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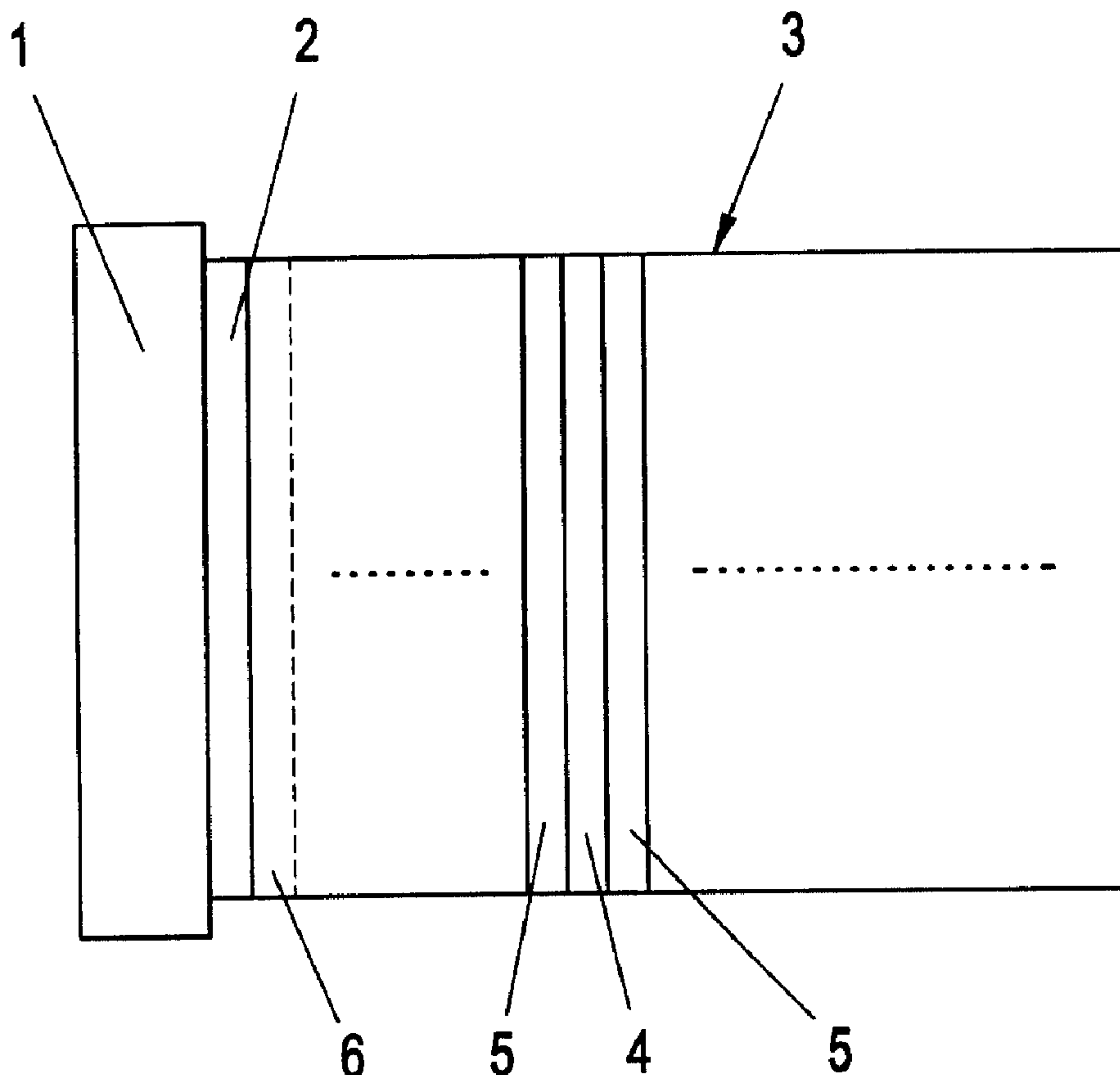
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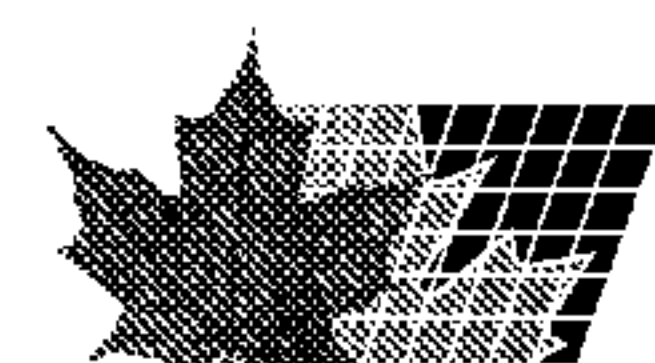
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(54) Title: A DISPERSIVE MULTILAYER MIRROR



(57) Abrégé/Abstract:

A dispersive multilayer mirror, e.g. for short-pulse laser arrangements, oscillators, laser amplifiers or hollow fiber compressors, said mirror comprising several individual dielectric layers (4, 5) applied onto a substrate (1) so as to produce given dispersion values for



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different frequency components of radiation short pulses to be reflected, wherein a highly-reflecting layer (2; 2') is provided on the substrate (1) for reflecting all the frequency components, with the individual dielectric layers (4, 5) being applied thereabove as a resonant coating structure (3) for modulating the phases of the reflected short pulses, different storage times being given for the different frequency components in the resonant coating structure (3).

Abstract

A Dispersive Multilayer Mirror

A dispersive multilayer mirror, e.g. for short-pulse laser arrangements, oscillators, laser amplifiers or hollow fiber compressors, said mirror comprising several individual dielectric layers (4, 5) applied onto a substrate (1) so as to produce given dispersion values for different frequency components of radiation short pulses to be reflected, wherein a highly-reflecting layer (2; 2') is provided on the substrate (1) for reflecting all the frequency components, with the individual dielectric layers (4, 5) being applied thereabove as a resonant coating structure (3) for modulating the phases of the reflected short pulses, different storage times being given for the different frequency components in the resonant coating structure (3).

A Dispersive Multilayer Mirror

The invention relates to a dispersive multilayer mirror, e.g. for short-pulse laser arrangements, oscillators, laser amplifiers or hollow fiber compressors, said mirror comprising several individual dielectric layers applied onto a substrate so as to produce given dispersion values for different frequency components of radiation short pulses to be reflected.

In laser technology, shorter laser pulses comprising pulse durations in the picosecond and femtosecond range are increasingly desired. Apart from their use in scientific fields, such short pulse laser arrangements increasingly are utilized in industry for the processing of materials. The laser crystals employed in such short pulse laser arrangements, cf. e.g. WO 98/10494 A, have excellent thermal properties as well as wide fluorescence bands so as to allow for the generation of laser pulses having pulse durations of less than 10 or even less than 5 femtoseconds. Here, in particular, laser crystals are used which are doped with transition metals, such as, particularly, the titan sapphire (TI:S) laser crystal.

One problem in the generation of such ultra-short laser pulses or, generally, radiation pulses resides in the remaining optical components of the laser system, wherein it would be particularly important to have

wide-band, highly reflective optical elements, or dispersive (i.e. a dispersion component-causing) components, respectively, available.

It has already been suggested to provide dispersive components for such laser arrangements in thin-layer technique, cf., e.g., US 5,734,503 A as well as A. Stingl et al., "Generation of 11-fs pulses from a Ti:sapphire laser without the use of prisms", Optics Letters, Vol. 19, No. 3, February 1994, pp. 204-206. In doing so, the mirrors are comprised of a plurality (42, e.g.) of individual layers having different refraction indexes which, when reflecting an ultra-short laser pulse - which has a correspondingly large bandwidth in the frequency range - fulfill their function: the different wave length components of the laser beam enter to different depths into the individual layers of the mirror before being reflected. In this manner, the different frequency components are delayed for different amounts of time, corresponding to the respective layer depth; the short-wave components will be reflected rather outwardly, the long-wave components, however, will be reflected deeper within the mirror. This means that the long-wave frequency components will be temporally delayed relative to the short-wave components. In this manner, a dispersion compensation can be attained for a short-pulse laser beam in a laser arrangement: pulses of a particularly short time range have a wide

frequency spectrum, with the different frequency components of the laser beam in the associated laser crystal - which is optically non-linear -, however, "seeing" a different refraction index (i.e., the optical thickness of the laser crystal is differently large for the various frequency components of the laser pulses); the different frequency components of the laser pulse therefore will be differently delayed when passing through the laser crystal. This effect can be counteracted by the above-mentioned dispersion compensation at the known thin film laser mirrors, which accordingly are called "dispersive". These known mirrors are also termed "chirped mirrors" (CM), and constitute a substantial progress as compared to the previously used delaying elements comprising prisms. It has been possible for the first time to obtain laser pulses having pulse durations of 10 fs and below directly from a laser oscillator, and the laser systems have become more compact and reliable. The CM mirrors control the wavelength dependence of the group delay as mentioned by the depth of entry of the various spectral components in the multilayer structure. However, such a multilayer structure is comparatively complex to produce and, moreover, has relatively large thickness dimensions.

It is now an object of the invention to provide wide-band dispersive mirrors allowing for a simple multilayer construction, wherein also comparatively short

optical path lengths are to be attainable, and wherein, nevertheless, also comparatively high dispersion values are to be allowed for the group delays.

The inventive dispersive mirror of the initially defined type is characterised in that a highly-reflecting layer is provided on the substrate for reflecting all the frequency components, with the individual dielectric layers being applied thereabove as resonant coating structure for modulating the phases of the reflected short pulses, different storage times being given for the different frequency components in the resonant coating structure.

With such a design of the mirror, the above objects are well achieved. The invention is based on the fact that the dependence of the pulse delay or group running time on the wave length can be controlled with the assistance of the storage time of the various spectral components in the mirror. The present dispersive mirror is a resonant mirror, wherein the entire optical thickness for attaining the same group-wise dispersion and the same reflection ability in the comparable spectral range can be comparatively smaller than in the known CM mirrors.

It has been long known per se to control the storage time of optical pulses in a resonant structure so as to introduce a temporal delay of a certain duration. In the past, however, these known structures have only

been associated with narrow-band optical components - the so-called Gires-Tournois interferometers (GTI); in contrast, tests leading to the invention have shown that broad band systems, e.g. for wave lengths in the range of 300 nm with a central wave length of 800 nm, can be obtained without any problem if according to the invention, a highly reflecting layer, in particular a highly reflecting metal layer, e.g. comprising silver or aluminum, is used in combination with a dielectric resonant coating structure having, e.g., merely 20 to 30 individual dielectric layers.

A GTI interefometer consists of a highly reflecting layer, an intermediate layer and a partially reflecting layer which form a resonant cavity (at a certain wave length). In the present case of the resonant dispersive mirror, the intermediate layer and the upper, partially reflecting layer are substituted by a weakly resonant multilayer structure. Thus, a cavity as such is no longer recognizable.

The dielectric resonant coating structure of the present mirror slightly enhances the reflection ability of the highly reflecting layer, yet its main purpose is to modulate the phase of the reflected pulses.

If the losses in the optical system are viewed as rather critical, yet the bandwidth is of less importance, it is also possible to use a highly reflecting dielectric standard reflector, such as, in particular,

a so-called Bragg reflector ($\lambda/4$ reflector) instead of a metallic highly reflecting layer. In that instance, the bandwidth of the mirror is somewhat restricted - in accordance with the bandwidth of the Bragg reflector.

The technological requirements for such a dispersive resonant mirror are comparable to those of CM mirrors. To attain the same group delay dispersion ability and reflection ability for the same spectral range, a comparatively slighter optical thickness may, however, be employed. For a CM mirror, the minimum value of the coating layer is given by the optic wave length according to the group delay which is introduced between the shortest and the longest wave length in the highly reflecting region. On account of their resonant structure, the dispersive mirrors according to the invention are, however, not subjected to this restriction, and higher dispersion values may be introduced with shorter optical thicknesses. A further difference as compared to CM mirrors consists in that the average optical layer thickness does not change monotonously with the distance from the carrier substrate, but will remain at the constant mean value.

On the whole, the present mirror thus contains a highly-reflecting optic interference coating in which a highly reflecting reflector is monolithically integrated with a weakly resonant dielectric layer structure. The dependence of the frequency on the group

delay (GD) is controlled via the storage time for the various spectral components in the resonant structure.

The mirror according to the invention is suitable for the dispersion control for wide-band electromagnetic signals generally in the frequency range from microwaves to X-rays, with applications in solid lasers, laser amplifiers and hollow fibre compressors being particularly preferred, where ultra-short pulses are generated which is advantageous for the present precise and compact dispersion control. The production is more suitable not only because of the reduced number of layers as compared to CM mirrors, but also because the highly reflecting layer as such is a standard layer.

The dielectric individual layers may, e.g., comprise silicon dioxide (SiO_2), and titanium dioxide (TiO_2), respectively, as known per se; the individual dielectric layers may, however, also be built up with tantalum pentoxide (Ta_2O_5). Particularly when using a metallic highly reflecting layer, problems of adhesion may occur when applying the superposed dielectric layers, and here it has furthermore proven as advantageous if an adhesion-promoting layer, e.g. of aluminum oxide (Al_2O_3), is provided between the highly reflective layers and the dielectric resonant coating structure.

In the following, the invention will be explained in more detail by way of examples and with reference to the drawings. In detail, in the drawings,

Fig. 1 schematically shows the structure of a dispersive resonant mirror with a highly-reflecting metal layer;

Fig. 2 shows an associated diagram of the reflectivity R (%) , and the group delay dispersion GDD (fs^2) versus the wave length λ ;

Fig. 3 shows a structure of another dispersive resonant mirror with a highly reflecting Bragg($\lambda/4$)-reflector; and

Fig. 4 shows a corresponding associated diagram of reflectivity R (%) and dispersion GDD (fs^2) versus the wave length λ .

The resonant dispersive mirror schematically illustrated in Fig. 1 has a highly reflecting metal layer 2 on a substrate 1, a resonant dielectric multilayer coating structure 3 comprising several, e.g. 20 to 30, individual layers 4, 5 being applied over said metal layer 2. These dielectric individual layers 4, 5 alternately are highly refractive and low-refractive layers of different thicknesses, and they may, e.g., be alternately made of titanium oxide (TiO_2), and silicon oxide (SiO_2), respectively, in a manner known per se.

Silver or also aluminum may, e.g., be used for the highly reflecting metal layer 2. Moreover, to improve the adhesion of the individual dielectric layers 4, 5 on the metal layer 2, an adhesion promoting layer 6

which may, e.g., be of aluminum oxide (Al_2O_3), can be provided on the metal layer 2.

For the structure of the resonant dispersive mirror schematically illustrated in Fig. 1, the following layer sequence having the respective layer thicknesses (in nm) may, e.g., be given:

Ag	300.00
Al_2O_3	112.36
TiO_2	91.66
SiO_2	139.61
TiO_2	87.46
SiO_2	129.80
TiO_2	55.59
SiO_2	93.11
TiO_2	86.20
SiO_2	141.73
TiO_2	86.37
SiO_2	148.84
TiO_2	52.21
SiO_2	55.53
TiO_2	85.60
SiO_2	158.43
TiO_2	91.84
SiO_2	83.49
TiO_2	30.00
SiO_2	120.28
TiO_2	98.41
SiO_2	156.27
TiO_2	21.04
SiO_2	67.20
TiO_2	97.16
SiO_2	164.70
TiO_2	20.18
SiO_2	60.92
TiO_2	94.78
SiO_2	139.05

At wave lengths λ of approximately 650 nm to approximately 950 nm, e.g., such a resonant dispersive mirror has a behavior as regards its reflectivity R (in %) and its dispersion (GDD, group delay dispersion, in fs^2 ; the GDD is the first derivative of the group delay GD), as represented in Fig. 2.

In Fig. 3, an alternative embodiment of the present resonant dispersive mirror is illustrated, with a Bragg ($\lambda/4$) reflector 2' now being provided on the substrate 1 as the highly reflecting mirror layer. This is followed by a resonant dielectric coating structure 3 comprising alternating respective high-refracting and low-refracting individual layers 4 and 5, respectively.

Such a mirror structure as illustrated in Fig. 3 is advantageous if the associated optical system is more critical as regards losses, yet smaller bandwidths are acceptable.

The typical behavior as regards reflectivity R and dispersion GDD results, e.g., from the diagram of Fig. 4, where it is apparent that the bandwidth now is smaller, e.g. from approximately 700 nm wavelength λ to approximately 900 nm wavelength λ (instead of from 650 nm to 950 nm according to Fig. 2).

For the individual layers 4 and 5, respectively, again titanium oxide (TiO_2) and silicon oxide (SiO_2) layers may be provided. Of course, also fewer or more than the indicated 28 individual layers 4, 5 may be used, as required. In particular, also fewer, e.g. only approximately 20, individual layers 4, 5 may be used. Moreover, also other materials, such as tantalum pentoxide (Ta_2O_5) etc. are conceivable. What is essential is that the individual layers 4, 5 altogether result in

one resonant multilayer structure and modulate the phases of the reflected pulses.

Claims:

1. A dispersive multilayer mirror, said mirror comprising several individual dielectric layers applied onto a substrate so as to produce given dispersion values for different frequency components of radiation short pulses to be reflected, wherein a highly-reflecting layer is provided on the substrate for reflecting all the frequency components, with the individual dielectric layers being applied thereabove as a resonant coating structure for modulating the phases of the reflected short pulses, different storage times being given for the different frequency components in the resonant coating structure.
2. A mirror according to claim 1, wherein the highly-reflecting layer is a metal layer.
3. A mirror according to claim 2, wherein the highly reflecting metal layer comprises silver.
4. A mirror according to claim 2, wherein the highly reflecting metal layer comprises aluminum.
5. A mirror according to claim 1, wherein the highly reflecting layer is a Bragg reflector.
6. A mirror according to any one of claims 1 to 5, wherein the resonant coating structure comprises 20 to 30 individual dielectric layers.
7. A mirror according to any one of claims 1 to 6, wherein the individual dielectric layers are alternately high-refracting and low-refracting.

8. A mirror according to any one of claims 1 to 7, wherein the individual dielectric layers alternately consist of silicon dioxide (SiO_2), and titanium dioxide (TiO_2), respectively.
9. A mirror according to any one of claims 1 to 8, wherein an adhesion-promoting layer is provided between the high-reflecting layer and the dielectric resonant coating structure.
10. A mirror according to claim 9, wherein the adhesion-promoting layer comprises aluminum oxide (Al_2O_3).
11. The use of a mirror according to any one of claims 1 to 10 for short-pulse laser arrangements, oscillators, laser amplifiers or hollow fiber compressors.

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FIG. 1

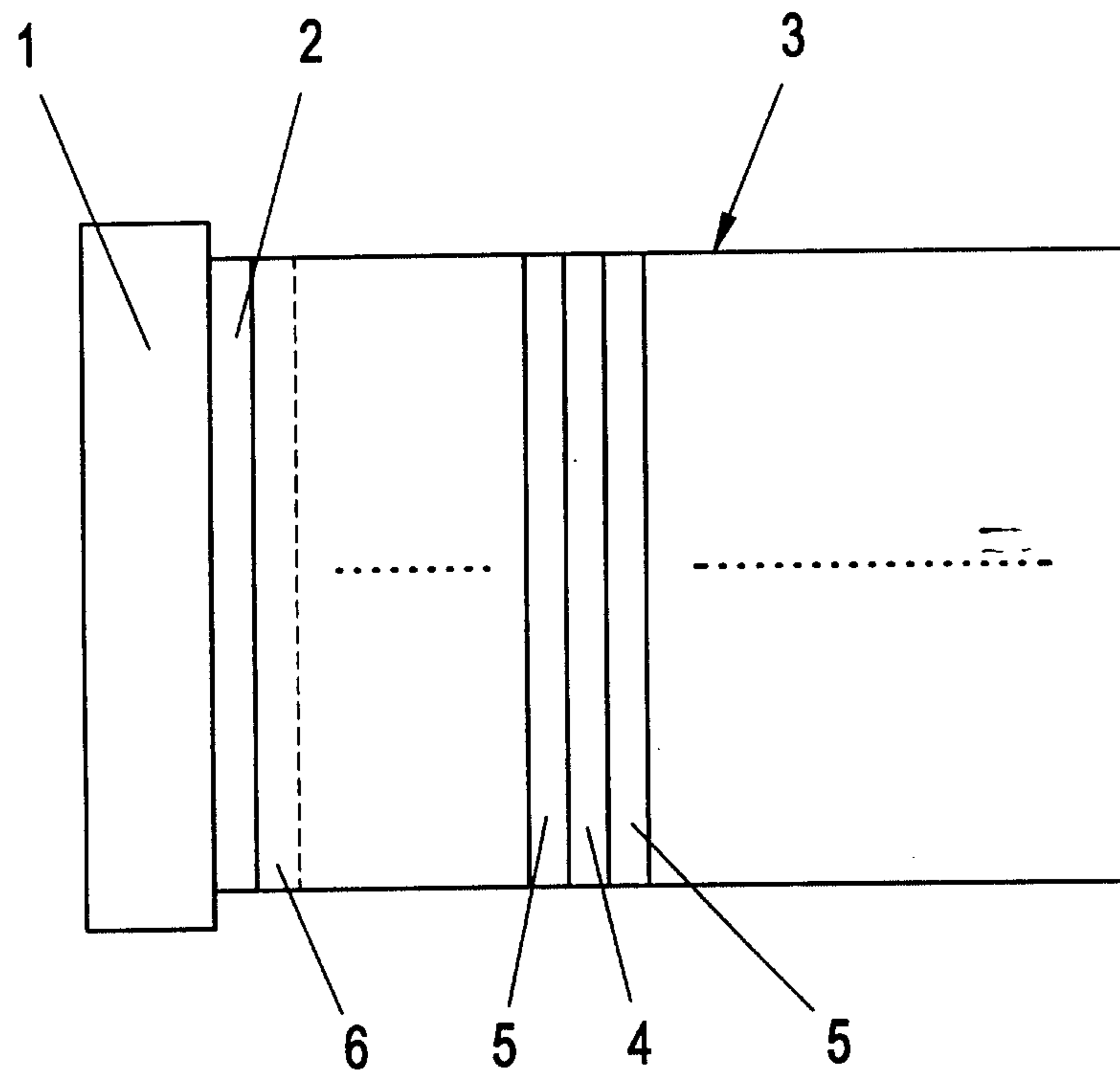


FIG. 2

