

SYSTEM AND METHOD FOR THERMALLY-STABLE OPERATION OF ACOUSTO-OPTIC DEFLECTOR WITH REDUCED ACOUSTIC TRANSIENTS

BACKGROUND

I. Technical Field

[0001] Embodiments of the present invention relate generally to acousto-optic deflectors, laser-processing apparatus incorporating the same, and techniques of operating the same.

II. Discussion of the Related Art

[0002] Referring to FIG. 1, a laser-processing apparatus 100 operative to process a workpiece 102 (e.g., to form one or more features such as a via, a slot, a hole, a trench, a pad, or the like or any combination thereof) often includes, among other components, a laser source 104, a positioner 106 and a scan lens 108. The apparatus will also typically include a controller 110 operative control an operation of the laser source 104 and positioner 106. The positioner 106 is operative to reflect, refract and/or diffract the beam of laser energy so as to deflect a beam path 112 along which laser energy in the beam of laser energy travels as it propagates from the laser source 104 to a scan lens 108. Laser energy deflected to the scan lens 108 is focused by the scan lens 108 and transmitted to propagate onto the workpiece 102 such that the beam waist of the focused beam of laser energy is located at or near the workpiece 102.

[0003] In order to effect extremely rapid deflection of the beam path 112 in two dimensions relative to the workpiece 102 (e.g., along the X-axis and Y-axis, which is orthogonal to the illustrated X- and Z-axes), the positioner 106 can include a galvanometer mirror scanning system and an acousto-optic deflector (AOD) scanning system arranged optically “upstream” of the galvanometer mirror scanning system. The galvanometer mirror scanning system typically includes a pair of galvanometer mirrors arranged optically in series with each other (e.g., such that one galvanometer mirror is operative to deflect the beam path 112 along the X-axis and the other galvanometer mirror is operative to deflect the beam path 112 along the Y-axis). The AOD scanning system typically includes a pair of acousto-optic deflectors (AODs) arranged optically in series with each other. For example, and with reference to FIG. 2, an AOD scanning system can include a first AOD 200 arranged and configured to deflect the beam path 112 along the X-axis and a second AOD 202 arranged and configured to deflect the beam path 112 along the Y-axis.

[0004] As will be recognized by those of ordinary skill in the art, AODs utilize diffraction effects caused by one or more acoustic waves propagating through an AO cell to diffract an incident optical wave (i.e., a beam of laser energy, in the context of the present application) contemporaneously propagating through the AO cell. Upon driving an AOD to diffract an incident beam of laser energy, a diffraction pattern is produced that typically includes zeroth- and first-order diffraction peaks, and may also include other higher-order diffraction peaks (e.g., second-order, third-order, etc.). Generally, the amount of optical power diffracted into the first-order diffraction peak (e.g., as compared to the zeroth-order diffraction peak) is determined by the manner in which the AOD is driven to diffract the incident beam of laser energy. As is known in the art, the portion of the diffracted beam of laser energy in the zeroth-order diffraction peak is referred to as a “zeroth-order” beam, the portion of the diffracted beam of laser energy in the first-order diffraction peak is referred to as a “first-order” beam, and so on. Generally, the zeroth-order beam and other diffracted-order beams (e.g., the first-order beam) propagate along different beam paths upon exiting the AO cell (e.g., through an optical output side of the AO cell). For example, the zeroth-order beam propagates along a zeroth-order beam path, the first-order beam propagates along a first-order beam path, and so on.

[0005] In FIG. 2, the zeroth-order beam path of the first AOD 200 is identified at 204 and the zeroth-order beam path of the second AOD 202 is identified at 206. Likewise, the first-order beam paths of the first AOD 200 and the second AOD 202 are each identified at 112. Furthermore, the positioner 106 shown in FIG. 2 includes one or more optical components (e.g., one or more mirrors, lenses, etc., generically identified at 208) arranged and configured to relay the zeroth-order beam path 204 and the first-order beam path 112 of the first AOD 200 to the second AOD 202. The positioner 106 shown in FIG. 2 also includes a beam trap 210 arranged and configured to intercept (e.g., block, absorb, etc.) laser energy propagating along the zeroth-order beam path 206 (as well as laser energy propagating along the second- or higher order beam paths) without intercepting laser energy propagating along the first-order beam path 112.

[0006] The AO cell of an AOD will absorb some amount of the beam of laser energy that propagates through it. If the beam of laser energy is sufficiently high in power, the absorbed energy can locally heat the material from which the AO cell is formed and induce a thermal

lensing phenomenon within the AO cell. Thermal lensing can focus, defocus, or otherwise distort the wavefront of the beam of laser energy propagating along the beam path 112. Thermal lensing within an AO cell is not, by itself, necessarily undesirable. If the beam of laser energy propagating to the AO cell is sufficiently stationary, and the power in the beam of laser energy is relatively constant (or varies in a periodic or otherwise predictable manner), then the wavefront distortion effects (e.g., focusing effects, defocusing effects or other wavefront distortions, as noted above) generated by thermal gradient(s) within the AO cell can be considered “stable” over time and can usually be compensated for to ensure that the workpiece 102 is satisfactorily processed. However, if the beam of laser energy propagating to the AO cell is not sufficiently stationary, or if the power in the beam of laser energy is not sufficiently constant or predictable, or if the spatial power distribution of laser energy incident to the AO cell varies significantly, then the wavefront distortion effects generated by the thermal gradient(s) within the AO cell become unstable and can be very difficult to compensate for to ensure that the workpiece 102 is satisfactorily processed.

[0007] For example, in the context of the positioner 106 shown in FIG. 2, the optical component(s) 208 ensure that the optical power incident upon the AO cell of the second AOD 202 is substantially constant, but the location where the zeroth-order beam path 204 is incident on the AO cell of the second AOD 202 may change slightly over time and the optical power in the zeroth-order beam path 204 may vary as a function of the deflection of the first-order beam path 112 imparted by the first AOD 200. Thus the thermal gradient within the AO cell of the second AOD 202 may be not sufficiently constant or stationary. Such instability of the thermal gradient within the AO cell of the second AOD 202 can undesirably produce an asymmetric energy distribution about the optical axis of the beam of laser energy ultimately delivered to the workpiece 102, as well as degrade the ability of the second AOD 202 (and, thus, the AOD scanning system in which it is incorporated) to accurately deflect the beam path 112 to a desired position relative to the workpiece 102 and degrade the ability of the AOD scanning system to ensure that the beam waist is desirably positioned at or near the workpiece 102.

SUMMARY

[0008] One embodiment of the present invention can be broadly characterized as a system that includes an acousto-optic deflector (AOD) scanning system operative to deflect a beam path,

from which a beam of laser energy is propagatable. The AOD scanning system can include a first acousto-optic deflector (AOD) arranged and operative to deflect the beam path along a first axis in response to a first drive signal, a second AOD arranged and operative to deflect the beam path deflected by the first AOD along a second axis in response to a second drive signal, a first driver connected to the first AOD and operative to generate the first drive signal, a second driver connected to the second AOD and operative to generate the second drive signal and a controller connected to the first driver and the second driver and operative to control operations of the first driver and the second driver. The controller is operative to control an operation of one of the first driver or the second driver to deflect the beam path from a first position to a second position, The controller is also operative to control an operation of the other of the first driver or second driver to cause the AOD connected thereto to decrease a transmission of laser energy in the deflected beam path during a period of time. Generally, the period of time ends when (or approximately when) the beam path is deflected from the first position to the second position.

[0009] Another embodiment of the present invention can be broadly characterized as a controller for use with an acousto-optic deflector (AOD) scanning system. The controller can, for example, include at least one processor and memory accessible by the at least one processor. The memory can, for example, have stored thereon instructions which when executed by the at least one processor, cause the controller to control an operation of the AOD scanning system to: a) control an operation of a driver of the AOD scanning system to deflect the beam path from a first position to a second position, and b) control an operation of the another driver of the AOD scanning system to cause an AOD connected thereto to decrease a transmission of laser energy in the deflected beam path during a period of time. Generally, the period of time ends when (or approximately when) the beam path is deflected from the first position to the second position.

[0010] Yet another embodiment of the present invention can be broadly characterized as a non-transitory computer readable medium for use with a controller capable of controlling an acousto-optic deflector (AOD) scanning system. The non-transitory computer readable medium can embody instructions which, when executed by the controller, cause the controller to: a) control an operation of a driver of the AOD scanning system to deflect a beam path from a first position to a second position, and b) control an operation of the

another driver of the AOD scanning system to cause an AOD connected thereto to decrease a transmission of laser energy in the deflected beam path during a period of time. Generally, the period of time ends when (or approximately when) the beam path is deflected from the first position to the second position.

BRIEF DESCRIPTION OF THE DRAWINGS

- [0011] FIG. 1 schematically illustrates a related art laser-processing apparatus in which a positioner according to embodiments of the present invention may be incorporated and operated according to embodiments of the present invention.
- [0012] FIG. 2 schematically illustrates a positioner according to the related art.
- [0013] FIG. 3 schematically illustrates a positioner according to one embodiment of the present invention.
- [0014] FIG. 4 illustrates a timing diagram for controlling AODs in the AOD scanning system shown in FIG. 3, according to one embodiment of the present invention.

DETAILED DESCRIPTION

- [0015] Example embodiments are described herein with reference to the accompanying FIGS. Unless otherwise expressly stated, in the drawings the sizes, positions, etc., of components, features, elements, etc., as well as any distances therebetween, are not necessarily to scale, but are exaggerated for clarity.
- [0016] The terminology used herein is for the purpose of describing particular example embodiments only and is not intended to be limiting. As used herein, the singular forms “a,” “an” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. It should be recognized that the terms “comprises” and/or “comprising,” when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof. Unless otherwise specified, a range of values, when recited, includes both the upper and lower limits of the range, as well as any sub-ranges therebetween. Unless indicated otherwise, terms such as “first,” “second,” etc., are only used to distinguish one element from another. For example, one node could be termed a “first node” and similarly, another node could be termed a “second node”, or vice versa. The section headings used herein are for

organizational purposes only and are not to be construed as limiting the subject matter described.

[0017] Unless indicated otherwise, the term “about,” “thereabout,” “substantially,” etc., means that amounts, sizes, formulations, parameters, and other quantities and characteristics are not and need not be exact, but may be approximate and/or larger or smaller, as desired, reflecting tolerances, conversion factors, rounding off, measurement error and the like, and other factors known to those of skill in the art.

[0018] Spatially relative terms, such as “below,” “beneath,” “lower,” “above,” and “upper,” and the like, may be used herein for ease of description to describe one element or feature's relationship to another element or feature, as illustrated in the FIGS. It should be recognized that the spatially relative terms are intended to encompass different orientations in addition to the orientation depicted in the FIGS. For example, if an object in the FIGS. is turned over, elements described as “below” or “beneath” other elements or features would then be oriented “above” the other elements or features. Thus, the exemplary term “below” can encompass both an orientation of above and below. An object may be otherwise oriented (e.g., rotated 90 degrees or at other orientations) and the spatially relative descriptors used herein may be interpreted accordingly.

[0019] Like numbers refer to like elements throughout. Thus, the same or similar numbers may be described with reference to other drawings even if they are neither mentioned nor described in the corresponding drawing. Also, even elements that are not denoted by reference numbers may be described with reference to other drawings.

[0020] It will be appreciated that many different forms and embodiments are possible without deviating from the spirit and teachings of this disclosure and so this disclosure should not be construed as limited to the example embodiments set forth herein. Rather, these examples and embodiments are provided so that this disclosure will be thorough and complete, and will convey the scope of the disclosure to those skilled in the art.

I. Discussion Concerning the Positioner, Generally

[0021] According to embodiments of the present invention, the AOD scanning system in the positioner 106 described above with respect to in FIG. 1 may be provided as exemplarily shown in FIG. 3 (i.e., as AOD scanning system 300).

[0022] Referring to FIG. 3, the AOD scanning system 300 includes a first AOD 302 arranged and configured to deflect a beam path 112 along a first axis (e.g., the aforementioned X-axis) and a second AOD 304 arranged and configured to deflect the beam path 112 along a second axis that is orthogonal to the first axis (e.g., the aforementioned Y-axis). In FIG. 3, the zeroth-order beam path of the first AOD 302 is identified at 306 and the zeroth-order beam path of the second AOD 304 is identified at 308. Likewise, the first-order beam path of the first AOD 302 is identified at 112' and the second AOD 304 is identified at 112". As will be appreciated, each of the first-order beam path 112' and first-order beam path 112" represent specific instances of a beam path along which the beam of laser energy can propagate (e.g., to the scan lens 108); therefore each of the beam path 112' and beam path 112" can also be generically referred to herein as "beam path 112" and, so, the first AOD 302 is arranged and configured to deflect the first-order beam path 112' along a first axis of the AOD scanning system 300 and the second AOD 304 is arranged and configured to deflect the first-order beam path 112" along a second axis of the AOD scanning system 300. An optical relay system 305 is arranged between the first AOD 302 and the second AOD 304 to image the pivot point of the first AOD 302 (i.e., located within the AO cell of the first AOD 302) at the pivot point of the second AOD 304 (i.e., located within the AO cell of the second AOD 304), as is known in the art.

[0023] Furthermore, the AOD scanning system 300 shown in FIG. 3 includes a first beam trap 310 arranged and configured to intercept laser energy propagating along the zeroth-order beam path 306 (as well as laser energy propagating along the second- or higher order beam paths) without intercepting laser energy propagating along the first-order beam path 112', a second beam trap 312 arranged and configured to intercept laser energy propagating along the zeroth-order beam path 308 (as well as laser energy propagating along the second- or higher order beam paths) without intercepting laser energy propagating along the first-order beam path 112", and a third beam trap 314 (also referred to herein as an "exercise beam trap") arranged and configured to intercept laser energy propagating along the first-order beam path 112" selectively deflected thereto (e.g., as indicated by arrow 315, and as will be described in greater detail below). Although not illustrated, a galvanometer mirror scanning system (e.g., comprised of a pair of galvanometer mirrors arranged and configured to deflect

the beam of laser energy along two axes, as is known in the art) may be located in the beam path 112” optically downstream of the second AOD 304 and upstream of the scan lens 108.

[0024] Generally, the AO cell of each of the first AOD 302 and second AOD 304 is formed of a material that is susceptible to thermal lensing (e.g., as described above) in the presence of a beam of laser energy having a sufficiently high optical power propagating along the beam path 112. For example, the AO cell of each of the first AOD 302 and second AOD 304 can be formed of crystalline germanium. In this example, the beam of laser energy propagating along the beam path 112 would have a wavelength in a range from 2 μm (or thereabout) to 20 μm (or thereabout) and be of a sufficiently high average power (e.g., greater than or equal to 150 W, or thereabout) to induce thermal lensing within the AO cell of the first AOD 302 and the second AOD 304. In this case, the beam of laser energy can be generated by a laser source (e.g., the laser source 104) provided as a suitably high-power carbon dioxide or carbon monoxide gas laser, for example. Typically, high-power carbon dioxide or carbon monoxide gas lasers are configured to generate continuous wave (CW) or quasi-CW (QCW) beams of laser energy, or to generate beams laser energy comprised of discrete pulses (typically many tens of microseconds, or longer, in duration).

[0025] Although not illustrated, each of the first AOD 302 and the second AOD 304 includes at least one transducer attached to the AO cell thereof. Generally, the transducer is a piezoelectric transducer operative to vibrate in response to an externally-applied RF signal (i.e., drive signal). The transducer is attached to the AO cell of an AOD such that the vibrating transducer creates a corresponding acoustic wave that propagates within the AO cell. As will be understood by those of ordinary skill, the amplitude, frequency and duration of the acoustic wave correspond to the amplitude and frequency of the RF power in the applied drive signal, as well as the duration of the applied drive signal itself.

[0026] Drive signals can be applied to an input of the transducer by an associated RF driver. Thus the AOD scanning system 300 can, for example, include a first RF driver 316 electrically connected to each transducer of the first AOD 302 and a second RF driver 318 electrically connected each transducer of the second AOD 304. Generally, each of the RF driver 316 and the second RF driver 318 can include an RF synthesizer, an amplifier coupled to an output of the RF synthesizer and an impedance matching circuit coupled to an output of the amplifier. The RF synthesizer (e.g., a DDS synthesizer) generates and outputs a

preliminary signal of a desired frequency; the amplifier amplifies the preliminary signal to a desired amplitude, thereby transforming the preliminary signal into the drive signal; and the drive signal is applied to the input of the transducer via the impedance matching circuit.

[0027] Operations of the first RF driver 316 and the second RF driver 318 can be controlled in response to command signals output by a controller (e.g., controller 320) to generate drive signals of different frequencies and amplitudes, which can be rapidly applied to each transducer of their respective AODs. Generally, the rate at which different drive signals can be applied to each transducer of an AOD can be greater than, equal to or less than 8 kHz, 10 kHz, 20 kHz, 30 kHz, 40 kHz, 50 kHz, 75 kHz, 80 kHz, 100 kHz, 250 kHz, 500 kHz, 750 kHz, 1 MHz, 5 MHz, 10 MHz, 20 MHz, 40 MHz, 50 MHz, 75 MHz, 100 MHz, 125 MHz, 150 MHz, 175 MHz, 200 MHz, 225 MHz, 250 MHz, etc., or between any of these values. Thus, the duration of any drive signal applied to the transducer of an AOD can be greater than, equal to or less than 200 μ s, 125 μ s, 100 μ s, 50 μ s, 33 μ s, 25 μ s, 20 μ s, 15 μ s, 13.3 μ s, 12.5 μ s, 10 μ s, 4 μ s, 2 μ s, 1.3 μ s, 1 μ s, 0.2 μ s, 0.1 μ s, 0.05 μ s, 0.025 μ s, 0.02 μ s, 0.013 μ s, 0.01 μ s, 0.008 μ s, 0.0067 μ s, 0.0057 μ s, 0.0044 μ s, 0.004 μ s, etc., or between any of these values. The controller 320 will thus replace the controller 110 shown in FIG. 1, and may control an operation of the laser source 104 in addition to the operation of the AOD scanning system 300 and any other scanning system of positioner 106 (e.g., the aforementioned galvanometer mirror scanning system).

[0028] For purposes of facilitating disclosure, the act of applying a drive signal to a transducer of an AOD is also referred to herein as “driving” the AOD. Thus, when the first AOD 302 is driven by a drive signal applied from the first RF driver 316, a portion of the laser energy incident upon the AO cell of the first AOD 302 is diffracted to propagate along its first-order beam path 112' to the AO cell of the second AOD 304, and another portion of the incident laser energy propagates along the zeroth-order beam path 306. If a drive signal is not applied from the first RF driver 316, then the laser energy incident upon the AO cell of the first AOD 302 simply propagates along the zeroth-order beam path 306. Likewise, when the second AOD 304 is driven by a drive signal applied from the second RF driver 318, a portion of the laser energy incident upon the AO cell of the second AOD 304 (i.e., propagating along the first-order beam path 112') is diffracted to propagate along its first-order beam path 112” (and, ultimately, on to scan lens 108), and another portion of the incident laser energy

propagates along the zeroth-order beam path 308. If a drive signal is not applied from the second RF driver 318, then the laser energy incident upon the AO cell of the second AOD 304 simply propagates along the zeroth-order beam path 308.

[0029] Generally, when an AOD is driven in response to an applied drive signal, the ratio of optical power diffracted into the first-order beam path 112 vs. a zeroth-order beam path is determined by the amplitude of RF power in the applied drive signal and, in some cases, the frequency of the RF power in the applied drive signal. Furthermore, the amount of optical power diffracted into the first-order beam path 112 will increase with increasing RF power, until it reaches a maximum at some saturation level of RF power. The act of setting or otherwise modulating the amplitude of the RF power in a drive signal to be applied to the AOD is referred to herein as “amplitude modulation control.” The act of setting or otherwise adjusting the amount of optical power diffracted into the first order beam path 112 can be considered as setting or adjusting the “transmission” of the AOD.

[0030] In embodiments where an AOD includes multiple transducers, the transmission of the AOD may also be adjusted by applying a drive signal to each of the transducers, wherein the RF frequency of each applied drive signal is the same, but is slightly out of phase with each other drive signal. As a result, acoustic waves generated within the AO cell of the AOD interfere in at least a somewhat destructive manner. Such destructively-interfering acoustic waves have the effect of decreasing the transmission of the AOD, whereby the degree to which the AOD transmission is decreased corresponds to the degree to which the acoustic waves interfere destructively with each other within the AO cell. The act of selecting or otherwise modulating the phase relationship of drive signals to be applied to different transducers of a common AOD is referred to herein as “phase modulation control.” It should be noted, however, that phase modulation control cannot be used to completely prevent optical power from diffracted into the first order beam path 112.

[0031] By successively driving the first AOD 302 and second AOD 304 (e.g., during a workpiece processing period) using drive signals of different frequencies, the AOD scanning system 300 can be operated to rapidly deflect the first-order beam path 112” to different positions within a two-dimensional scan field that is projectable onto the workpiece 102 by the scan lens 108. During the workpiece processing period, one or both of the first AOD 302 and the second AOD 304 can be driven using amplitude modulation control and/or phase

modulation control (e.g., as a function of the frequency of the drive signal) to ensure that amount of optical power propagating along the first-order beam path 112'' is at least substantially constant, regardless of the frequencies in the drive signals applied to the first AOD 302 and the second AOD 304. Additionally or alternatively, one or both of the first AOD 302 and the second AOD 304 can be driven using amplitude modulation control and/or phase modulation control (e.g., as a function of the frequency of the drive signal) to modulate the optical power propagating along the first-order beam path 112'', regardless of the frequencies in the drive signals applied to the first AOD 302 and the second AOD 304, in any desired or suitable manner, during the workpiece processing period.

[0032] Provided as described above, the first beam trap 310 of the AOD scanning system 300 prevents the zeroth-order beam path 306 from reaching the AO cell of the second AOD 304, thereby avoiding problems discussed above with respect to FIG. 2 (concerning not-suitably-constant or -stationary thermal gradients within the AO cell of the second AOD 304). As will be apparent from FIG. 3, however, the AO cell of the first AOD 302 will always be exposed to laser energy propagating along the beam path 112 whereas the AO cell of the second AOD 304 will only be exposed to laser energy propagating from the first AOD 302 along the first-order beam path 112'. That is, the AO cell of the second AOD 304 would only be exposed to the beam of laser energy when the first AOD 302 is driven by the first RF driver 316 to produce a first-order beam propagating along the first-order beam path 112'. As a result, the wavefront distortion effects created by the thermal gradient within the AO cell of the second AOD 304 may become undesirably unstable and lead to problems such as those discussed above.

[0033] To beneficially stabilize the wavefront distortion effects created by the thermal gradient within the AO cell of the second AOD 304 according to embodiments of the present invention, the first AOD 302 is driven (in response to one or more drive signals applied by the first RF driver 316 as commanded by the controller 320) to continuously (or almost continuously, as will be discussed in greater detail below) to propagate a beam of laser energy along the first-order beam path 112' to the AO cell of the second AOD 304, regardless of whether the beam of laser energy is or is not being used to process the workpiece 102. As a result, the beam of laser energy propagating along the first-order beam

path 112' is continuously (or almost continuously) deflected to the AO cell of the second AOD 304 to increase the stability of the thermal gradient therein.

[0034] Illuminated by the beam of laser energy propagating from the first-order beam path 112', the second AOD 304 can thus be driven (in response to one or more drive signals applied by the second RF driver 318 as commanded by the controller 320) to propagate a beam of laser energy along the first-order beam path 112". For example, the second AOD 304 can be driven in any known or otherwise suitable manner to deflect the first-order beam path 112" to the galvanometer mirror scanning system (which, in turn, deflects the incident beam of laser energy to the scan lens 108) if, for example, the workpiece 102 is to be processed (e.g., during a workpiece processing period). In another example, the second AOD 304 can be driven in any known or otherwise suitable manner to deflect the first-order beam path 112" to the exercise beam trap 314 (e.g., if, during workpiece processing, there is a long distance between features to be successively-formed in the workpiece 102, when the workpiece 102 is being removed from (or loaded into) the system, etc.). As used herein, the period of time during which the first-order beam path 112" is deflected to the exercising beam trap 314 is referred to herein as a "beam trap exercising period."

[0035] FIG. 4 illustrates a timing diagram for driving the first AOD 302 and second AOD 304 during workpiece processing and beam trap exercising periods. In FIG. 4, the transmission of the first AOD 302, driven in response to a series of drive signals successively applied from the first RF driver 316 to the first AOD 302, is indicated by line 400. Similarly, the frequency of each RF drive signal successively applied to the transducer(s) of the second AOD 304 from the second RF driver 318, is indicated by line 402. Further, workpiece processing periods are denoted by periods 404 (e.g., as illustrated, a first workpiece processing period 404 starting at some point in time prior to time t_1 and ending at time t_1 , and a second workpiece processing period 404 starting at time t_4 and ending at some point in time after time t_4). A beam trap exercising period is denoted by period 406, which starts at time t_2 and ends at time t_3 .

[0036] During a workpiece processing period 404, the frequency of any drive signal applied to the second AOD 304 is within a first frequency range (also referred to herein as a "first processing frequency range" or " f_{proc} ") and, during a beam trap exercising period 406 the frequency of any drive signal applied to the second AOD 304 is within a second frequency

range (also referred to herein as an “exercising frequency range” or “ f_{ex} ”). The range of frequencies spanned by the first processing frequency range, f_{proc} (i.e., the difference between the maximum and minimum frequencies of the first processing frequency range), is larger than the range of frequencies spanned by the exercising frequency range, f_{ex} (i.e., the difference between the maximum and minimum frequencies of the exercising frequency range).

[0037] Generally, the first processing frequency range f_{proc} is not continuous or contiguous with the exercising frequency range f_{ex} . That is, there exists a step difference between the maximum frequency of the first processing frequency range f_{proc} (i.e., f_{proc_max}) and the minimum frequency of the exercising frequency range f_{ex} (i.e., f_{ex_min}). The magnitude of the step difference between the maximum frequency of the first processing frequency range f_{proc_max} and the minimum frequency of the exercising frequency range f_{ex_min} (i.e., the threshold magnitude). If the magnitude of the frequency difference between any two drive signals (e.g., a first drive signal and a second drive signal) to be successively applied to the second AOD 304 is greater than or equal to the threshold magnitude, then one or more transient acoustic waveforms will be generated within the AO cell of the second AOD 304. The transition between frequencies of such first and second drive signals, which results in the generation of the transient acoustic waveform(s), is herein referred to as a “transient event.” If a beam of laser energy propagating through the AOD cell of the second AOD 304 is diffracted by such transient acoustic waveform(s), then the spatial power distribution of a spot illuminated at the workpiece 102 will become undesirably distorted, preventing the workpiece 102 from being satisfactorily processed. Transient acoustic waveforms may also be generated within the AO cell of the first AOD 302 by driving the first AOD 302 in the same manner as described with respect to the second AOD 304.

[0038] To prevent transient acoustic waveform(s) within the AO cell of the second AOD 304 from undesirably affecting the ability to satisfactorily process the workpiece 102, the transmission of the first AOD 302 is reduced by effecting amplitude modulation control, phase modulation control, or any combination thereof, during operation of the first AOD 302, or by simply discontinuing application of a drive signal to the first AOD 302 for a period of time (also referred to herein as a “transient decay period”) prior to the transient event. For example, the controller 320 may analyze data representing or otherwise associated with a

distance along the second axis between each pair of spot locations at the workpiece 102 to be successively irradiated upon operation of the AOD scanning system 300 (or simply the second AOD 304) and, if the analysis indicates that a transient event will occur, the controller 320 can output a control signal to cause the transmission of the first AOD 302 to be reduced.

[0039] As the name suggests, the duration of the transient decay period is sufficiently long such that the any acoustic waves within the AO cell of the first AOD 302 have decayed (e.g., to zero amplitude or close thereto) by the time the transient event will occur. As a result, the first AOD 302 will not output any first-order beam of laser energy along the first-order beam path 112' (or, if a first-order beam of laser energy is output, the power in the output beam of laser energy is insufficient to affect the processing of the workpiece 102) to the AO cell of the second AOD 304 by the time the transient event will occur. According to embodiments of the present invention, the duration of a transient decay period 408 may be equal to or about 2 μ s, 1 μ s, 0.5 μ s, 0.25 μ s, 0.1 μ s, etc., or between of these values, depending on one or more factors such as the amplitude and velocity of the acoustic wave propagating in the AO cell of the first AOD 302, the size of the optical aperture of the first AOD 302, the diameter of the incident beam of laser energy incident upon the AO cell of the first AOD 302, or the like or any combination thereof. In FIG. 4, examples of transient decay periods are shown at 408, and the transient events are exemplarily shown to occur at times t_2 and t_4 .

[0040] In the example embodiment shown in FIG. 4, the magnitude of the difference between the maximum frequency of the first processing frequency range f_{proc} (i.e., $f_{\text{proc_max}}$) and the minimum frequency of the first processing frequency range f_{proc} (i.e., $f_{\text{proc_min}}$) is smaller than the aforementioned threshold magnitude. In another embodiment, however, the magnitude of the difference between the maximum frequency of the first processing frequency range f_{proc} (i.e., $f_{\text{proc_max}}$) and the minimum frequency of the first processing frequency range f_{proc} (i.e., $f_{\text{proc_min}}$) can be greater than or equal to the threshold magnitude. In such an embodiment, the difference in frequencies between drive signals to be successively applied to the second AOD 304 will typically be less than the threshold magnitude. Nevertheless, there may be occasions when the difference in frequencies between drive signals to be successively applied to the second AOD 304 will typically be greater than or equal to the threshold magnitude (e.g., when, during a workpiece processing period 404, the distance between features to be

successively formed in the workpiece 102, as measured along the aforementioned second axis, is relatively long). In such a case, the first AOD 302 is operated (e.g., as discussed above) to allow the transient acoustic waves to desirably decay during a transient decay period, prior to the transient event.

[0041] Although FIG. 4 illustrates the transmission of the first AOD 302 as being constant (or substantially constant) during each workpiece processing period 404 and beam trap exercising period 406, it will be appreciated that the transmission of the first AOD 302 may be adjusted during any workpiece processing period 404 or beam trap exercising period 406 (e.g., by effecting amplitude modulation control, phase modulation control, or any combination thereof).

[0042] Although not illustrated, it will be appreciated that the frequency of each RF drive signal successively applied to the transducer(s) of the first AOD 302 from the first RF driver 316 during a workpiece processing period 404 may be within a frequency range (also referred to herein as a “second processing frequency range”). The second processing frequency range may be the same as or different from the first processing frequency range. For example, the frequencies spanned by the second processing frequency range may be the same as or different from the frequencies spanned by the first processing frequency range, the magnitude of the second processing frequency range may be the same as or different from the magnitude of the first processing frequency range, or the like or any combination thereof.

[0043] Generally, the magnitude of the difference between the maximum frequency of the second processing frequency range and the minimum frequency of the second processing frequency range can be smaller than, equal to or greater than the aforementioned threshold magnitude. If the difference in frequencies between drive signals to be successively applied to the first AOD 302 is greater than or equal to the threshold magnitude (e.g., when, during a workpiece processing period 404, the distance between features to be successively formed in the workpiece 102, as measured along the aforementioned first axis, is relatively long), the second AOD 304 can be operated (e.g., as discussed above with respect to the first AOD 302) to allow the transient acoustic waves to desirably decay during a transient decay period, prior to the transient event in the first AOD 302.

[0044] Although not illustrated, drive signals applied from the second RF driver 318 to the transducer(s) of the second AOD 304 may cause the second AOD 304 to be operated at a

constant (or substantially constant) or variable transmission during any workpiece processing period 404 or beam trap exercising period 406 (e.g., by effecting amplitude modulation control, phase modulation control, or any combination thereof).

VII. Additional Comments

[0045] Generally, the controller 320 includes one or more processors operative to generate the aforementioned commands and control signals (e.g., upon executing one or more instructions). A processor can be provided as a programmable processor (e.g., including one or more general purpose computer processors, microprocessors, digital signal processors, or any other suitable form of circuitry including programmable logic devices (PLDs), central processing units (CPUs), graphics processing units (GPUs), accelerated processing units (APUs), real-time processing units (RPU), field-programmable gate arrays (FPGAs), field-programmable object arrays (FPOAs), application-specific integrated circuits (ASICs) - including digital, analog and mixed analog/digital circuitry - or the like, or any combination thereof) operative to execute the instructions. Execution of instructions can be performed on one processor, distributed among multiple processors, made parallel across processors within a device or across a network of devices, or the like or any combination thereof.

[0046] Generally, the instructions may be embodied as software (e.g., an executable code, file, library file, or the like or any combination thereof), hardware configuration (e.g., in the case of FPGAs, ASICs, etc.), or the like or any combination thereof, which can be readily specified by artisans, from the descriptions provided herein (e.g., written in C, C++, Visual Basic, Java, Python, Tel, Perl, Scheme, Ruby, assembly language, hardware description language such as LUCID, VHDL or VERILOG, etc.). Software is commonly stored in one or more data structures conveyed by tangible media such as computer memory, which is accessible (e.g., via one or more wired or wireless communications links) by a processor. Examples of tangible media include magnetic media (e.g., magnetic tape, hard disk drive, etc.), optical discs, volatile or non-volatile semiconductor memory (e.g., RAM, ROM, NAND-type flash memory, NOR-type flash memory, SONOS memory, etc.), or the like or any combination thereof, and may be accessed locally, remotely (e.g., across a network), or any combination thereof.

VIII. Conclusion

[0047] The foregoing is illustrative of embodiments and examples of the invention and is not to be construed as limiting thereof. Although a few specific embodiments and examples have been described with reference to the drawings, those skilled in the art will readily appreciate that many modifications to the disclosed embodiments and examples, as well as other embodiments, are possible without materially departing from the novel teachings and advantages of the invention. For example, although embodiments concerning exercising operations have been described above as being used with the beam positioner shown in FIG. 3, it will be appreciated that the first AOD 200 in the beam positioner 106 shown in FIG. 2 may also be driven to implement the exercising operations described herein. In another example, although beam trap exercising has been described above as involving use of the exercise beam trap 314 of the AOD scanning system 300, it will be appreciated that, in another embodiment, the exercise beam trap 314 may be replaced with one or more optical components (e.g., one or more mirrors, lenses, or the like or any combination thereof) arranged and configured to intercept laser energy, propagating along the first-order beam path 112" during a beam trap exercising operation, and redirect the laser energy into the first beam trap 310 or the second beam trap 312. In yet another embodiment, the second beam trap 312 may be configured to intercept laser energy, propagating from the second AOD 304 along the first-order beam path 112" during a beam trap exercising operation.

[0048] Accordingly, all such modifications are intended to be included within the scope of the invention as defined in the claims. For example, skilled persons will appreciate that the subject matter of any sentence, paragraph, example or embodiment can be combined with subject matter of some or all of the other sentences, paragraphs, examples or embodiments, except where such combinations are mutually exclusive. The scope of the present invention should, therefore, be determined by the following claims, with equivalents of the claims to be included therein.

WHAT IS CLAIMED IS:

1. A system, comprising:
 - an acousto-optic deflector (AOD) scanning system operative to deflect a beam path from which a beam of laser energy is propagatable, the AOD scanning system comprising:
 - a first acousto-optic deflector (AOD) arranged and operative to deflect the beam path along a first axis in response to a first drive signal;
 - a second AOD arranged and operative to deflect the beam path deflected by the first AOD along a second axis in response to a second drive signal;
 - a first driver connected to the first AOD and operative to generate the first drive signal;
 - a second driver connected to the second AOD and operative to generate the second drive signal; and
 - a controller connected to the first driver and the second driver and operative to control operations of the first driver and the second driver,
 - wherein the controller is operative to control an operation of one of the first driver or the second driver to deflect the beam path from a first position to a second position, and
 - wherein the controller is operative to control an operation of the other of the first driver or second driver to cause the AOD connected thereto to decrease a transmission of laser energy in the deflected beam path during a period of time, wherein the period of time ends when the operation of the one of the first driver or the second driver is controlled to deflect the beam path from the first position to the second position.
2. The system of claim 1, wherein the one of the first driver or the second driver is the first driver and the other of the first driver or the second driver is the second driver.
3. The system of claim 1, wherein the one of the first driver or the second driver is the second driver and the other of the first driver or the second driver is the first driver.
4. The system of claim 1, wherein the controller is operative to control the operation of the other of the first driver or second driver, through amplitude modulation of a generated drive signal, to cause the AOD connected thereto to decrease the transmission of laser energy.

5. The system of claim 1, wherein the controller is operative to control the operation of the other of the first driver or second driver, through phase modulation of generated drive signals, to cause the AOD connected thereto to decrease the transmission of laser energy.
6. The system of claim 1, wherein the period of time corresponds to a decay period of a transient acoustic wave within the AOD connected to the one of the first driver or the second driver.
7. The system of claim 1, wherein the period of time is between 2 μs and 0.1 μs .
8. The system of claim 1, further comprising a first beam trap arranged to intercept laser energy propagating along a zeroth-order beam path of the first AOD.
9. The system of claim 8, further comprising at least one optical component arranged and configured to redirect laser energy propagating beam path deflected by the second AOD to the first beam trap.
10. The system of claim 1, further comprising a second beam trap arranged to intercept laser energy propagating along a zeroth-order beam path of the second AOD.
11. The system of claim 10, wherein the second beam trap is arranged to intercept laser energy propagating along the beam path deflected by the second AOD.
12. The system of claim 10, further comprising a third beam trap arranged to intercept laser energy propagating beam path deflected by the second AOD.
13. The system of claim 10, further comprising at least one optical component arranged and configured to redirect laser energy propagating beam path deflected by the second AOD to the second beam trap.

14. The system of claim 10, further comprising a scan lens arranged optically downstream of the AOD scanning system, the scan lens configured to focus laser energy propagating along the beam path deflected by the AOD scanning system.

15. The system of claim 14, further comprising a scanning system arranged optically between the AOD scanning system and the scan lens, the scanning system operative to deflect the beam path deflected by the AOD scanning system.

16. A controller for use with an acousto-optic deflector (AOD) scanning system operative to deflect a beam path from which a beam of laser energy is propagatable, the AOD scanning system comprising a first acousto-optic deflector (AOD) arranged and operative to deflect the beam path along a first axis in response to a first drive signal, a second AOD arranged and operative to deflect the beam path deflected by the first AOD along a second axis in response to a second drive signal, a first driver connected to the first AOD and operative to generate the first drive signal and a second driver connected to the second AOD and operative to generate the second drive signal, the controller comprising:

at least one processor; and

memory accessible by the at least one processor, wherein the memory has stored thereon instructions which when executed by the at least one processor, cause the controller to control an operation of the AOD scanning system to:

control an operation of one of the first driver or the second driver to deflect the beam path from a first position to a second position, and

control an operation of the other of the first driver or second driver to cause the AOD connected thereto to decrease a transmission of laser energy in the deflected beam path during a period of time, wherein the period of time ends when the operation of the one of the first driver or the second driver is controlled to deflect the beam path from the first position to the second position.

17. A non-transitory computer readable medium for use with a controller capable of controlling an acousto-optic deflector (AOD) scanning system operative to deflect a beam path from which a beam of laser energy is propagatable, the AOD scanning system comprising a first

acousto-optic deflector (AOD) arranged and operative to deflect the beam path along a first axis in response to a first drive signal, a second AOD arranged and operative to deflect the beam path deflected by the first AOD along a second axis in response to a second drive signal, a first driver connected to the first AOD and operative to generate the first drive signal and a second driver connected to the second AOD and operative to generate the second drive signal, the non-transitory computer readable medium embodying instructions which, when executed by the controller, cause the controller to:

control an operation of one of the first driver or the second driver to deflect the beam path from a first position to a second position, and

control an operation of the other of the first driver or second driver to cause the AOD connected thereto to decrease a transmission of laser energy in the deflected beam path during a period of time, wherein the period of time ends when the operation of the one of the first driver or the second driver is controlled to deflect the beam path from the first position to the second position.