce a diffraction grating. Simultaneously, a resonant or nonresonant

signal beam 22 is propagated down one of the waveguides, e.g., the waveguide 47, to be diffracted (by the diffraction grating), and thus switched, into the other waveguide, e.g., the waveguide 49.

A fourth embodiment of the device 40, depicted in FIG. 8, is useful as a modulator. This embodiment includes a planar waveguide 47, e.g., a thin layer 42 of PDA formed in a monomeric, crystalline substrate. In operation, two resonant control beams 46 and 48 are interfered on an upper surface of the waveguide 47 to produce a periodic variation in refractive index. Simultaneously, a signal beam 22 is propagated down the waveguide 47. If the distance, d , between adjacent minima in the periodic refractive index variation is equal to half the wavelength of the signal beam radiation (in the waveguide), then the periodic variation in refractive index functions as a Bragg reflector, which reflects the signal beam radiation. Thus, by forming the Bragg reflector at selected instants in time, the signal beam 22 is modulated, i.e., its intensity is selectively reduced.

Yet a fifth embodiment of the device 40 is depicted in FIG. 9, and is also usefully employed as a modulator. This embodiment (which is a variant of the known Mach-Zender switch) includes a waveguide 45, which bifurcates into waveguides 47 and 49 which, in turn, converge to once again form the single waveguide 45. This embodiment also includes a material region 42 (exhibiting a resonant, nonlinear optical response) overlying one of the waveguides resulting from the bifurcation, e.g., the waveguide 47. In operation, a signal beam 22 is propagated down the waveguide 45 (from left to right, as viewed in FIG. 9), and thus split into two signal beam portions on propagating through the waveguides 47 and 49. By impinging the material region 42 with a resonant control beam 46, a change in refractive index is produced in the material region 42, which affects the portion of the signal beam 22 propagating through the underlying waveguide 47. This change in refractive index will necessarily result in different propagation speeds for the signal beam portions in the waveguides 47 and 49, resulting in a phase difference between the two beam portions at the juncture of the waveguides 47 and 49. If the refractive index change is large enough, and is experienced over a long enough path length, then a phase difference of π is readily produced. As a consequence, the signal beam portions will destructively interfere with one another at the juncture of the waveguides 47 and 49, with the resulting, single beam having diminished intensity. Thus, by selectively impinging the material region 42 with the control beam 46, the signal beam 22 is readily modulated.

As noted above, the GaAs etalon reported by

J. L. Jewell et al, supra, is useful as an optical processing device. However, in addition to its inability to achieve a repetition rate higher than about 3.3×10^{10} Hz, this device has other limitations. For example, in the absence of control beam radiation, the etalon exhibits a plurality of transmission peaks, with each peak centered at a wavelength, λ_m , given by the relation

$$m \lambda_m / 2 = n l \quad (1)$$

Here, m denotes a positive integer ($m = 1, 2, 3, \dots$), n denotes the refractive index of the GaAs (prior to being impinged by the control beam), and l denotes the thickness of the GaAs. Significantly, in the operation of the etalon, the wavelength of the control beam is chosen so that the corresponding photon energy is equal to or greater than the bandgap for GaAs, e.g., the control beam wavelength is chosen to be 800 nm (as noted above). Consequently, the control beam radiation is absorbed, resulting in the formation of electron-hole pairs within the GaAs. As noted above, the presence of these electron-hole pairs produces a significant change in the refractive index of the GaAs, but only over a narrow range of wavelengths of electromagnetic radiation, i.e., at room temperature, the range extends from about 870 nanometers (the wavelength having a corresponding photon energy equal to the bandgap edge in GaAs) to about 900 nanometers (nm). Thus, by choosing the thickness of the GaAs, l , so that one of the etalon transmission peaks lies within the above 30 nm range of wavelengths, e.g., lies at 890 nm (as noted above), then the refractive index change induced by the control beam serves to produce a corresponding shift in the wavelength-position of this transmission peak (the shift being calculable using Eq. (1)). Therefore, if the wavelength of the signal beam is chosen to be the (initially unshifted) transmission peak wavelength, the subsequent shift in the transmission peak (induced by the control beam) produces a substantial decrease in the transmission of the signal beam (and a corresponding increase in the amount of signal beam radiation reflected from the etalon), thus achieving the desired signal beam processing. However, because the GaAs etalon is incapable of producing significant shifts in transmission peaks positioned at wavelengths greater than about 900 nm (0.90 μ m), this etalon is incapable of processing signal beams having wavelengths of current commercial significance, e.g., wavelengths of 1.31 μ m and 1.55 μ m, presently favored in optical fiber communication systems. (In present, commercially available silica optical fibers, the minimum dispersion wavelength is typically at about 1.31 μ m, while the minimum loss wavelength is typically at about 1.55 μ m.)

Not only is the GaAs etalon limited in terms of the maximum achievable repetition rate and in terms of the wavelengths of the signal beams it is capable of processing, it is also limited in terms of spatial resolution. That is, it has been proposed that pairs of control and signal beams be simultaneously impinged upon separate regions of the GaAs etalon to achieve simultaneous, parallel processing of the signal beams. But the electron-hole pairs formed within each region of the GaAs (as a result of control beam absorption) have a lifetime of about 20 ns, during which they diffuse as much as about 20 μm . To avoid the possibility of cross-talk resulting from the diffusion of electron-hole pairs from one spatial region of the GaAs (where a first signal beam is being processed) to a second spatial region (where a second signal beam is being processed), the dimensions of these spatial regions must be bigger than about 20 μm , which limits the number of signal beams which can be simultaneously processed by the etalon.

Yet another limitation of the GaAs etalon is its sensitivity to temperature. That is, temperature changes produce shifts in the conduction band edge relative to the valence band of the GaAs. This band edge shift results in a significant change in refractive index, which has the effect of shifting all transmission peaks of the etalon, and particularly the transmission peak whose wavelength corresponds most closely to the bandgap edge. As a result, the ability of the device to process a signal beam having a wavelength equal to that of one of the unshifted transmission peaks is degraded.

It has been found that replacing GaAs with many of the materials 42 useful in the above-described embodiments of the optical processing device 40, results in etalons which overcome the limitations of the GaAs etalon. That is, and as noted above, it has been found that many of the materials 42 (exhibiting resonant, nonlinear optical responses having decay times less than, for example, about 40 μs , or less than about 2 ns, or less than about 15 ps, or equal to or less than about 2 ps) often also exhibit induced absorptions (having correspondingly short decay times) at other wavelengths. (For purposes of the invention, an induced absorption is one which is characterized by a substantial change in absorption per incident absorbed (photon) energy per unit area and/or a substantial change in refractive index per incident absorbed (photon) energy per unit area. In addition, it has been found that many of the materials 42 also exhibit substantial nonlinear optical responses at nonresonant wavelengths, which also have decay times less than, for example, about 40 μs , or less than about 2 ns, or less than about 15 ps, or equal to or less than about 2 ps, and which also lead to the same type of induced absorptions

(having correspondingly short decay times), discussed above. (For purposes for the invention, a material exhibits a substantial nonlinear optical response at a nonresonant wavelength if the absorption coefficient, α , at that wavelength is less than about $2 \times 10^4 \text{ cm}^{-1}$ but greater than or equal to about $1 \times 10^3 \text{ cm}^{-1}$.) Moreover, it has been found, in many instances, that the wavelengths at which the induced absorptions occur are often higher than about 0.90 μm , that the induced absorptions often extend over wavelength ranges larger than about 30 nm, and that the induced-absorption wavelengths often include commercially significant wavelengths.

If material 42 exhibiting induced absorptions of the type described above, at one or more wavelengths, is employed in an etalon, if the induced absorptions lead primarily to, for example, substantial increases in absorption per incident absorbed (photon) energy per unit area, and if the thickness of the etalon is chosen to produce etalon transmission peaks at the induced-absorption wavelengths, then impinging a (resonant- or nonresonant-wavelength) control beam upon such an etalon will necessarily produce significant increases in absorption at the induced-absorption wavelengths, and consequently produce substantial reductions in the magnitudes of the transmission peaks. Thus, if the signal beam impinging the etalon has a wavelength equal to that of one of the etalon transmission peaks, the signal beam will suffer substantially reduced transmission through, and a corresponding increase in reflection from, the etalon when the etalon is impinged by the control beam, resulting in the processing of the signal beam. As discussed more fully below, the material 42 and control beam are readily chosen so as to permit the processing of a signal beam having a wavelength greater than 0.90 μm , e.g., 1.31 μm or 1.55 μm , which is not possible with the GaAs etalon. In addition, if the nonlinear optical response, and the induced absorption, of the material 42 have decay times smaller than about 15 ps (materials exhibiting such decay times are readily found, as described below), then the etalon will be operable at repetition rates higher than about $3.3 \times 10^{10} \text{ Hz}$, which is also not achievable with the GaAs etalon.

Materials 42 exhibiting both a nonlinear optical response, i.e., a resonant, nonlinear optical response and/or a substantial nonlinear optical response at a nonresonant wavelength, and an associated induced absorption at a wavelength greater than, for example, about 0.90 μm and/or extending over a wavelength range greater than about 30 nm, with the nonlinear optical response and induced absorption having the relatively short decay times, discussed above, are readily found using the two-step procedure, described above. That is, during

the first step, condensed phase materials are sought having absorption spectra which include resonant wavelengths and/or nonresonant wavelengths exhibiting substantial, nonlinear optical responses. Then, during the second step, the wavelength, intensity and duration of the control beam radiation are varied until a wavelength-intensity-duration regime (or regimes) is found which yields a resonant or nonresonant, nonlinear optical response and an induced absorption at a desired wavelength or wavelengths, having the desired decay time. The presence, and duration, of the resonant or nonresonant, nonlinear optical response and induced absorptions are readily detected using, for example, the conventional technique of time-resolved absorption spectroscopy (see, e.g., R. B. Weisman and B. I. Greene, *supra*).

Using the above procedure, it has been found, in the case of, for example, PDA-PTS, that a single excited state, which decays to the ground state (via a relatively short-lived intermediate state) over a decay time of about 2 ps, is readily populated by using a control beam pulse having a resonant wavelength of 0.64 μm , a duration of 0.2 ps (full-width-at-half-maximum) and an intensity (the ratio of pulse energy to pulse width, per unit area) of $5 \times 10^8 \text{ W/cm}^2$. Moreover, populating this excited state results in induced absorptions, characterized primarily by substantial increases in absorption per incident absorbed (photon) energy per unit area, at virtually all wavelengths extending from about 0.7 μm up to at least 1.7 μm , including the wavelengths of 1.31 μm and 1.55 μm , and exhibiting decay times of about 0.8 ps. (The existence of these induced absorptions has only been measured up to 1.7 μm , and may also exist at higher wavelengths.) Thus, an etalon containing PDA-PTS permits optical processing of signal beam radiation having wavelengths currently favored in optical fiber communication systems, permits signal beam processing extending over a range of wavelengths much greater than 30 nm, and at repetition rates of, for example, $2.5 \times 10^{11} \text{ Hz}$.

If the material 42 is chosen to exhibit, for example, an excited state and an induced absorption having a decay time less than that of the electron-hole pairs produced in GaAs, i.e., a decay time less than about 15 ps, and if the rate of transfer of the energy associated with the excitation in the material 42 is similar to the electron-hole diffusion rate in GaAs, then this energy (associated with the excitation in the material 42) will be propagated over a distance, during the relatively short decay time of the excited state and induced absorption, which is smaller than the distance traversed by the electron-hole pairs in GaAs during their longer decay time. As a consequence, an etalon employing such a material 42 will be ca-

pable of overcoming yet another limitation of the GaAs etalon, i.e., it will be capable of simultaneously processing more signal beams than an equally-sized GaAs etalon.

As noted above, the materials 42 are typically (although not exclusively) organic materials, rather than inorganic semiconductor materials, as is the case with GaAs. Significantly, it has been found that the performance of etalons employing organic materials is not nearly as sensitive to temperature fluctuations as is the performance of etalons employing GaAs.

As a result of the above findings, a new embodiment of the optical processing device 40 has been developed, useful in the above-described optical system 10. This new embodiment is depicted in FIG. 13 and includes an etalon 70, as well as a source 44 (see FIG. 3) of control beam radiation 46. The etalon 70 includes a material region 42 sandwiched between two material regions 64 having inwardly-facing (as viewed in FIG. 13), mirror-like surfaces 66. The material region 42 is chosen to exhibit a resonant, nonlinear optical response and/or a substantial nonlinear optical response at a nonresonant wavelength, and an associated, induced absorption, at one or more wavelengths, having the relatively short decay times, discussed above. Preferably, this induced absorption is at a wavelength greater than about 0.90 μm and/or extends over a wavelength range greater than about 30 nm.

Each of the two material regions 64, which typically include dielectric materials such as magnesium fluoride or zinc sulfide, has both an inwardly facing surface 66 and an outwardly facing surface 68. Significantly, the two outwardly facing surfaces 68 are designed to exhibit relatively low reflectivity to both the control beam 46 and signal beam 22, i.e., the surfaces 68 are designed to reflect less than about 5 percent of impinging electromagnetic radiation at the control beam and signal beam wavelengths (to permit the control and signal beams to penetrate into the interior of the etalon). This relatively low reflectivity is achieved, for example, by applying conventional (single-layer) anti-reflection coatings to the surfaces 68. In addition, at least one of the inner surfaces 66, i.e., the surface 66 initially impinged by the control beam, is designed to exhibit relatively low reflectivity (as defined above) to electromagnetic radiation at the control beam wavelength, while both inner surfaces are also designed to exhibit relatively high reflectivity (i.e., a reflectivity greater than about 50 percent) to electromagnetic radiation at the signal beam wavelength. This difference in reflectivities at the two wavelengths is achieved, for example, by applying conventional multi-layered coatings to the surfaces 66.

During the operation of the etalon 70, the wavelength of the signal beam 22 must necessarily be equal to one of the induced-absorption wavelengths. Thus, the thickness of the material region 42 is chosen to produce an etalon transmission peak at this particular induced-absorption wavelength. In general, the thickness of the material region 42 is preferably less than about 50 μm . Thicknesses greater than about 50 μm , while not precluded, are less desirable because they lead to relatively low device contrast ratios.

Significantly, the etalon depicted in FIG. 13 is useful in achieving amplitude modulation, as well as time-division and wavelength-division multiplexing and demultiplexing. For example, in the event that a single signal beam 22 is to be modulated, then selectively impinging the etalon with the control beam 46 will produce a shift and/or change in amplitude of the transmission peak initially centered at a wavelength equal to the signal beam wavelength, selectively reducing the transmission of the signal beam through the etalon, and thus achieving the desired amplitude modulation. In addition, if a single, unmodulated signal beam, e.g., a constant intensity signal beam, having a wavelength equal to that of one of the etalon transmission peaks, is impinged upon the etalon, and if the etalon is also impinged by two or more modulated, i.e., information-containing, control beams 46, then the information contained in the control beams will be impressed upon the originally unmodulated single beam, resulting in the creation of a time-division multiplexed signal beam. Similarly, if the material 42 exhibits induced absorptions at two or more wavelengths, if the etalon has transmission peaks at these wavelengths, and if the etalon is impinged by a single, unmodulated signal beam having wavelengths encompassing the etalon transmission peaks, then impinging the etalon with two or more information-containing control beams 46 will transform the single, unmodulated signal beam into a wavelength-division multiplexed signal beam. On the other hand, if the etalon is impinged by a time-division or wavelength-division multiplexed signal beam, then selectively impinging the etalon with one or more control beams 46 will result in one or more signal beams, contained within the time-division or wavelength-division, multiplexed signal beam being selectively reflected from the etalon, thus achieving demultiplexing.

Example 1

An irregularly shaped sample of PDA-PTS, having length and width dimensions of about 1 centimeter (cm), and a thickness of about 2 millimeters (mm), was formed by thermally polymerizing a monomer crystal, using the technique de-

scribed in J. Berrehar et al., *supra*. This sample included a naturally occurring facet (a surface) which contained the *b* axis of the crystal (i.e., the *b* axis was parallel to the plane defined by the facet), and had length and width dimensions of about 1 cm.

A single amplified, colliding pulse modelocked (CPM) dye laser was used to produce both the signal and control beam optical pulses impinging upon the PDA-PTS facet. The laser produced light pulses at a repetition rate of 10 Hz, of wavelength centered at 625 nm (FWHM 7nm), of duration equal to 70 femtoseconds, and having energies of 400 microjoules per pulse. In operation, each optical pulse emitted by the laser was split (using a conventional beam splitter) into two pulses, i.e., a signal beam pulse and a control beam pulse, and one of the pulses (the signal beam pulse) was variably delayed (using a conventional optical delay line) relative to the other pulse (the control beam pulse).

The control beam pulses emitted by the laser were focused (using a conventional lens) onto the PDA-PTS facet to a spot size having a diameter of about 1 mm. Prior to being focused, each control beam pulse was variably attenuated, using conventional neutral density filters, to vary the control beam intensity. In addition, each control beam pulse was passed through a polarizer to achieve a control beam polarization parallel to the *b* axis of the crystal.

Each signal beam pulse was focused (using a conventional lens) into a water-containing cuvette, having a 3 cm-long optical path length, to achieve continuum generation, i.e., to produce a spectrally broadened laser pulse of essentially unchanged duration (70 femtoseconds). The resulting continuum pulse was then passed through a spectral notch filter, centered (in wavelength) at 625 nm (with a FWHM of 9 nm), to select out the desired wavelengths. The spectrally filtered pulse was then passed through neutral density filters to achieve a signal beam pulse intensity less than the corresponding control beam pulse intensity. In addition, each signal beam pulse was passed through a polarizer to achieve a signal beam polarization identical to the control beam polarization. The resulting signal beam pulse was then focused (using a conventional lens) onto the facet, to the same spot as the control beam pulse.

A conventional 50/50 beam splitter was placed in the path of the signal beam to redirect a portion of the signal beam radiation away from the facet and onto a first, silicon photodiode detector. The remainder of the signal beam radiation was impinged upon the facet, reflected, and detected by a second, silicon photodiode detector.

The signals produced by the two detectors

were subtracted from each other to produce a resultant signal. In the absence of the control beam pulse, there was no change in the magnitude of the resultant signal. However, when the control beam pulse was impinged upon the facet, a change in reflectivity, ΔR , was produced via the resonant, nonlinear optical response, which resulted in a change in magnitude of the resultant signal.

The temporal component or components of the resonant, nonlinear optical response induced in the PDA-PTS was mapped by measuring, and plotting, ΔR as a function of delay time for different delay times and different control beam pulse intensities. Such a plot is shown in FIG. 10, for the case where the control beam pulse intensity was equal to 10^{10} W/cm². Analysis of this plot indicates the existence of a first, relatively short-lived temporal component, having a decay time of about 2.0 ps, and a second, much longer-lived temporal component.

Reducing the intensity of the control beam pulse yielded a reduced (compared to the signal shown in FIG. 10) resultant signal. Significantly, the second temporal component was more reduced than the first.

Example 2

The PDA-PTS sample, described above, was again subjected to signal and control beam pulses, with the signal beam pulses being variably delayed, as described above. However, and prior to being impinged upon the sample, each control beam pulse was split into two pulses by a conventional 50/50 beam splitter. The split control beam pulses then traversed paths of identical length prior to being recombined, via mirrors, at the surface of the facet. These recombined pulses, which met at an angle of about 16 degrees, interfered with each other at the facet surface to produce a periodic intensity pattern which, via the resonant nonlinear optical response, served to reflectively diffract the portion of the signal beam pulse incident on the facet.

Rather than subtracting the signals produced by the two detectors from each other, the two signals were ratioed (the ratio of the detector signal produced by the diffracted portion of the signal beam pulse to the detector signal produced by the redirected portion of the signal beam pulse) to produce a resultant signal. One such resultant signal, for the case where the interfering control beam pulses had intensities of 6×10^9 W/cm², is shown in FIG. 11. Analysis indicates that this resultant signal includes both the relatively short-lived and long-lived temporal components, discussed above. Reducing the intensities of the interfering control beam pulses to 6×10^8 W/cm² yielded the resultant signal shown in FIG. 12. Here, analysis in-

dicates that essentially only the relatively short-lived temporal component is present.

Example 3

A PDA-PTS single crystal film, having a thickness of about 1.7 μ m, was grown using the technique described by M. Thakur and S. Meyler in, "Growth Of Large-Area Thin-Film Single Crystals Of Poly (diacetylenes)", *Macromolecules*, Vol. 18, p. 2341, 1985.

The transient-absorption spectroscopy technique described by R. B. Weisman and B. I. Greene, *supra*, was used to detect induced absorptions in the PDA-PTS. That is, a single, colliding pulse modelocked (CPM) dye laser was used to produce optical pulses having wavelengths of 630 nm and durations of 200 femtoseconds. These pulses were amplified by a neodymium-YAG pumped dye laser/amplifier to achieve pulse energies of 500 microjoules. Each (amplified) optical pulse generated by the CPM laser was split (using a conventional beam splitter) into two pulses, i.e., a signal beam pulse and a control beam pulse. One of these pulses (the signal beam pulse) was variably delayed (using a conventional optical delay line) relative to the other pulse (the control beam pulse), prior to both pulses being impinged upon the PDA-PTS, to probe the temporal response of the PDA-PTS. Both the control and signal beam spot sizes at the surface of the PDA-PTS were about 1 mm in diameter, and the control beam pulse energy, at the PDA-PTS surface, was about 1 microjoule. Conventional photodiodes were used to detect the signal beam pulses transmitted by the PDA-PTS.

Each signal and control beam pulse was also subjected to the continuum generation technique, described in Example 1, to achieve spectrally broadened pulses, i.e., optical pulses having wavelengths ranging from about 0.4 μ m to about 1.7 μ m. However, the spectrally broadened control beam pulses were passed through a spectral notch filter which only transmitted light at 640 (± 5) nm, thus yielding control beam pulses having wavelengths of 640 nm. Thus, the temporal response of the PDA-PTS, at (signal beam) wavelengths ranging from about 0.4 μ m to about 1.7 μ m, was measured.

The results of the above spectroscopy technique clearly indicated the presence of induced absorptions within the PDA-PTS (in response to the control beam pulse), extending in wavelength from about 0.7 μ m to about 1.7 μ m, and having decay times of about 0.8 ps.

Example 4

An etalon was fabricated by using optical cement to adhere the PDA-PTS film of Example 3 to two dielectrically-coated mirrors, purchased from the CVI Corporation of Albuquerque, New Mexico. These mirrors were specifically designed to be 95 percent reflecting to 0.96 μm light (but were also 95 percent reflecting to 1.0 μm light) and more than 85 percent transmissive to 0.64 μm light.

The transient-absorption spectroscopy technique of Example 3 was used to obtain the temporal response of the etalon, for different signal beam wavelengths, as a function of the delay time between the control and signal beam pulses. One such temporal record is displayed in FIG. 14, and corresponds to the case where the signal beam spot size was about 25 μm , the control beam spot size was about 100 μm , and the control beam pulse energy was about 8 nanojoules. This record shows a transient change in the transmission of the etalon at a wavelength of about 1.0 μm (a transmission peak of the etalon). The record also indicates that the transient change had a decay time of about 1 ps.

Claims

1. An optical system comprising:
 - means (20) for producing at least one signal beam (22);
 - means (44) for producing at least one pulsed control beam (46);
 - and an optically non-linear material (42), configured such that the said at least one signal beam is controlled by changes in the optical properties of the non-linear material responsive to the said at least one control beam;

CHARACTERISED IN THAT

the non-linear material is essentially free of GaAs and has an absorption coefficient, for light at the wavelength of the said at least one control beam, of at least $2 \times 10^4 \text{ cm}^{-1}$, associated with the resonant excitation of an excited state having a decay time τ less than 15 ps and at least one excited state having a decay time which is long compared with τ , but less than 40 μs ; and in that the control beam producing means are arranged such that the intensity and pulse width of the at least one control beam are such that there is substantially no excitation of any said excited state having a long decay time;

the pulse repetition rate of the said at least one control beam being less than or equal to

$$\frac{1}{2\tau}$$

but greater than $1.25 \times 10^4 \text{ Hz}$.

2. The optical system according to claim 1 wherein the non-linear material is disposed in an etalon.
3. The optical system according to claim 2, wherein the non-linear material exhibits induced absorption at the wavelength of the signal beam in response to the control beam.
4. The optical system according to claim 3 wherein the thickness of the non-linear material is such as to provide a transmission peak of the etalon at the said signal-beam wavelength.
5. The optical system according to claim 3, wherein said induced absorption extends over a wavelength range greater than about 30nm.
6. The optical system according to claim 3, wherein said induced absorption occurs at a wavelength equal to about 1.31 μm .
7. The optical system according to claim 3, wherein said induced absorption occurs at a wavelength equal to about 1.55 μm .
8. The optical system according to claim 3, wherein the composition of said non-linear material is chosen to achieve an induced absorption at a wavelength greater than 0.9 μm .
9. The optical system according to any of the preceding claims wherein said non-linear material includes organic material.
10. The optical system according to claim 9, wherein said organic material includes polydiacetylene.
11. The optical system according to any of the preceding claims wherein said non-linear material is disposed to provide an amplitude modulator.
12. The optical system according to any of claims 1 to 10 wherein said non-linear material is disposed to provide a demultiplexer.
13. The optical system according to any of claims 1 to 10 wherein said non-linear material is disposed to provide a switch.

Patentansprüche

1. Optisches System, mit einer Einrichtung (20), zur Erzeugung mindestens eines Signalstrahls



An etalon was fabricated by using optical cement to adhere the PDA-PTS film of Example 3 to two dielectrically-coated mirrors, purchased from the CVI Corporation of Albuquerque, New Mexico. These mirrors were specifically designed to be 95 percent reflecting to 0.96 μm light (but were also 95 percent reflecting to 1.0 μm light) and more than 85 percent transmissive to 0.64 μm light.

The transient-absorption spectroscopy technique of Example 3 was used to obtain the temporal response of the etalon, for different signal beam wavelengths, as a function of the delay time between the control and signal beam pulses. One such temporal record is displayed in FIG. 14, and corresponds to the case where the signal beam spot size was about 25 μm , the control beam spot size was about 100 μm , and the control beam pulse energy was about 8 nanojoules. This record shows a transient change in the transmission of the etalon at a wavelength of about 1.0 μm (a transmission peak of the etalon). The record also indicates that the transient change had a decay time of about 1 ps.

Claims

1. An optical system comprising:

means (20) for producing at least one signal beam (22);

means (44) for producing at least one pulsed control beam (46);

and an optically non-linear material (42), configured such that the said at least one signal beam is controlled by changes in the optical properties of the non-linear material responsive to the said at least one control beam; CHARACTERISED IN THAT

the non-linear material is essentially free of GaAs and has an absorption coefficient, for light at the wavelength of the said at least one control beam, of at least $2 \times 10^4 \text{ cm}^{-1}$, associated with the resonant excitation of an excited state having a decay time τ less than 15 ps and at least one excited state having a decay time which is long compared with τ , but less than 40 μs ; and in that the control beam producing means are arranged such that the intensity and pulse width of the at least one control beam are such that there is substantially no excitation of any said excited state having a long decay time;

the pulse repetition rate of the said at least one control beam being less than or equal to

$$\frac{1}{2\tau}$$

but greater than $1.25 \times 10^4 \text{ Hz}$.

2. The optical system according to claim 1 wherein the non-linear material is disposed in an etalon.
3. The optical system according to claim 2, wherein the non-linear material exhibits induced absorption at the wavelength of the signal beam in response to the control beam.
4. The optical system according to claim 3 wherein the thickness of the non-linear material is such as to provide a transmission peak of the etalon at the said signal-beam wavelength.
5. The optical system according to claim 3, wherein said induced absorption extends over a wavelength range greater than about 30nm.
6. The optical system according to claim 3, wherein said induced absorption occurs at a wavelength equal to about 1.31 μm .
7. The optical system according to claim 3, wherein said induced absorption occurs at a wavelength equal to about 1.55 μm .
8. The optical system according to claim 3, wherein the composition of said non-linear material is chosen to achieve an induced absorption at a wavelength greater than 0.9 μm .
9. The optical system according to any of the preceding claims wherein said non-linear material includes organic material.
10. The optical system according to claim 9, wherein said organic material includes polydiacetylene.
11. The optical system according to any of the preceding claims wherein said non-linear material is disposed to provide an amplitude modulator.
12. The optical system according to any of claims 1 to 10 wherein said non-linear material is disposed to provide a demultiplexer.
13. The optical system according to any of claims 1 to 10 wherein said non-linear material is disposed to provide a switch.

Patentansprüche

1. Optisches System, mit einer Einrichtung (20), zur Erzeugung mindestens eines Signalstrahls



- (22), einer Einrichtung (44) zur Erzeugung mindestens eines gepulsten Steuerstrahls (46), und einem optisch nichtlinearen Material (42), das so angeordnet ist, daß der Signalstrahl durch Änderungen der optischen Eigenschaften des nichtlinearen Materials, das auf den steuerstrahl anspricht, gesteuert wird, dadurch gekennzeichnet, daß das nichtlineare Material im Wesentlichen frei von GaAs ist, und einen Absorptionskoeffizient für Licht bei der Wellenlänge des Steuerstrahles von mindestens $2 \times 10^4 \text{ cm}^{-1}$ besitzt, der mit der resonanten Anregung eines angeregten Zustandes, der eine Abklingzeit τ von weniger als 15 ps besitzt, und mindestens einem angeregten Zustand, der eine Abklingzeit besitzt, die lang im Vergleich zu τ , aber weniger als 40 μs beträgt, verknüpft ist, daß die Einrichtung, die den Steuerstrahl erzeugt, so angeordnet ist, daß die Intensität und Pulsbreite des Steuerstrahles derart ist, daß im wesentlichen keine Anregung des Anregungszustandes mit langer Abklingzeit stattfindet, und daß die pulswiederholungsrate des Steuerstrahles kleiner gleich $1/2\tau$, aber größer als $1,25 \times 10^4 \text{ Hz}$ ist.
2. Optisches System nach Anspruch 1, dadurch gekennzeichnet, daß das nichtlineare Material in einem Etalon angeordnet ist.
 3. Optisches System nach Anspruch 2, dadurch gekennzeichnet, daß das nichtlineare Material eine induzierte Absorption bei der Wellenlänge des Signalstrahls unter Ansprechen auf den Steuerstrahl aufweist.
 4. Optisches System nach Anspruch 3, dadurch gekennzeichnet, daß die Dicke des nichtlinearen Materials so gewählt ist, daß sie für einen Transmissions-Peak des Etalons bei der Signalstrahlwellenlänge sorgt.
 5. Optisches System nach Anspruch 3, dadurch gekennzeichnet, daß die induzierte Absorption sich über einen Wellenlängenbereich größer als ungefähr 30 nm erstreckt.
 6. Optisches System nach Anspruch 3, dadurch gekennzeichnet, daß die induzierte Absorption bei einer Wellenlänge von ungefähr $1,31 \mu\text{m}$ auftritt.

7. Optisches System nach Anspruch 3, dadurch gekennzeichnet, daß die induzierte Absorption bei einer Wellenlänge von ungefähr $1,55 \mu\text{m}$ auftritt.
8. Optisches System nach Anspruch 3, dadurch gekennzeichnet, daß die Zusammensetzung des nichtlinearen Materials so gewählt ist, daß eine induzierte Absorption bei einer Wellenlänge größer als $0,9 \mu\text{m}$ erreicht wird.
9. Optisches System nach einem der vorhergehenden Ansprüche, dadurch gekennzeichnet, daß das nichtlineare Material ein organisches Material enthält.
10. Optisches System nach Anspruch 9, dadurch gekennzeichnet, daß das organische Material Polydiacetylen enthält.
11. Optisches System nach einem der vorhergehenden Ansprüche, dadurch gekennzeichnet, daß das nichtlineare Material so angeordnet ist, daß es einen Amplituden-Modulator bildet.
12. Optisches System nach einem der Ansprüche 1-10, dadurch gekennzeichnet, daß das nichtlineare Material so angeordnet ist, daß es einen Demultiplexer bildet.
13. Optisches System nach einem der Ansprüche 1-10, dadurch gekennzeichnet, daß das nichtlineare Material so angeordnet ist, daß es einen Schalter bildet.

Revendications

1. Un système optique comprenant :
des moyens (20) destinés à produire au moins un faisceau de signal (22);
des moyens (44) destinés à produire au moins un faisceau de commande impulsif (46);
et un matériau non linéaire au point de vue optique (42), ayant une configuration telle que le ou les faisceaux de signal soient commandés par des changements des propriétés optiques du matériau non linéaire sous l'effet du ou des faisceaux de commande; CARACTERISE EN CE QUE
le matériau non linéaire ne contient pratiquement pas de GaAs et il a un coefficient



d'absorption, pour la lumière à la longueur d'onde du ou des faisceaux de commande, au moins égal à $2 \times 10^4 \text{ cm}^{-1}$, associé à l'excitation résonnante d'un état excité ayant un temps de relaxation τ inférieur à 15 ps et d'au moins un état excité ayant un temps de relaxation qui est long en comparaison avec τ , mais qui est inférieur à 40 μs ;

et en ce que les moyens produisant le faisceau de commande sont conçus de façon que l'intensité et la largeur d'impulsion du ou des faisceaux de commande soient telles qu'il n'y ait pratiquement aucune excitation du ou des états excités précités ayant un temps de relaxation long;

la cadence de répétition d'impulsions du ou des faisceaux de commande étant inférieure ou égale à $1/2\tau$, mais supérieure à $1,25 \times 10^4 \text{ Hz}$.

2. Le système optique selon la revendication 1, dans lequel le matériau non linéaire est incorporé dans une cavité.
3. Le système optique selon la revendication 2, dans lequel le matériau non linéaire présente une absorption induite à la longueur d'onde du faisceau de signal sous l'effet du faisceau de commande.
4. Le système optique selon la revendication 3, dans lequel l'épaisseur du matériau non linéaire est telle qu'elle établit un maximum de transmission de la cavité à la longueur d'onde du faisceau de signal.
5. Le système optique selon la revendication 3, dans lequel l'absorption induite s'étend sur une plage de longueurs d'onde supérieure à environ 30 nm.
6. Le système optique selon la revendication 3, dans lequel l'absorption induite apparaît à une longueur d'onde égale à environ 1,31 μm .
7. Le système optique selon la revendication 3, dans lequel l'absorption induite apparaît à une longueur d'onde égale à environ 1,55 μm .
8. Le système optique selon la revendication 3, dans lequel la composition du matériau non linéaire est choisie de façon à obtenir une absorption induite à une longueur d'onde supérieure à 0,9 μm .
9. Le système optique selon l'une quelconque des revendications précédentes, dans lequel le matériau non linéaire comprend un matériau

organique.

10. Le système optique selon la revendication 9, dans lequel le matériau organique comprend du polydiacétylène.
11. Le système optique selon l'une quelconque des revendications précédentes, dans lequel le matériau non linéaire est disposé de façon à former un modulateur d'amplitude.
12. Le système optique selon l'une quelconque des revendications 1 à 10, dans lequel le matériau non linéaire est disposé de façon à former un démultiplexeur.
13. Le système optique selon l'une quelconque des revendications 1 à 10, dans lequel le matériau non linéaire est disposé de façon à former un élément de commutation.