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(54) Title: A WRITE DEVICE FOR MAGNETIC MEDIA

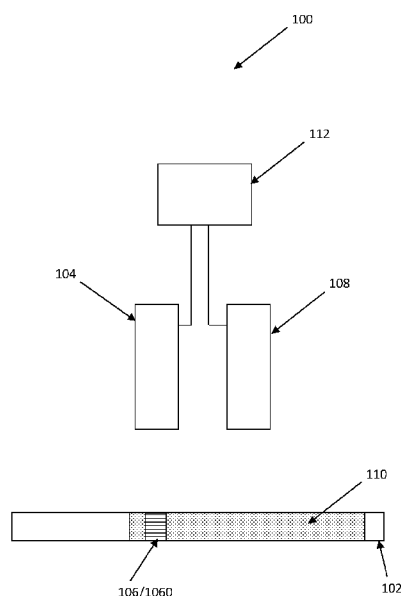


FIG. 1

(57) Abstract: A write device for magnetic media, a method of writing a magnetic media, and a HAMR head structure are provided, the device comprising a write component configured to heat a first portion of a magnetic media; at least one additional heat source, the additional heat source being configured to heat a second portion of the magnetic media to a background temperature which is a proportion of a writing temperature; wherein the second portion of the magnetic media encompasses the first portion of the magnetic media; and further wherein the write component is configured to heat the encompassed portion to a resultant temperature that is at least the writing temperature.



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A WRITE DEVICE FOR MAGNETIC MEDIA

5 TECHNICAL FIELD

The present disclosure relates broadly to a write device for magnetic media and to a method of writing a magnetic media.

10

BACKGROUND

Heat Assisted Magnetic Recording (HAMR) is considered to be a promising candidate for next generation magnetic recording technology beyond 1.5 Tb/in². The HDD (hard disk drive) industry has achieved a demonstration of HAMR technology with an areal density of over 1.4 Tbps (or about 2 MBPI * 5000 kTPI; MBPI: 10⁶ bits per inch, kTPI: 10³ tracks per inch).

HAMR typically involves heating a portion/region of media (having relatively high coercivity at room temperature) to about the Curie temperature (T_c) so that the coercivity of the heated region is significantly reduced (i.e. significantly smaller than the coercivity at room temperature) and the magnetization of the heated region is able to be switched by a smaller writing field from a write pole. The switched magnetic region is then frozen to form a switched bit upon the cooling process. A write bubble is thus a result from both the thermal and magnetic field distribution/ footprint of this process.

Typically, for HAMR, a single laser pulse is used to heat a portion of a media, e.g. media grains. To heat the media to the Curie temperature T_c of about 400-500°C (or about 673-773 K), a significantly high laser power is required to input into a NFT (near-field transducer) for the laser due to low NFT efficiency (e.g. typically less than 20% of the laser power is converted). That is, a significant portion of the laser power is absorbed and dissipated in and around the NFT, leading to a significant temperature rise in the HAMR head. Simulation results have shown that the temperature in a NFT can rise by several

hundred degrees Celsius because of the self-heating effect as well as a back-heating effect caused by proximity to the media. The inventors recognise that a NFT with a relatively high temperature can cause serious head reliability problems and may even cause a HAMR head to fail.

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In view of the above, there exists a need for a write device for magnetic media and a method of writing a magnetic media that seek to address at least one of the above problems.

10 SUMMARY

In accordance with a first aspect of the present disclosure, there is provided a write device for magnetic media, the device comprising, a write component configured to heat a first portion of a magnetic media; at least one additional heat source, the additional heat source being configured to heat a second portion of the magnetic media to a background temperature which is a proportion of a writing temperature; wherein the second portion of the magnetic media encompasses the first portion of the magnetic media; and further wherein the write component is configured to heat the encompassed portion to a resultant temperature that is at least the writing temperature.

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The write component may comprise a first light energy source coupled to a first waveguide for providing a first waveguide output, and the additional heat source may comprise a heat-source light energy source coupled to a heat-source waveguide for providing a heat-source waveguide output.

25

The first light energy source may be a laser diode and the first waveguide may be coupled to a near-field transducer for providing the first waveguide output as a focused laser beam at the first waveguide output.

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The first light energy source and the heat-source light energy source may be a same light energy source.

The first light energy source and the heat-source light energy source may be different light energy sources.

The additional heat source may be configured to heat the second portion of the magnetic media with the centre of the second portion substantially centred at a centre of the first portion of the magnetic media.

5

The additional heat source may be configured to heat the second portion of the magnetic media with the centre of the second portion offset from a centre of the first portion of the magnetic media.

10

The at least one additional heat source may comprise two or more heat sources, the two or more heat sources being configured to heat two or more portions of the magnetic media to the background temperature which is a proportion of the writing temperature, wherein the encompassed portion is in an overlapped portion of the two or more portions of the magnetic media.

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In accordance with a second aspect of the present disclosure, there is provided a method of writing a magnetic media, the method comprising, heating a second portion of the magnetic media with at least one additional heat source to a background temperature which is a proportion of a writing temperature; heating a first portion of the magnetic media with a write component; wherein the second portion of the magnetic media encompasses the first portion of the magnetic media; and heating the encompassed portion with the write component to a resultant temperature that is at least the writing temperature.

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The write component may comprise a first light energy source coupled to a first waveguide for providing a first waveguide output, and the additional heat source may comprise a heat-source light energy source coupled to a heat-source waveguide for providing a heat-source waveguide output.

25

The first light energy source may be a laser diode and the first waveguide may be coupled to a near-field transducer for providing the first waveguide output as a focused laser beam at the first waveguide output.

30

The first light energy source and the heat-source light energy source may be a same light energy source.

The first light energy source and the heat-source light energy source may be different light energy sources.

5 The method may further comprise heating the second portion of the magnetic media with the additional heat source such that the centre of the second portion is substantially centred at a centre of the first portion of the magnetic media.

10 The method may further comprise heating the second portion of the magnetic media with the additional heat source such that the centre of the second portion is offset from a centre of the first portion of the magnetic media.

15 The step of heating a second portion may comprise heating two or more portions of the magnetic media with two or more heat sources, the two or more heat sources being configured to heat the two or more portions of the magnetic media to the background temperature which is a proportion of the writing temperature, wherein the encompassed portion is in an overlapped portion of the two or more portions of the magnetic media.

20 In accordance with a third aspect of the present disclosure, there is provided a HAMR head structure comprising a write device for a magnetic media, the write device comprising, a write component configured to heat a first portion of a magnetic media; at least one additional heat source, the additional heat source being configured to heat a second portion of the magnetic media to a background temperature which is a proportion of a writing temperature; wherein the second portion of the magnetic media encompasses the first
25 portion of the magnetic media; and further wherein the write component is configured to heat the encompassed portion to a resultant temperature that is at least the writing temperature.

BRIEF DESCRIPTION OF THE DRAWINGS

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Exemplary embodiments of the invention will be better understood and readily apparent to one of ordinary skill in the art from the following written description, by way of example only, and in conjunction with the drawings, in which:

FIG. 1 is a schematic drawing of a write device for writing a magnetic media in an exemplary embodiment.

FIG. 2A is a schematic drawing of a first heating profile by a first laser beam L1 in a dual-laser heat assisted magnetic recording (HAMR) in an exemplary embodiment.

FIG. 2B is a schematic drawing of a second heating profile by a second laser beam L2 in the dual-laser heat assisted magnetic recording (HAMR) in the exemplary embodiment.

FIG. 2C is a schematic drawing of a combined heating profile by the first laser beam L1 and second laser beam L2 in the dual-laser heat assisted magnetic recording (HAMR) in the exemplary embodiment.

FIG. 3 is a schematic drawing of a write device in an exemplary embodiment.

FIG. 4 is a schematic drawing of a write device in an exemplary embodiment.

FIG. 5A is a schematic front view drawing of a write device in an exemplary embodiment.

FIG. 5B is a schematic top view drawing (not drawn to scale) of the media.

FIG. 6A is a schematic front view drawing of a write device in an exemplary embodiment.

FIG. 6B is a schematic top view drawing (not drawn to scale) of the media.

FIG. 7A is a schematic front view drawing of a write device in an exemplary embodiment.

FIG. 7B is a schematic top view drawing (not drawn to scale) of the media.

FIG. 8A is a schematic front view drawing of a write device in an exemplary embodiment.

FIG. 8B is a schematic top view drawing (not drawn to scale) of the media.

FIG. 9A is a schematic front view drawing of a write device in an exemplary
5 embodiment.

FIG. 9B is a schematic top view drawing (not drawn to scale) of the media.

FIG. 10A is a schematic front view drawing of a write device in an exemplary
10 embodiment.

FIG. 10B is a schematic top view drawing (not drawn to scale) of the media.

FIG. 11A is a schematic front view drawing of a write device in an exemplary
15 embodiment.

FIG. 11B is a schematic top view drawing (not drawn to scale) of the media.

FIG. 12A is a schematic front view drawing of a write device in an exemplary
20 embodiment.

FIG. 12B is a schematic top view drawing (not drawn to scale) of the media.

FIG. 13A is a photograph showing an experimental setup for verifying HAMR writing
25 with a dual laser heating arrangement.

FIG. 13B is a schematic reproduction of the experimental setup.

FIG. 14A is a magnetic force microscope (MFM) image of written HAMR dots using a
30 conventional single laser heating.

FIG. 14B is a MFM image of written HAMR dots using a dual laser heating
arrangement of an exemplary embodiment.

FIG. 15A is a magnetic force microscope (MFM) images of written HAMR dots using a conventional single laser heating.

FIG. 15B is a MFM image of written HAMR dots using a dual laser heating arrangement of an exemplary embodiment with a second laser power of 6.5 mW.

FIG. 15C is a MFM image of written HAMR dots using a dual laser heating arrangement of an exemplary embodiment with a second laser power of 11 mW.

FIG. 15D is a MFM image of written HAMR dots using a dual laser heating arrangement of an exemplary embodiment with a second laser power of 18.5 mW.

FIG. 15E is a MFM image of written HAMR dots using a dual laser heating arrangement of an exemplary embodiment with a second laser power of 30 mW.

FIG. 15F shows a temperature profile of heating by a first laser L1.

FIG. 15G shows a temperature profile of heating by a second laser L2.

FIG. 16A is a MFM image of written HAMR dots using a dual laser heating arrangement of an exemplary embodiment with a second laser offset of +4 μm .

FIG. 16B is a MFM image of written HAMR dots using a dual laser heating arrangement of an exemplary embodiment with a second laser offset of +2 μm .

FIG. 16C is a MFM image of written HAMR dots using a dual laser heating arrangement of an exemplary embodiment with a second laser offset of 0 μm .

FIG. 16D is a MFM image of written HAMR dots using a dual laser heating arrangement of an exemplary embodiment with a second laser offset of -2 μm .

FIG. 16E is a MFM image of written HAMR dots using a dual laser heating arrangement of an exemplary embodiment with a second laser offset of -4 μm .

FIG. 16F is a schematic drawing of a dual laser heating arrangement with zero offset of the second laser L2 with respect to the first laser L1.

FIG. 16G is a schematic drawing of a dual laser heating arrangement with an offset
5 of the second laser L2 with respect to the first laser L1.

FIG. 17 is a graph showing simulated optical intensity profiles for dual laser beam heating versus single beam heating in an exemplary embodiment for a Pw2:Pw1 ratio of 1:1.

10 FIG. 18 is a graph showing simulated optical intensity profiles for dual laser beam heating versus single beam heating in an exemplary embodiment for a Pw2:Pw1 ratio of 3:1.

FIG. 19 is a schematic flowchart for illustrating a method of writing a magnetic media in an exemplary embodiment.
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DETAILED DESCRIPTION

Exemplary, non-limiting embodiments may provide a write device for
20 recording/erasing information or data on a magnetic media. The write device is based on a dual heating method or scheme or arrangement. The dual heating arrangement may comprise, but is not limited to, a dual (or multi) laser heating arrangement.

FIG. 1 is a schematic drawing of a write device 100 for magnetic media 102 in an
25 exemplary embodiment. The write device 100 may be incorporated into a write head or HAMR head for writing/erasing information or data. The write device 100 comprises a write component 104 configured to heat a first portion 106 of a magnetic media 102, and an additional heat source 108 configured to heat a second portion 110 of the magnetic media 102 to a background temperature which is a proportion of a writing temperature.

30

In the exemplary embodiment, the second portion 110 of the magnetic media 102 encompasses the first portion 106 of the magnetic media 102. The write component 104 is configured to heat the encompassed portion 106 to a resultant temperature that is at least

the writing temperature. The writing temperature is a temperature at which thermomagnetic switching may occur in the media.

In the exemplary embodiment, the write component 104 may comprise a light energy source coupled to a waveguide for providing a waveguide output. The additional heat source 108 may comprise a heat-source light energy source coupled to a heat-source waveguide for providing a heat-source waveguide output. The heat-source light energy source may be the same as the light energy source or may be different from the light energy source. The light energy source and the heat-source light energy source may be a laser diode. The waveguide may be coupled to a near-field transducer for providing the waveguide output as a focused laser beam at the waveguide output.

In the exemplary embodiment, the write component 104 and the additional heat source 108 may be coupled to a processing module 112. The processing module 112 may function to control and monitor the write component 104 and the additional heat source 108 for writing on the magnetic media 102. The processing module 112 may control the power delivered to the light energy source and the heat-source light energy source, and the power delivered via the waveguide output and heat-source waveguide output. The processing module 112 may coordinate settings such as the powering sequence, duration and synchronization of the light energy source and the heat-source light energy source. The processing module 112 may be coupled to sensors for monitoring the temperatures at the magnetic media 102, specifically the first portion 106 and the second portion 110. When the write device 100 is implemented in a write head or HAMR head, the processing module 112 may act as an interface with other components of the write head or HAMR head.

In the exemplary embodiment, writing information may involve heating and changing a magnetisation state of a media, while erasing information may involve heating the media to cause the media to lose the magnetisation. It will be appreciated that an electromagnet may be implemented in the exemplary embodiment for writing information.

FIG. 2A is a schematic drawing of a first heating profile by a first laser beam L1 in a dual-laser heat assisted magnetic recording (HAMR) 200 in an exemplary embodiment. FIG. 2B is a schematic drawing of a second heating profile by a second laser beam L2 in the dual-laser heat assisted magnetic recording (HAMR) 200 in the exemplary embodiment. FIG.

2C is a schematic drawing of a combined heating profile by the first laser beam L1 and second laser beam L2 in the dual-laser heat assisted magnetic recording (HAMR) 200 in the exemplary embodiment. In order for information or data to be written on a magnetic media 202, the magnetic media 202 is heated to at least a threshold writing temperature T_w , as represented by line 204 such that thermomagnetic switching occurs.

In the exemplary embodiment, the first laser beam L1 has a temperature profile 206 with a peak lower than the writing temperature T_w ($T_1 < T_w$). The first laser beam L1 is configured to heat a first portion 210 of the media, resulting in a first thermal spot 212 (represented by darker shaded regions). The second laser beam L2 has a temperature profile 208 with a peak lower than the writing temperature T_w ($T_2 < T_w$). The second laser beam L2 is configured to heat a second portion 214 of the media, resulting in a second thermal spot 216 being of higher temperature at darker regions at the centre of the second thermal spot 216.

The first laser beam L1 has a higher thermal gradient and steeper temperature profile 206 with respect to the second laser beam L2, which has a lower thermal gradient and flatter temperature profile 208. The first laser beam L1 has a smaller diameter resulting in the first thermal spot 212 being smaller in size as compared to the second thermal spot 216. The steeper thermal gradient and smaller diameter of the first laser beam L1 allow more focused heating of the media 202 as compared to the second laser beam L2. As the second thermal spot 216 is relatively larger, the temperature T_2 is set to be significantly less than the write temperature T_w to prevent adjacent track erasure (ATE).

In the dual-laser heat assisted magnetic recording (HAMR) 200 of the exemplary embodiment, the first laser beam L1 and the second laser beam L2 are combined such that the first (heated) portion 210 of the media 202 is encompassed inside or within the second (heated) portion 214 of the media 202. When used together, the resultant combined dual laser heating (L1+L2) results in a temperature profile 218 and the encompassed portion 220 (represented by the cross) having a temperature T_3 which exceeds the threshold write temperature ($T_3 > T_w$) for thermomagnetic switching (schematically represented by the arrow for magnetisation).

FIG. 3 and FIG. 4 show exemplary embodiments of write device structures having a single light energy source and one or more waveguide output for providing one or more heat sources apart from the write component.

FIG. 3 is a schematic drawing of a write device 300 in an exemplary embodiment. The write device 300 may be incorporated in a HAMR head structure. The write device 300 comprises a laser diode LD 302 coupled to a first waveguide WG1 304 and a second waveguide WG2 306. The laser diode LD 302, first waveguide WG1 304 and second waveguide WG2 306 are disposed on a slider 308. The write device 300 is arranged to be oriented and movable for writing with the slider 308 with respect to a media having a cross track direction represented by numeral 310. The first waveguide WG1 304 is arranged to have a substantially linear optical path and is coupled to a near-field transducer (NFT) 312 for providing a first waveguide output 314 at the near-field transducer (NFT) 312. The second waveguide WG2 306 is arranged to provide a second waveguide output 316. In the exemplary embodiment, the second waveguide WG2 306 is arranged to have a non-linear optical path. The first waveguide WG1 304 is configured to heat a first portion of a media to a first temperature T_1 at the first waveguide output 314, and the second waveguide WG2 306 is configured to heat a second portion of the media to a second temperature T_2 at the second waveguide output 316.

In the exemplary embodiment, the laser diode LD 302 is configured to provide a laser beam to the first waveguide output 314 via the first waveguide WG1 304 and to the waveguide output 316 via the second waveguide WG2 306. The power delivery ratio/percentage power between the optical paths (of waveguides and NFT) may be adjusted. For example, the total laser power Pw_0 (e.g., 20 mW) from the laser diode LD 302 is delivered (or beam split) via the first waveguide WG1 304 with power Pw_1 and via the second waveguide WG2 306 with Pw_2 . The ratio of Pw_1/Pw_0 and Pw_2/Pw_0 can be adjusted by the waveguide size (e.g., $Pw_1=Pw_2=10\text{mW}$). Temperature T_2 , which is the media temperature achieved by the heating from the WG2 laser/light beam, is determined by the input light energy and thermal spot size (e.g., 500 nm in diameter) as well as the film structure of the media. T_2 is kept to be significantly lower than the media Curie temperature T_c (e.g., half of the Curie temperature, $T_2 = 0.5 * T_c = 350 \text{ K}$ for $T_c = 700 \text{ K}$). The thermal spot created by the first waveguide output 314 is much smaller (e.g., 50 nm in diameter). The NFT heating efficiency (η) from WG1 304 is recognised to be a fraction or a percentage of Pw_1 (e.g., for η

= 2%, NFT heating power $Pw_{NFT} = 10 * 2\% = 0.2 \text{ mW}$). The media temperature by the heating from the NFT is T_1 , and is estimated to be about 700 K based on the following calculation.

$$\frac{T_1}{T_2} * \frac{\text{Area of thermal spot formed by WG1}}{\text{Area of thermal spot formed by WG2}} = \frac{\text{WG1 output}}{\text{WG2 output}}$$

$$T_1 \approx T_2 * \frac{0.2 \text{ mW}}{10 \text{ mW}} * \left[\frac{500 \text{ nm}}{50 \text{ nm}} \right]^2 \approx 700 \text{ K}$$

Accordingly, the energy distribution from the laser diode LD 302 to the first waveguide WG1 304 and second waveguide WG2 306 is about 1:1 (or 10 mW : 10 mW).

In the described exemplary embodiments, temperatures may be measured e.g. by temperature sensors (such as by a thermal resistor) for close loop feedback/control. In addition, it will be appreciated that other forms of determination may be used. For example, open loop or indirect temperature control may be used. For example, input laser powers and media temperatures can be calibrated/determined by the start/beginning of successful HAMR writing or thermomagnetic switching.

FIG. 4 is a schematic drawing of a write device 400 in an exemplary embodiment. The write device 400 comprises a laser diode LD 402 coupled to a first waveguide WG1 404, a second waveguide WG2a 406, and a third waveguide WG2b 408. The laser diode LD 402, first waveguide WG1 404, second waveguide WG2a 406, and third waveguide WG2b 408 are disposed on a slider 410. The write device 400 is arranged to be oriented and movable for writing with the slider 410 with respect to a media having a cross track direction represented by numeral 412.

The first waveguide WG1 404 is arranged to have a substantially linear optical path and is coupled to a near-field transducer (NFT) 414 for providing a first waveguide output 416 at the near-field transducer (NFT) 414. The second waveguide WG2a 406 is arranged to provide a second waveguide output 418 and the third waveguide output WG2b 408 is arranged to provide a third waveguide output 420. In the exemplary embodiment, the second waveguide WG2a 406 and third waveguide WG2b 408 are arranged to have non-linear optical paths. The first waveguide WG1 404 is configured to heat a first portion of a media to a first temperature T_1 at the first waveguide output 416. The second waveguide WG2a 406 is configured to heat a second portion of the media to a second temperature T_2 at the second

waveguide output 418. The third waveguide WG2b 408 is configured to heat a third portion of the media to a third temperature T_3 at the third waveguide output 420. The first to third portions of the media are arranged such that the first portion is encompassed by an overlapped region between the second and third portions. Under this arrangement, the encompassed portion of the media may achieve a temperature T which exceeds a writing temperature T_w for writing to the media, where $T = T_1 + T_2 + T_3$.

The write device 400 functions substantially similarly to the write device 300 and the power delivery ratio/ percentage power between the optical paths (of waveguides and NFT) can be adjusted in a similar manner as the exemplary embodiment of FIG. 3.

FIG. 5 to FIG. 12 each show different exemplary embodiments of write device structures having one or more additional heat sources for providing auxiliary heating, apart from the write component. The additional heat sources in these figures are provided by separate laser diodes.

FIG. 5A is a schematic front view drawing of a write device 500 in an exemplary embodiment. The write device 500 comprises a write component 502 and an additional heat source 504, each coupled to a processing member (not shown but an example illustration is provided as 112 of FIG. 1). The write component 502 comprises a light energy source 506 providing a beam L1 to a waveguide 508. The light energy source 506 is in the form of a laser diode. The waveguide 508 is coupled to a near-field transducer 510 for providing a waveguide output 512, which is configured to heat a first portion 514 of a media 516 e.g. magnetic media.

The additional heat source 504 comprises a heat-source light energy source 518 providing an auxiliary beam L2 to a heat-source waveguide 520. The heat-source light energy source 518 is in the form of another laser diode. The heat-source waveguide 520 provides a heat-source waveguide output 522, which is configured to heat a second portion 524 of the media 516. In the exemplary embodiment, the heat-source waveguide 520 is disposed adjacent i.e. offset to the left side of the waveguide 508 along the X-axis, i.e. along cross track direction 526.

FIG. 5B is a schematic top view drawing (not drawn to scale) of the media 516. Heating of the first portion 514 of the media 516 results in the formation of a first thermal spot 528 and heating of the second portion 524 of the media 516 results in the formation of a second thermal spot 530. The first thermal spot 528 is comparatively smaller in area than the second thermal spot 530. The first thermal spot 528 is encompassed/overlapped within the second thermal spot 530. The first thermal spot 528 is positioned at the 3 o'clock position of the second thermal spot 530 as viewed from FIG. 5B. It is appreciated from the locations of the thermal spots 528, 530 that the heat-source waveguide 520 is offset to the left side of the waveguide 508 along the X-axis. In the exemplary embodiment, the resultant encompassed portion 5280 has a temperature that is at or higher than the writing temperature of the media 516, allowing information or data to be written or erased at the encompassed portion 5280.

FIG. 6A is a schematic front view drawing of a write device 600 in an exemplary embodiment. The write device 600 comprises a write component 602 and an additional heat source 604, each coupled to a processing member (not shown but an example illustration is provided as 112 of FIG. 1). The write component 602 comprises a light energy source 606 providing a beam L1 to a waveguide 608. The light energy source 606 is in the form of a laser diode. The waveguide 608 is coupled to a near-field transducer 610 for providing a waveguide output 612, which is configured to heat a first portion 614 of a media 616 e.g. magnetic media.

The additional heat source 604 comprises a heat-source light energy source 618 providing an auxiliary beam L2 to a heat-source waveguide 620. The heat-source light energy source 618 is in the form of another laser diode. The heat-source waveguide 620 provides a heat-source waveguide output 622, which is configured to heat a second portion 624 of the media 616. In the exemplary embodiment, the heat-source waveguide 620 is disposed adjacent i.e. offset to the right side of the waveguide 608 along the X-axis, i.e. along cross track direction 626.

FIG. 6B is a schematic top view drawing (not drawn to scale) of the media 616. Heating of the first portion 614 of the media 616 results in the formation of a first thermal spot 628 and heating of the second portion 624 of the media 616 results in the formation of a second thermal spot 630. The first thermal spot 628 is comparatively smaller in area than the second thermal spot 630 and is encompassed/overlapped within the second thermal spot

630. The first thermal spot 628 is positioned at the 9 o'clock position of the second thermal spot 630 as viewed from FIG. 6B. It is appreciated from the locations of the thermal spots 628, 630 that the heat-source waveguide 620 is offset to the right side of the waveguide 608 along the X-axis. In the exemplary embodiment, the resultant encompassed portion 6280 has a temperature that is at or higher than the writing temperature of the media 616, allowing information or data to be written or erased at the encompassed portion 6280.

FIG. 7A is a schematic front view drawing of a write device 700 in an exemplary embodiment. The write device 700 comprises a write component 702 and an additional heat source 704, each coupled to a processing member (not shown but an example illustration is provided as 112 of FIG. 1). The write component 702 comprises a light energy source 706 providing a beam L1 to a waveguide 708. The light energy source 706 is in the form of a laser diode. The waveguide 708 is coupled to a near-field transducer 710 for providing a waveguide output 712, which is configured to heat a first portion 714 of a media 716 e.g. magnetic media.

The additional heat source 704 comprises a heat-source light energy source 718 providing an auxiliary beam L2 to a heat-source waveguide 720. The heat-source light energy source 718 is in the form of another laser diode. The heat-source waveguide 720 provides a heat-source waveguide output 722, which is configured to heat a second portion 724 of the media 716. In the exemplary embodiment, the heat-source waveguide 720 is disposed adjacent i.e. offset to the left side of the waveguide 708 along the X-axis, i.e. along cross track direction 726 and to the back side of the waveguide 708 along the Z-axis (i.e. into the paper).

FIG. 7B is a schematic top view drawing (not drawn to scale) of the media 716. Heating of the first portion 714 of the media 716 results in the formation of a first thermal spot 728 and heating of the second portion 724 of the media 716 results in the formation of a second thermal spot 730. The first thermal spot 728 is comparatively smaller in area than the second thermal spot 730 and is encompassed/overlapped within the second thermal spot 730. The first thermal spot 728 is positioned approximately between the 4 o'clock and 5 o'clock positions of the second thermal spot 730 as viewed from FIG. 7B. It is appreciated from the locations of the thermal spots 728, 730 that the heat-source waveguide 720 is offset to the left side of the waveguide 708 along the X-axis and to the back side of the waveguide

708 along the Z-axis (i.e. into the paper). In the exemplary embodiment, the resultant encompassed portion 7280 has a temperature that is at or higher than the writing temperature of the media 716, allowing information or data to be written or erased at the encompassed portion 7280.

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FIG. 8A is a schematic front view drawing of a write device 800 in an exemplary embodiment. The write device 800 comprises a write component 802 and an additional heat source 804, each coupled to a processing member (not shown but an example illustration is provided as 112 of FIG. 1). The write component 802 comprises a light energy source 806
10 providing a beam L1 to a waveguide 808. The light energy source 806 is in the form of a laser diode. The waveguide 808 is coupled to a near-field transducer 810 for providing a waveguide output 812, which is configured to heat a first portion 814 of a media 816 e.g. magnetic media.

15 The additional heat source 804 comprises a heat-source light energy source 818 providing an auxiliary beam L2 to a heat-source waveguide 820. The heat-source light energy source 818 is in the form of another laser diode. The heat-source waveguide 820 provides a heat-source waveguide output 822, which is configured to heat a second portion 824 of the media 816. In the exemplary embodiment, the heat-source waveguide 820 is
20 disposed adjacent i.e. offset to the right side of the waveguide 808 along the X-axis, i.e. along cross track direction 826 and to the back side of the waveguide 808 along the Z-axis (i.e. into the paper).

FIG. 8B is a schematic top view drawing (not drawn to scale) of the media 816.
25 Heating of the first portion 814 of the media 816 results in the formation of a first thermal spot 828 and heating of the second portion 824 of the media 816 results in the formation of a second thermal spot 830. The first thermal spot 828 is comparatively smaller in area than the second thermal spot 830 and is encompassed/overlapped within the second thermal spot 830. The first thermal spot 828 is positioned approximately between the 7 o'clock and 8
30 o'clock positions of the second thermal spot 830 as viewed from FIG. 8B. It is appreciated from the locations of the thermal spots 828, 830 that the heat-source waveguide 820 is offset to the right side of the waveguide 808 along the X-axis and to the back side of the waveguide 808 along the Z-axis (i.e. into the paper). In the exemplary embodiment, the resultant encompassed portion 8280 has a temperature that is at or higher than the writing

temperature of the media 816, allowing information or data to be written or erased at the encompassed portion 8280.

FIG. 9A is a schematic front view drawing of a write device 900 in an exemplary embodiment. The write device 900 comprises a write component 902, a first additional heat source 904 and a second additional heat source 906, each coupled to a processing member (not shown but an example illustration is provided as 112 of FIG. 1). The write component 902 comprises a light energy source 908 providing a beam L1 to a waveguide 910. The light energy source 908 is in the form of a laser diode. The waveguide 910 is coupled to a near-field transducer 912 for providing a waveguide output 914, which is configured to heat a first portion 916 of a media 918 e.g. magnetic media.

The first additional heat source 904 comprises a first heat-source light energy source 920 providing an auxiliary beam L2a to a first heat-source waveguide 922. The first heat-source light energy source 920 is in the form of another laser diode. The first heat-source waveguide 922 provides a first heat-source waveguide output 924, which is configured to heat a second portion 926 of the media 918. In the exemplary embodiment, the first heat-source waveguide 922 is disposed adjacent i.e. offset to the left side of the waveguide 910 along the X-axis, i.e. along cross track direction 928.

The second additional heat source 906 comprises a second heat-source light energy source 930 providing an auxiliary beam L2b to a second heat-source waveguide 932. The second heat-source light energy source 930 is in the form of yet another laser diode. Alternatively, it will also be appreciated that the laser diode for providing auxiliary beam L2a can also provide auxiliary beam L2b. The second heat-source waveguide 932 provides a second heat-source waveguide output 934, which is configured to heat a second portion 936 of the media 918. In the exemplary embodiment, the second heat-source waveguide 932 is disposed adjacent i.e. offset to the right side of the waveguide 910 along the X-axis, i.e. along cross track direction 928.

FIG. 9B is a schematic top view drawing (not drawn to scale) of the media 918. Heating of the first portion 916, second portion 926 and third portion 936 of the media 918 results in the formation of a first thermal spot 938, a second thermal spot 940 and a third thermal spot 942, respectively. The first thermal spot 938 is comparatively smaller in area

than the second thermal spot 940 and third thermal spot 942. The second thermal spot 940 and third thermal spot 942 overlap and the first thermal spot 938 is encompassed within the overlapped region. It is appreciated from the locations of the thermal spots 938, 940 and 942 that the first heat-source waveguide 922 is offset to the left side of the waveguide 910 along the X-axis and the second heat-source waveguide 932 is offset to the right side of the waveguide 910 along the X-axis. In the exemplary embodiment, the resultant encompassed portion 9380 has a temperature that is at or higher than the writing temperature of the media 918, allowing information or data to be written or erased at the encompassed portion 9380. In the exemplary embodiment, the overlapped regions may provide a higher background temperature such that an even lower power provided to the beam L1 can provide sufficient heat to the encompassed portion 9380 for thermomagnetic switching.

FIG. 10A is a schematic front view drawing of a write device 1000 in an exemplary embodiment. The write device 1000 comprises a write component 1002, a first additional heat source 1004 and a second additional heat source 1006, each coupled to a processing member (not shown but an example illustration is provided as 112 of FIG. 1). The write component 1002 comprises a light energy source 1008 providing a beam L1 to a waveguide 1010. The light energy source 1008 is in the form of a laser diode. The waveguide 1010 is coupled to a near-field transducer 1012 for providing a waveguide output 1014, which is configured to heat a first portion 1016 of a media 1018 e.g. magnetic media.

The first additional heat source 1004 comprises a first heat-source light energy source 1020 providing an auxiliary beam L2a to a first heat-source waveguide 1022. The first heat-source light energy source 1020 is in the form of another laser diode. The first heat-source waveguide 1022 provides a first heat-source waveguide output 1024, which is configured to heat a second portion 1026 of the media 1018. In the exemplary embodiment, the first heat-source waveguide 1022 is disposed adjacent i.e. offset to the left side of the waveguide 1010 along the X-axis, i.e. along cross track direction 1028 and to the back side of the waveguide 1010 along the Z-axis (i.e. into the paper).

The second additional heat source 1006 comprises a second heat-source light energy source 1030 providing an auxiliary beam L2b to a second heat-source waveguide 1032. The second heat-source light energy source 1030 is in the form of yet another laser diode. Alternatively, it will also be appreciated that the laser diode for providing auxiliary

beam L2a can also provide auxiliary beam L2b. The second heat-source waveguide 1032 provides a second heat-source waveguide output 1034, which is configured to heat a second portion 1036 of the media 1018. In the exemplary embodiment, the second heat-source waveguide 1032 is disposed adjacent i.e. offset to the right side of the waveguide 1010 along the X-axis, i.e. along cross track direction 1028 and to the back side of the waveguide 1010 along the Z-axis (i.e. into the paper).

FIG. 10B is a schematic top view drawing (not drawn to scale) of the media 1018. Heating of the first portion 1016, second portion 1026 and third portion 1036 of the media 1018 results in the formation of a first thermal spot 1038, a second thermal spot 1040 and a third thermal spot 1042, respectively. The first thermal spot 1038 is comparatively smaller in area than the second thermal spot 1040 and third thermal spot 1042. The second thermal spot 1040 and third thermal spot 1042 overlap and the first thermal spot 1038 is encompassed within the overlapped region. It is appreciated from the locations of the thermal spots 1038, 1040 and 1042 that the first heat-source waveguide 1022 is offset to the left side of the waveguide 1010 along the X-axis and the second heat-source waveguide 1032 is offset to the right side of the waveguide 1010 along the X-axis. It is also appreciated that both the first heat-source waveguide 1022 and the second heat-source waveguide 1032 are offset to the back side of the waveguide 1010 along the Z-axis (i.e. into the paper). In the exemplary embodiment, the resultant encompassed portion 10380 has a temperature that is at or higher than the writing temperature of the media 1018, allowing information or data to be written or erased at the encompassed portion 10380. In the exemplary embodiment, the overlapped regions may provide a higher background temperature such that an even lower power provided to the beam L1 can provide sufficient heat to the encompassed portion 10380 for thermomagnetic switching.

FIG. 11A is a schematic front view drawing of a write device 1100 in an exemplary embodiment. The write device 1100 comprises a write component 1102, a first additional heat source 1104, a second additional heat source 1106 and a third additional heat source 1108, each coupled to a processing member (not shown but an example illustration is provided as 112 of FIG. 1). The write component 1102 comprises a light energy source 1110 providing a beam L1 to a waveguide 1112. The light energy source 1110 is in the form of a laser diode. The waveguide 1112 is coupled to a near-field transducer 1114 for providing a

waveguide output 1116, which is configured to heat a first portion 1118 of a media 1120 e.g. magnetic media.

The first additional heat source 1104 comprises a first heat-source light energy source 1122 providing an auxiliary beam L2a to a first heat-source waveguide 1124. The first heat-source light energy source 1122 is in the form of another laser diode. The first heat-source waveguide 1124 provides a first heat-source waveguide output 1126, which is configured to heat a second portion 1128 of the media 1120. In the exemplary embodiment, the first heat-source waveguide 1124 is disposed adjacent i.e. offset to the left side of the waveguide 1112 along the X-axis, i.e. along cross track direction 1130.

The second additional heat source 1106 comprises a second heat-source light energy source 1132 providing an auxiliary beam L2b to a second heat-source waveguide 1134. The second heat-source light energy source 1132 is in the form of yet another laser diode. The second heat-source waveguide 1134 provides a second heat-source waveguide output 1136, which is configured to heat a second portion 1138 of the media 1120. In the exemplary embodiment, the second heat-source waveguide 1134 is disposed adjacent i.e. offset to the right side of the waveguide 1112 along the X-axis, i.e. along cross track direction 1130.

The third additional heat source 1108 (represented by a block and an arrow in dotted lines) comprises a third heat-source light energy source providing an auxiliary beam L2c to a third heat-source waveguide. The third heat-source light energy source is in the form of a fourth laser diode. The third heat-source waveguide provides a third heat-source waveguide output, which is configured to heat a third portion 1140 of the media 1120. In the exemplary embodiment, the third heat-source waveguide is disposed adjacent i.e. offset to the back side of the waveguide 1112 along the Z-axis, i.e. into the paper. As an alternative to having multiple laser diodes above two, it will also be appreciated that the laser diode for providing auxiliary beam L2a can also provide one or both of auxiliary beams L2b and L2c.

FIG. 11B is a schematic top view drawing (not drawn to scale) of the media 1120. Heating of the first portion 1118, second portion 1128, third portion 1138 and fourth portion 1140 of the media 1120 results in the formation of a first thermal spot 1142, a second thermal spot 1144, a third thermal spot 1146 and a fourth thermal spot 1148, respectively.

The first thermal spot 1142 is comparatively smaller in area than the second thermal spot 1144, third thermal spot 1146, and fourth thermal spot 1148. The second thermal spot 1144, third thermal spot 1146 and fourth thermal spot 1148 overlap and the first thermal spot 1142 is encompassed within the overlapped region. It is appreciated from the locations of the thermal spots 1142, 1144, 1146 and 1148 that the first heat-source waveguide 1124 is offset to the left side of the waveguide 1112 along the X-axis and the second heat-source waveguide 1134 is offset to the right side of the waveguide 1112 along the X-axis. It is also appreciated that the third heat-source waveguide is offset to the back side of the waveguide 1112 along the Z-axis (i.e. into the paper). In the exemplary embodiment, the resultant encompassed portion 11420 has a temperature that is at or higher than the writing temperature of the media 1120, allowing information or data to be written or erased at the encompassed portion 11420. In the exemplary embodiment, the overlapped regions may provide a higher background temperature such that an even lower power provided to the beam L1 can provide sufficient heat to the encompassed portion 11420 for thermomagnetic switching.

FIG. 12A is a schematic front view drawing of a write device 1200 in an exemplary embodiment. The write device 1200 comprises a write component 1202, a first additional heat source 1204, a second additional heat source 1206 and a third additional heat source 1208, each coupled to a processing member (not shown but an example illustration is provided as 112 of FIG. 1). The write component 1202 comprises a light energy source 1210 providing a beam L1 to a waveguide 1212. The light energy source 1210 is in the form of a laser diode. The waveguide 1212 is coupled to a near-field transducer 1214 for providing a waveguide output 1216, which is configured to heat a first portion 1218 of a media 1220 e.g. magnetic media.

The first additional heat source 1204 comprises a first heat-source light energy source 1222 providing an auxiliary beam L2a to a first heat-source waveguide 1224. The first heat-source light energy source 1222 is in the form of another laser diode. The first heat-source waveguide 1224 provides a first heat-source waveguide output 1226, which is configured to heat a second portion 1228 of the media 1220. In the exemplary embodiment, the first heat-source waveguide 1224 is disposed adjacent i.e. offset to the left side of the waveguide 1212 along the X-axis, i.e. along cross track direction 1230 and to the back side of the waveguide 11212 along the Z-axis (i.e. into the paper).

The second additional heat source 1206 comprises a second heat-source light energy source 1232 providing an auxiliary beam L2b to a second heat-source waveguide 1234. The second heat-source light energy source 1232 is in the form of yet another laser diode. The second heat-source waveguide 1234 provides a second heat-source waveguide output 1236, which is configured to heat a second portion 1238 of the media 1220. In the exemplary embodiment, the second heat-source waveguide 1234 is disposed adjacent i.e. offset to the right side of the waveguide 1212 along the X-axis, i.e. along cross track direction 1230 and to the back side of the waveguide 1212 along the Z-axis (i.e. into the paper).

The third additional heat source 1208 (represented by a block and an arrow in dotted lines) comprises a third heat-source light energy source providing an auxiliary beam L2c to a third heat-source waveguide. The third heat-source light energy source is in the form of a fourth laser diode. The third heat-source waveguide provides a third heat-source waveguide output, which is configured to heat a third portion 1240 of the media 1220. In the exemplary embodiment, the third heat-source waveguide is disposed adjacent i.e. offset to the back side of the waveguide 1212 along the Z-axis, i.e. into the paper. As an alternative to having multiple laser diodes above two, it will also be appreciated that the laser diode for providing auxiliary beam L2a can also provide one or both of auxiliary beams L2b and L2c.

FIG. 12B is a schematic top view drawing (not drawn to scale) of the media 1220. Heating of the first portion 1218, second portion 1228, third portion 1238 and fourth portion 1240 of the media 1220 results in the formation of a first thermal spot 1242, a second thermal spot 1244, a third thermal spot 1246 and a fourth thermal spot 1248, respectively. The first thermal spot 1242 is comparatively smaller in area than the second thermal spot 1244, third thermal spot 1246, and fourth thermal spot 1248. The second thermal spot 1244, third thermal spot 1246 and fourth thermal spot 1248 overlap and the first thermal spot 1242 is encompassed within the overlapped region. It is appreciated from the locations of the thermal spots 1242, 1244, 1246 and 1248 that the first heat-source waveguide 1224 is offset to the left side of the waveguide 1212 along the X-axis and the second heat-source waveguide 1234 is offset to the right side of the waveguide 1212 along the X-axis. It is also appreciated that the first heat-source waveguide 1224, second heat-source waveguide 1234 and third heat-source waveguide are offset to the back side of the waveguide 1212 along the

Z-axis (i.e. into the paper). In the exemplary embodiment, the resultant encompassed portion 12420 has a temperature that is at or higher than the writing temperature of the media 1220, allowing information or data to be written or erased at the encompassed portion 12420. In the exemplary embodiment, the overlapped regions may provide a higher background
5 temperature such that an even lower power provided to the beam L1 can provide sufficient heat to the encompassed portion 12420 for thermomagnetic switching.

In the described exemplary embodiments, exemplary values and/or parameters described with reference to e.g. FIGs. 3 or 14 may also be applied similarly.

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FIG. 13A is a photograph showing an experimental setup 1300 for verifying HAMR writing with a dual laser heating arrangement. FIG. 13B is a schematic reproduction of the experimental setup 1300. The experimental setup 1300 comprises a first laser diode 1302 for delivering a first laser beam L1, a second laser diode 1304 for delivering a second laser
15 beam L2, an electromagnet 1306 for applying a magnetic field to a sample 1308. The components 1302, 1304, 1306 are coupled to a processing module 1312 in the form of a computer. The first laser diode 1302 functions as a write component (compare 104 of FIG. 1) for writing on the sample 1308. The first laser beam L1 is a red laser with a wavelength of 785 nm and is configured as a Gaussian beam with a diameter of 1.5 μm . The second laser
20 diode 1304 functions as an additional heat source (compare 108 of FIG. 1). The second laser L2 is a green laser with a wavelength of 532 nm is configured as a flat-top beam with a diameter of 8 μm . This configuration may be provided with, or approximates from, a light intensity profile that is substantially of Gaussian distribution. Heating of the sample 1308 by the output of the first laser beam L1 and the second laser beam L2 result in the formation of
25 a first thermal spot 1310 and a second thermal spot 1314, respectively. The experimental results obtained using this setup are shown in FIG. 14 to FIG. 17.

FIG. 14A is a magnetic force microscope (MFM) image of written HAMR dots using a conventional single laser heating. FIG. 14B is a MFM image of written HAMR dots using a
30 dual laser heating arrangement of an exemplary embodiment. The MFM image of FIG. 14B is an experimental result of dual laser HAMR writing obtained using the experimental setup described in FIG. 13 and investigates the effect of dual laser heating against conventional single laser heating as a control setup. The lasers used for obtaining the results of FIG. 14A and 14B are moved in the direction 1400 and an electromagnet is used to apply a constant

magnetic field of 1.5 kOe. For the experiment of FIG. 14B, the second laser beam L2 is provided with 11 mW of power. The bank of numbers at 1401 show the laser power for the first laser L1 (with pulse width of 1 μ s).

5 As shown by the MFM image of written HAMR dots of FIG. 14A, it is observed that a minimum power of 65 mW is required for successful HAMR switching in a single laser only scheme (i.e. conventional HAMR). See numeral 1402. On the other hand, for FIG. 14B, it is observed that a smaller laser power of 49 mW for the first laser L1 is sufficient for a successful HAMR switch with the assistance of a laser power of 11mW from the second
10 laser L2. See numeral 1404. The total power used for the result in FIG. 14B is about 60 mW. In addition, using a lower power for the first laser L1 results in less heating to the NFT of the first laser L1 during the writing process.

FIG. 15A is a magnetic force microscope (MFM) images of written HAMR dots using
15 a conventional single laser heating. FIG. 15B is a MFM image of written HAMR dots using a dual laser heating arrangement of an exemplary embodiment with a second laser power of 6.5 mW. FIG. 15C is a MFM image of written HAMR dots using a dual laser heating arrangement of an exemplary embodiment with a second laser power of 11 mW. FIG. 15D is a MFM image of written HAMR dots using a dual laser heating arrangement of an exemplary
20 embodiment with a second laser power of 18.5 mW. FIG. 15E is a MFM image of written HAMR dots using a dual laser heating arrangement of an exemplary embodiment with a second laser power of 30 mW. FIG. 15F shows a temperature profile 1502 of heating by a first laser L1. FIG. 15G shows a temperature profile 1504 of heating by a second laser L2.

25 The MFM images of FIG. 15B to 15E are experimental results of dual laser HAMR writing obtained using the experimental setup described in FIG. 13 and investigates the effects of increasing power provided to the additional heat source on the recording bit size. In the experiment, the additional heat source is the laser L2. The first laser L1 has a temperature profile 1502 and the second laser has a temperature profile 1504. Increasing
30 the power of the second laser shifts the temperature profile 1504 upwards while maintaining the general shape of the profile. The lasers used for obtaining the results of FIG. 15 are moved in the direction 1500 and an electromagnet is used to apply a constant magnetic field of 1.5 kOe. The bank of numbers at 1501 show the laser power for the first laser L1 (with pulse width of 1 μ s).

From the MFM image of written HAMR dots of FIG. 15A, it is observed that a minimum power of 65 mW is required for successful HAMR switching in a single laser only scheme (i.e. conventional HAMR). See numeral 1506.

On the other hand, for FIG. 15B, it is observed that a smaller laser power of 57 mW for the first laser L1 is sufficient for a successful HAMR switch with the assistance of a laser power of 6.5 mW for the second laser L2. The total power used for the result in FIG. 15B is about 63.5 mW. See numeral 1508.

For FIG. 15C, it is observed that a laser power of 49 mW for the first laser L1 is sufficient for a successful HAMR switch with the assistance of a laser power of 11 mW for the second laser L2. The total power used for the result in FIG. 15C is about 60 mW. See numeral 1510.

For FIG. 15D, it is observed that a laser power of 41 mW for the first laser L1 is sufficient for a successful HAMR switch with the assistance of a laser power of 18.5 mW for the second laser L2. The total power used for the result in FIG. 15D is about 59.5 mW. See numeral 1512.

For FIG. 15E, it is observed that a laser power of 41 mW for the first laser L1 is sufficient for a successful HAMR switch with the assistance of a laser power of 30 mW for the second laser L2. The total power used for the result in FIG. 15B is about 71 mW. See numeral 1514.

The results also show that with a higher L2 power, a smaller L1 power is sufficient to switch the media grain. Compare 1508 of FIG. 15B against 1510 of FIG. 15C; 1510 of FIG. 15C against 1512 of FIG. 15D. For example, when the L2 laser power of 18.5 mW is used, a power of 41 mW for the first laser L1 is sufficient for successful switching. The results also show that when the laser power L1 is kept constant, a larger bit or HAMR dot size was observed when the L2 laser power increases, signifying a higher temperature in the media. For example, comparing 1512 of FIG. 15D and 1514 of FIG. 15E, at a same laser power L1 of 41 mW, the bit or HAMR dot size increases as the L2 laser power increases, signifying a higher temperature in the media.

FIG. 16A is a MFM image of written HAMR dots using a dual laser heating arrangement of an exemplary embodiment with a second laser offset of +4 μm . FIG. 16B is a MFM image of written HAMR dots using a dual laser heating arrangement of an exemplary embodiment with a second laser offset of +2 μm . FIG. 16C is a MFM image of written HAMR dots using a dual laser heating arrangement of an exemplary embodiment with a second laser offset of 0 μm . FIG. 16D is a MFM image of written HAMR dots using a dual laser heating arrangement of an exemplary embodiment with a second laser offset of -2 μm . FIG. 16E is a MFM image of written HAMR dots using a dual laser heating arrangement of an exemplary embodiment with a second laser offset of -4 μm . FIG. 16F is a schematic drawing of a dual laser heating arrangement with zero offset of the second laser L2 with respect to the first laser L1. FIG. 16G is a schematic drawing of a dual laser heating arrangement with an offset of the second laser L2 with respect to the first laser L1.

The MFM images of FIG. 16A to 16E are experimental results of dual laser HAMR writing obtained using the experimental setup described in FIG. 13 and investigates the effects of offsetting the position of the L2 laser with respect to the L1 laser. The lasers used for obtaining the results of FIG. 16 are moved in the direction 1600 and an electromagnet is used to apply a constant magnetic field of 1.5 kOe. The power of the laser L2 is kept constant at 12 mW. The bank of numbers at 1601 show the laser power for the first laser L1 (with pulse width of 1 μs).

The first laser L1 has a temperature profile 1602 and the second laser L2 has a temperature profile 1604. FIG. 16F shows that when there is zero offset of the second laser L2 with respect to the first laser L1, the peaks of the temperature profiles 1602 and 1604 are substantially aligned. The centre of the thermal spot 1606 created by the first laser L1 is substantially centred at the centre of the thermal spot 1608 created by the second laser L2. On the other hand, FIG. 16G shows that when there is an offset of the second laser L2 with respect to the first laser L1 along the X-axis, the peaks of the temperature profiles 1602 and 1604 are not aligned. The centre of the thermal spot 1606 created by the first laser L1 is offset from the centre of the thermal spot 1608 created by the second laser L2.

As shown by the MFM images of written HAMR dots in FIG. 16A, when the L1 and L2 lasers are kept constant, e.g., at L1 = 57 mW and L2 = 12 mW, smaller bit sizes were

observed as the positional offset of the L2 laser from the L1 laser increased from 2 μm to 4 μm along the X-axis. This signifies a lower temperature in the media. It is also observed that the bit sizes are larger at a lesser offset i.e. larger bit sizes are observed at 2 μm offset than at 4 μm offset. The written HAMR dots are the largest when the offset is zero. See numeral 1610. In addition, when the L1 and L2 lasers are kept constant, e.g. at L1 = 49 mW and L2 = 12 mW, successful switching occurs when the offset is zero. However, as the offset of the L2 laser from the L1 laser increases, the same power intensities of L1 and L2 are not able to perform successful switching, as shown by the faint HAMR dots at FIG. 16A and FIG. 16E. See numeral 1612.

Based on the described exemplary embodiments, zero offset may be obtained from, for example, the exemplary embodiments using multiple waveguides, as described with reference to, for example, FIGs. 3 or 4.

In the described exemplary embodiments, the light energy source and the heat-source light energy source may be provided from a same light energy source or different light energy sources. One advantage for having individual laser diodes as different light energy sources is that each laser power can be independently controlled. The light energy source may be a laser diode configured to provide laser beam L1 and the heat-source light energy source may be a laser diode configured to provide a laser beam such as L2, L2a, L2b or L2c. Each laser beam may be a continuous wave (CW) laser or pulsed laser. For pulsed laser, the sequence of the laser L1 and the laser L2 can be configured such that L2 is ahead of L1 in sequence and synchronization can be provided with instructions from a processing module (e.g. the processing module 112 of FIG. 1). An auxiliary laser beam with a relatively higher laser power may also be used for band track erase.

FIG. 17 is a graph showing simulated optical intensity profiles for dual laser beam heating versus single beam heating in an exemplary embodiment for a $P_{w2}:P_{w1}$ ratio of 1:1. FIG. 18 is a graph showing simulated optical intensity profiles for dual laser beam heating versus single beam heating in an exemplary embodiment for a $P_{w2}:P_{w1}$ ratio of 3:1. The profile shown in a solid line is for dual laser beam heating while the profile shown in dotted lines is for conventional single beam heating.

In general, the light intensity distribution of the second laser beam L2 (Gaussian beam) is much broader than NFT light spot (of the first laser beam L1) and the thermal gradient of NFT thermal spot is much larger than that for the pre-heating thermal spot of the second laser beam L2. As shown in FIG. 17, the normalized intensity of dual laser beam heating shows only a slightly less steep curve at the recording position (with temperature near the Curie temperature T_c) than single beam heating. Even when the pre-heat to main beam power ratio is increased (e.g., $P_{w2}:P_{w1}$ changed from 1:1 to 3:1, see Fig. 18), the thermal gradient does not degrade significantly. Generally, preheat power (for the second laser beam L2) is set to be low to avoid ATE (adjacent track erasure) and ATI (adjacent track interference) as mentioned. It has been observed that thermal gradient (TG) degradation may not be significant for dual laser beam HAMR. Furthermore, if a flat-top laser beam instead of a Gaussian beam can be used for pre-heating (i.e. for the second laser L2), the effect of the preheating beam on the overall thermal gradient can be almost eliminated, and thus the effect on recording density is negligible.

FIG. 19 is a schematic flowchart 1900 for illustrating a method of writing a magnetic media in an exemplary embodiment. At step 1902, a second portion of the magnetic media is heated with at least one additional heat source to a background temperature which is a proportion of a writing temperature. At step 1904, a first portion of the magnetic media is heated with a write component. At step 1906, the first portion of the magnetic media is encompassed within the second portion of the magnetic media. At step 1908, the encompassed portion is heated with the write component to a resultant temperature that is at least the writing temperature.

In some exemplary embodiments, a preheating is performed using one or more additional heat sources until a region of a magnetic media reaches a background temperature. A write component is then used to heat an area/portion/region encompassed within the preheated region to a writing temperature. In other exemplary embodiments, the heating sequence may be simultaneous or may be reversed.

In the exemplary embodiments described herein, a laser heating scheme comprising dual (or multi) laser HAMR head structures may be provided. The laser heating scheme in the described exemplary embodiments may use additional auxiliary laser beams such as a second or third laser beam (L2 / L3) of larger beam size and smaller energy density than a

first laser (as a writing component) to preheat HAMR media to a background temperature (which is significantly lower than HAMR writing temperature T_w , which is in turn close to a media grain Curie temperature T_c for thermomagnetic switching).

5 One significant advantage of HAMR is that a higher linear density (i.e. even higher than current demonstration of 2 MBPI) can be achieved due to a significantly higher total writing field gradient because of the increased product of high thermal gradient (dT/dx) and steep coercivity (H_c) drop (dH_c/dT at $\sim T_c$) than a conventional head field gradient.

10 The dual/multi laser arrangement in some of the described exemplary embodiments is in contrast to conventional HAMR, where only a single laser beam of relatively high thermal gradient (TG) is used to heat the magnetic media which is typically made of thermomagnetic material. The dual/multi laser arrangement reduces the input light energy into a near-field transducer (NFT), thereby reducing the NFT temperature rise. Consequently,
15 the thermal load to the NFT structure can thus be significantly decreased. This advantageously improves the HAMR head reliability and its work lifetime. The inventors have recognised that it is desirable for the NFT to remain relatively cool during drive operations to avoid head failures.

20 The dual/multi laser arrangement in the described exemplary embodiments surprisingly allows the first laser beam (a writing component e.g. L1; of smaller beam size and higher gradient for writing HAMR bits) to achieve a higher media temperature of $\sim T_c$ at a lower input laser power for L1 than conventional laser heating which utilizes a single laser beam only. The concept was further verified by experiments using a HAMR testing system
25 with 2 heating laser beams. Such a laser heating scheme/method described in the exemplary embodiments advantageously reduces the NFT input laser energy and temperature rise in the NFT, without adversely sacrificing the thermal gradient. The inventors have recognised that when implemented in a write device, such a dual heating scheme advantageously improves head reliability and lifetime (e.g. can be more than 1000 wPOH
30 (write power on hour)).

 The terms "coupled" or "connected" as used in this description are intended to cover both directly connected or connected through one or more intermediate means, unless otherwise stated.

In addition, it is submitted that the description also implicitly covers a computer program, in that it would be clear that the steps of the methods described herein may be put into effect by computer code. It will be appreciated that a large variety of programming languages and coding can be used to implement the teachings of the description herein. Moreover, the computer program if applicable is not limited to any particular control flow and can use different control flows without departing from the scope of the invention.

Furthermore, one or more of the steps of the computer program if applicable may be performed in parallel and/or sequentially. Such a computer program if applicable may be stored on any computer readable medium. The computer readable medium may include storage devices such as magnetic or optical disks, memory chips, or other storage devices suitable for interfacing with a suitable reader/general purpose computer. In such instances, the computer readable storage medium is non-transitory. Such storage medium also covers all computer-readable media e.g. medium that stores data only for short periods of time and/or only in the presence of power, such as register memory, processor cache and Random Access Memory (RAM) and the like. The computer readable medium may even include a wired medium such as exemplified in the Internet system, or wireless medium such as exemplified in bluetooth technology. The computer program when loaded and executed on a suitable reader effectively results in an apparatus that can implement the steps of the described methods.

Additionally, when describing some embodiments, the disclosure may have disclosed a method and/or process as a particular sequence of steps. However, unless otherwise required, it will be appreciated the method or process should not be limited to the particular sequence of steps disclosed. Other sequences of steps may be possible. The particular order of the steps disclosed herein should not be construed as undue limitations. Unless otherwise required, a method and/or process disclosed herein should not be limited to the steps being carried out in the order written. The sequence of steps may be varied and still remain within the scope of the disclosure.

Further, in the description herein, the word "substantially" whenever used is understood to include, but not restricted to, "entirely" or "completely" and the like. In addition, terms such as "comprising", "comprise", and the like whenever used, are intended to be non-

restricting descriptive language in that they broadly include elements/components recited after such terms, in addition to other components not explicitly recited. Further, terms such as "about", "approximately" and the like whenever used, typically means a reasonable variation, for example a variation of +/- 5% of the disclosed value, or a variance of 4% of the disclosed value, or a variance of 3% of the disclosed value, a variance of 2% of the disclosed value or a variance of 1% of the disclosed value.

Furthermore, in the description herein, certain values may be disclosed in a range. The values showing the end points of a range are intended to illustrate a preferred range. Whenever a range has been described, it is intended that the range covers and teaches all possible sub-ranges as well as individual numerical values within that range. That is, the end points of a range should not be interpreted as inflexible limitations. For example, a description of a range of 1% to 5% is intended to have specifically disclosed sub-ranges 1% to 2%, 1% to 3%, 1% to 4%, 2% to 3% etc., as well as individually, values within that range such as 1%, 2%, 3%, 4% and 5%. The intention of the above specific disclosure is applicable to any depth/breadth of a range.

In the described exemplary embodiments, it is appreciated that writing is to change the magnetisation of the media such that in certain scenarios, a write procedure includes an erase procedure.

In the described exemplary embodiments, for dual-laser heating setups, it is appreciated that the first portion of the media heated by the laser beam passing through the waveguide coupled to the near-field transducer may be positioned anywhere within the boundary defined/encompassed by the portion of the media heated by an auxiliary laser beam. For multi-laser heating setups with more than one auxiliary laser beams, the first portion may be positioned anywhere within the boundary defined by the overlapped portions heated by the auxiliary laser beams. The positioning of the heated portions depends on the arrangement of the waveguides relative to one another.

In the described exemplary embodiments, although it is described that the first portion heated by the waveguide output of the write component is smaller than the portion(s) heated by at least one heat source waveguide output, the exemplary embodiments are not limited as such. The first portion heated by the waveguide output of the write component

may be of the same area as the portion(s) heated by at least one heat source waveguide output.

5 In the described exemplary embodiments, although it is described that the additional lasers e.g. L2, L2a, L2b or L2c are switched on before the first laser L1 for heating, the exemplary embodiments are not limited as such and may be arranged such that the first laser L1 is switched on before the additional lasers e.g. L2, L2a, L2b or L2c for heating.

10 In the described exemplary embodiments, light energy sources such as laser diodes are used for the write component and the at least one additional heat sources. However, it will be appreciated that the exemplary embodiments are not limited as such and may include using any suitable heat sources for the heating to the background temperature and/or heating to the writing temperature.

15 It will be appreciated by a person skilled in the art that other variations and/or modifications may be made to the specific embodiments without departing from the scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects to be illustrative and not restrictive.

CLAIMS

1. A write device for magnetic media, the device comprising,
a write component configured to heat a first portion of a magnetic media;
5 at least one additional heat source, the additional heat source being configured to
heat a second portion of the magnetic media to a background temperature which is a
proportion of a writing temperature;

wherein the second portion of the magnetic media encompasses the first portion of
the magnetic media; and

10 further wherein the write component is configured to heat the encompassed portion
to a resultant temperature that is at least the writing temperature.

2. The write device according to claim 1, wherein the write component
comprises a first light energy source coupled to a first waveguide for providing a first
15 waveguide output, and the additional heat source comprises a heat-source light energy
source coupled to a heat-source waveguide for providing a heat-source waveguide output.

3. The write device according to claim 1 or 2, wherein the first light energy
source is a laser diode and the first waveguide is coupled to a near-field transducer for
20 providing the first waveguide output as a focused laser beam at the first waveguide output.

4. The write device according to claim 2 or 3, wherein the first light energy
source and the heat-source light energy source is a same light energy source.

25 5. The write device according to claim 2 or 3, wherein the first light energy
source and the heat-source light energy source are different light energy sources.

6. The write device according to any one of claims 1 to 5, wherein the additional
heat source is configured to heat the second portion of the magnetic media with the centre of
30 the second portion substantially centred at a centre of the first portion of the magnetic media.

7. The write device according to any one of claims 1 to 5, wherein the additional
heat source is configured to heat the second portion of the magnetic media with the centre of
the second portion offset from a centre of the first portion of the magnetic media.

8. The write device according to any one of claims 1 to 7, wherein the at least one additional heat source comprises two or more heat sources, the two or more heat sources being configured to heat two or more portions of the magnetic media to the background temperature which is a proportion of the writing temperature, wherein the encompassed portion is in an overlapped portion of the two or more portions of the magnetic media.

9. A method of writing a magnetic media, the method comprising,
heating a second portion of the magnetic media with at least one additional heat source to a background temperature which is a proportion of a writing temperature;
heating a first portion of the magnetic media with a write component;
wherein the second portion of the magnetic media encompasses the first portion of the magnetic media; and
heating the encompassed portion with the write component to a resultant temperature that is at least the writing temperature.

10. The method according to claim 9, wherein the write component comprises a first light energy source coupled to a first waveguide for providing a first waveguide output, and the additional heat source comprises a heat-source light energy source coupled to a heat-source waveguide for providing a heat-source waveguide output.

11. The method according to claim 9 or 10, wherein the first light energy source is a laser diode and the first waveguide is coupled to a near-field transducer for providing the first waveguide output as a focused laser beam at the first waveguide output.

12. The method according to claim 10 or 11, wherein the first light energy source and the heat-source light energy source is a same light energy source.

13. The method according to claim 10 or 11, wherein the first light energy source and the heat-source light energy source are different light energy sources.

14. The method according to any one of claims 9 to 13, further comprising heating the second portion of the magnetic media with the additional heat source such that

the centre of the second portion is substantially centred at a centre of the first portion of the magnetic media.

15. The method according to any one of claims 9 to 13, further comprising
5 heating the second portion of the magnetic media with the additional heat source such that the centre of the second portion is offset from a centre of the first portion of the magnetic media.

16. The method according to any one of claims 9 to 15, wherein the step of
10 heating a second portion comprises heating two or more portions of the magnetic media with two or more heat sources, the two or more heat sources being configured to heat the two or more portions of the magnetic media to the background temperature which is a proportion of the writing temperature, wherein the encompassed portion is in an overlapped portion of the two or more portions of the magnetic media.

15

17. A HAMR head structure comprising a write device for a magnetic media, the write device comprising,

a write component configured to heat a first portion of a magnetic media;

20 at least one additional heat source, the additional heat source being configured to heat a second portion of the magnetic media to a background temperature which is a proportion of a writing temperature;

wherein the second portion of the magnetic media encompasses the first portion of the magnetic media; and

25 further wherein the write component is configured to heat the encompassed portion to a resultant temperature that is at least the writing temperature.

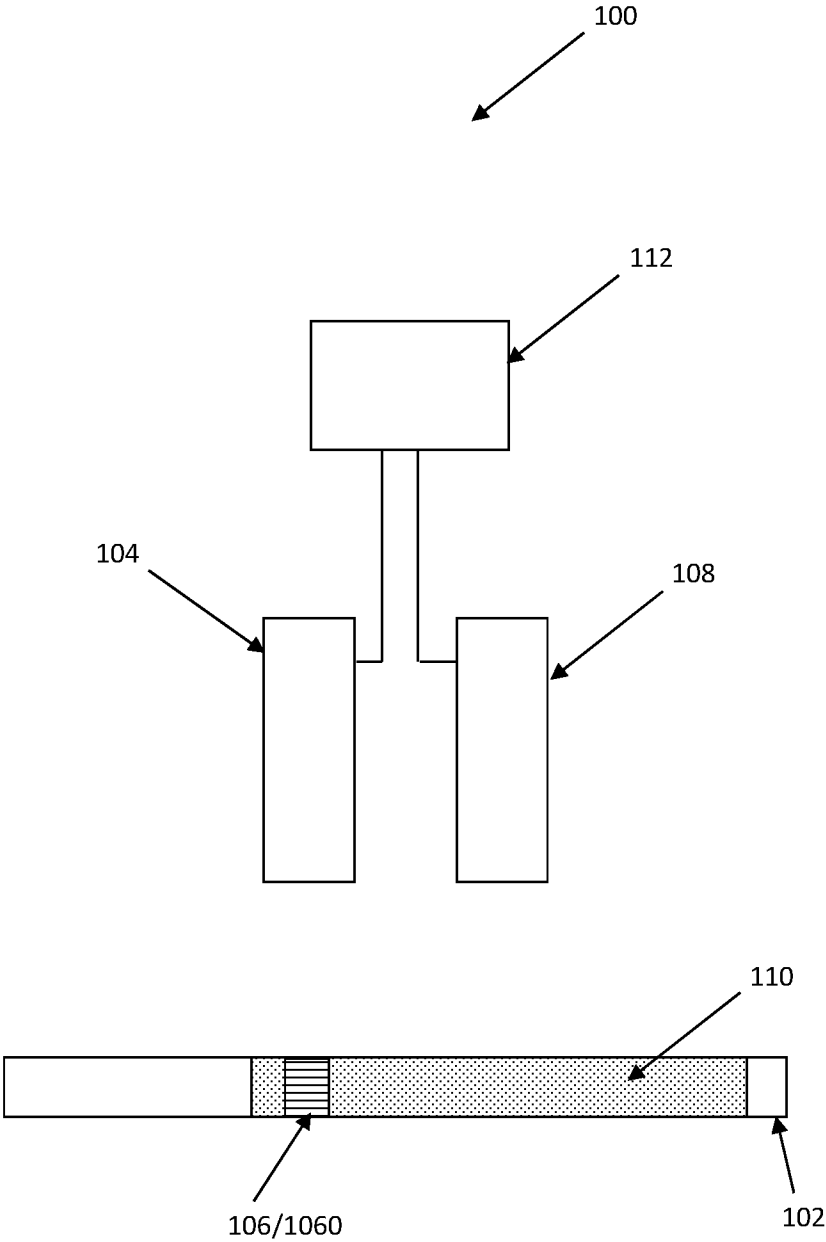


FIG. 1

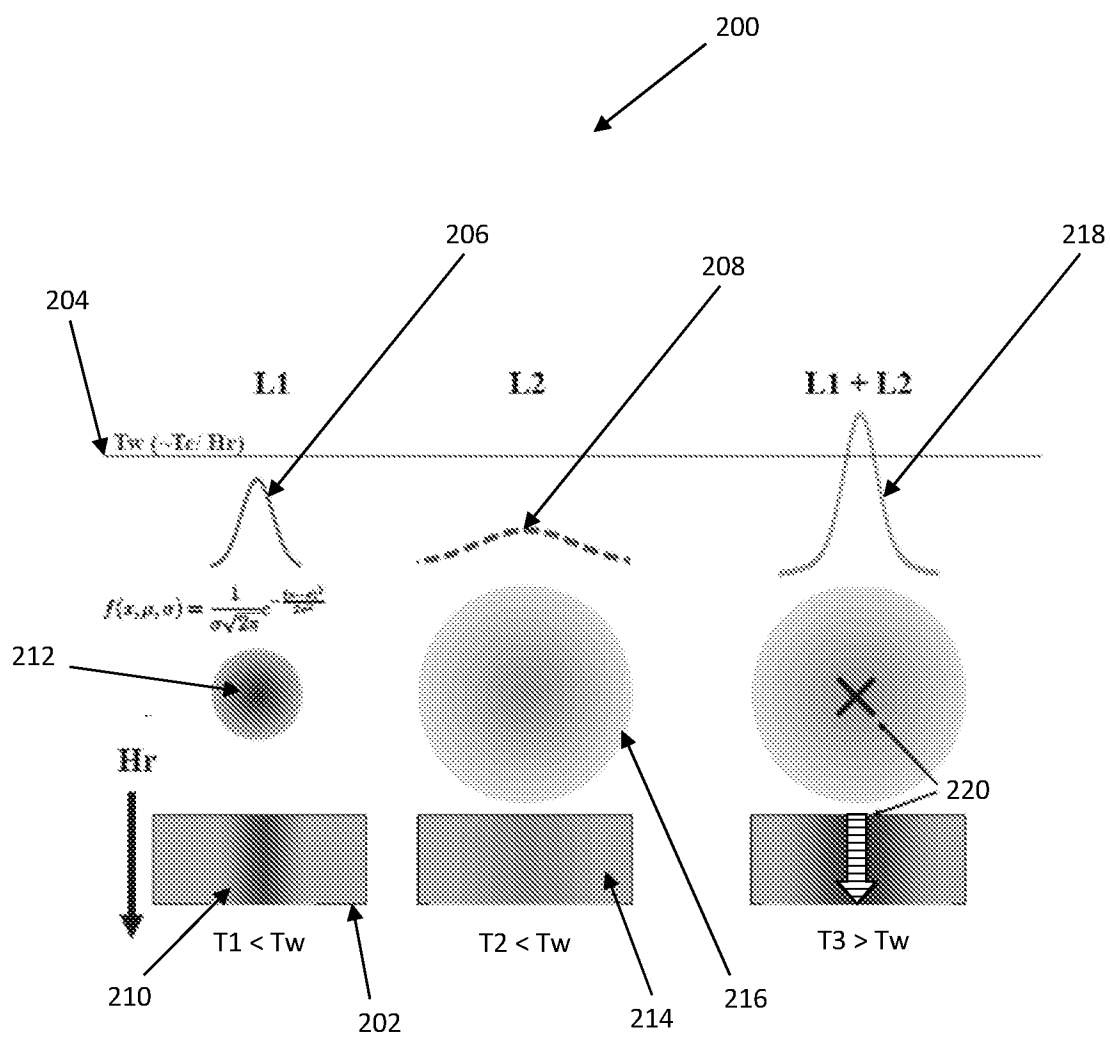


FIG. 2A

FIG. 2B

FIG. 2C

FIG. 2

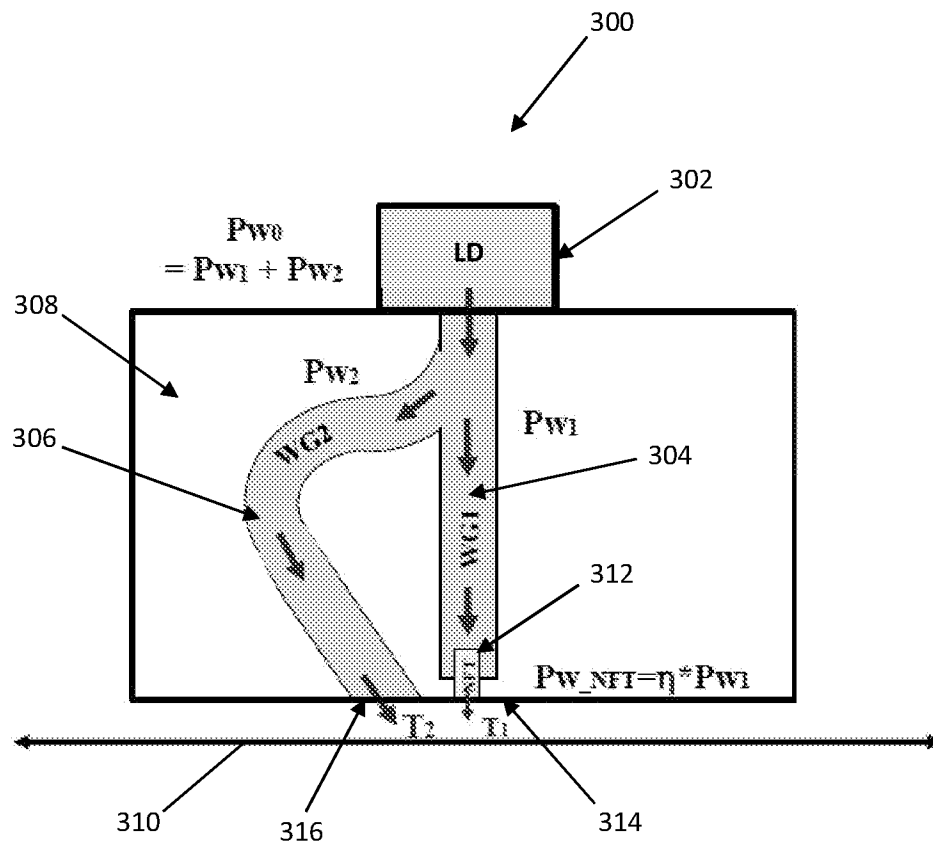


FIG. 3

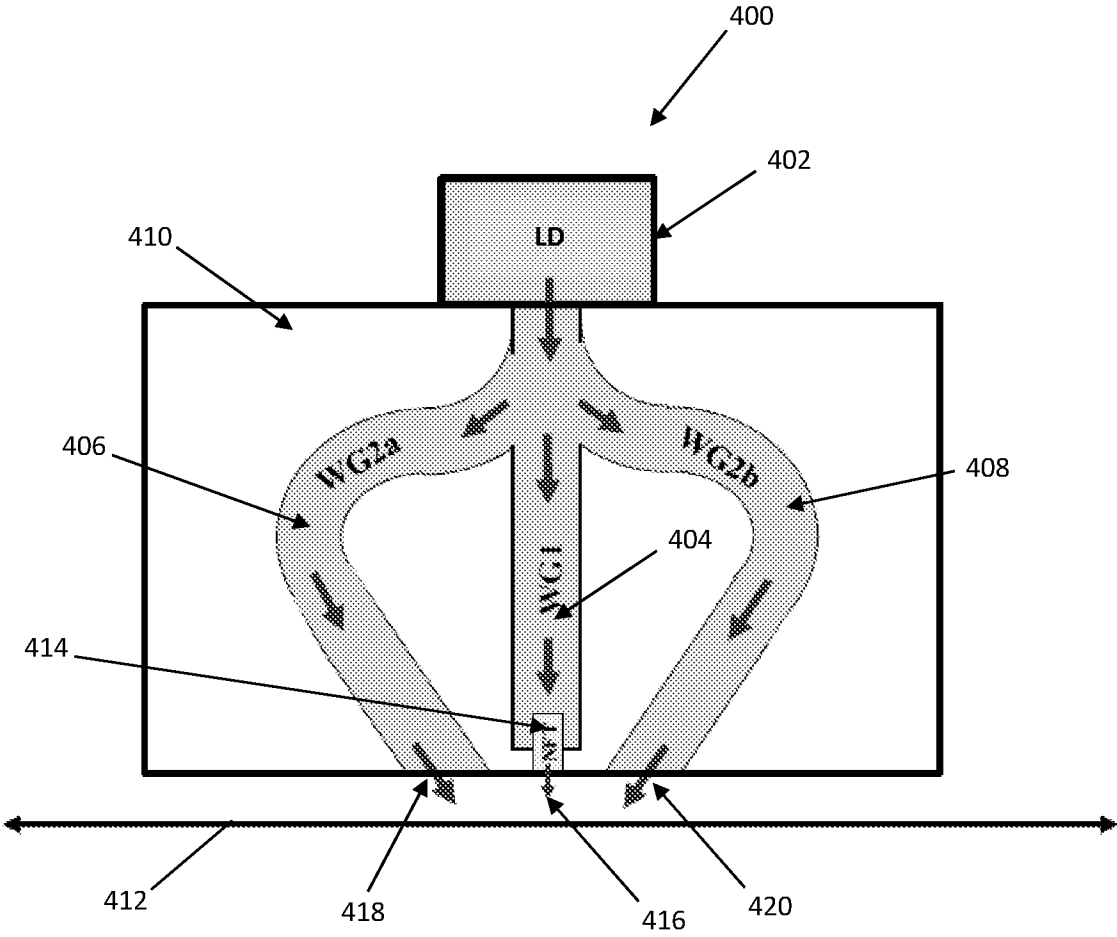


FIG. 4

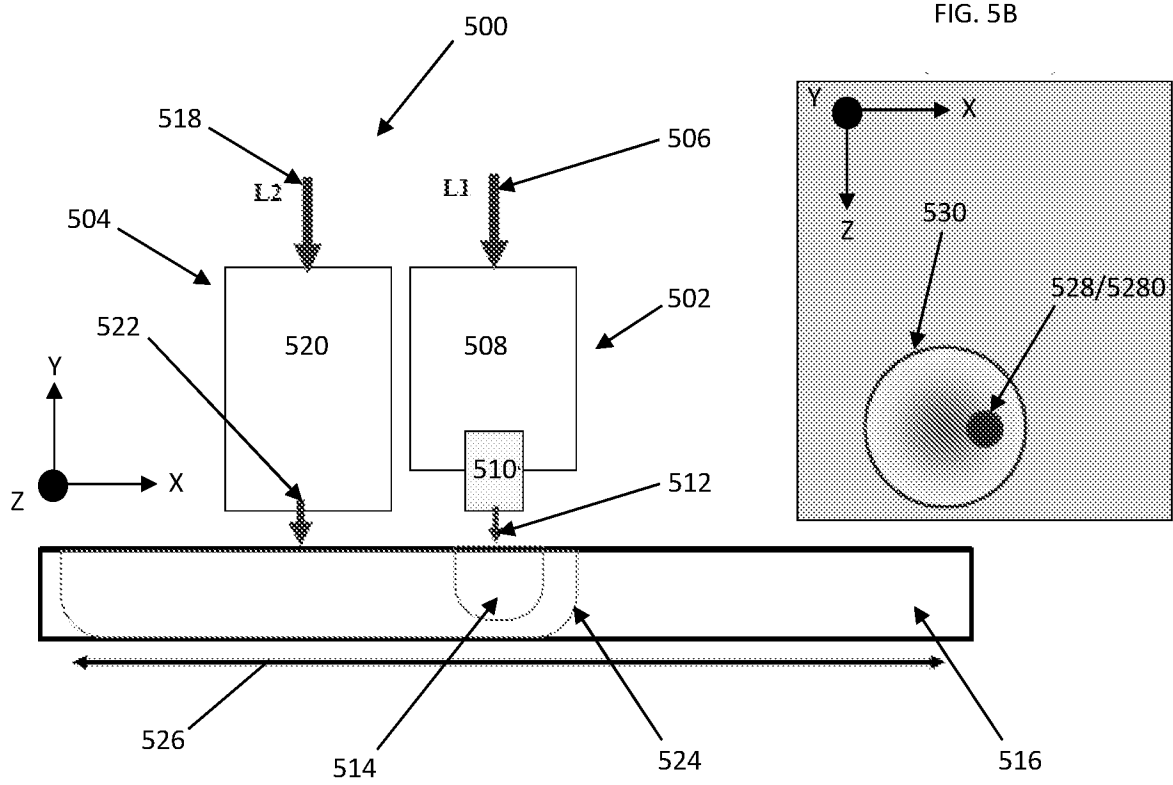


FIG. 5A

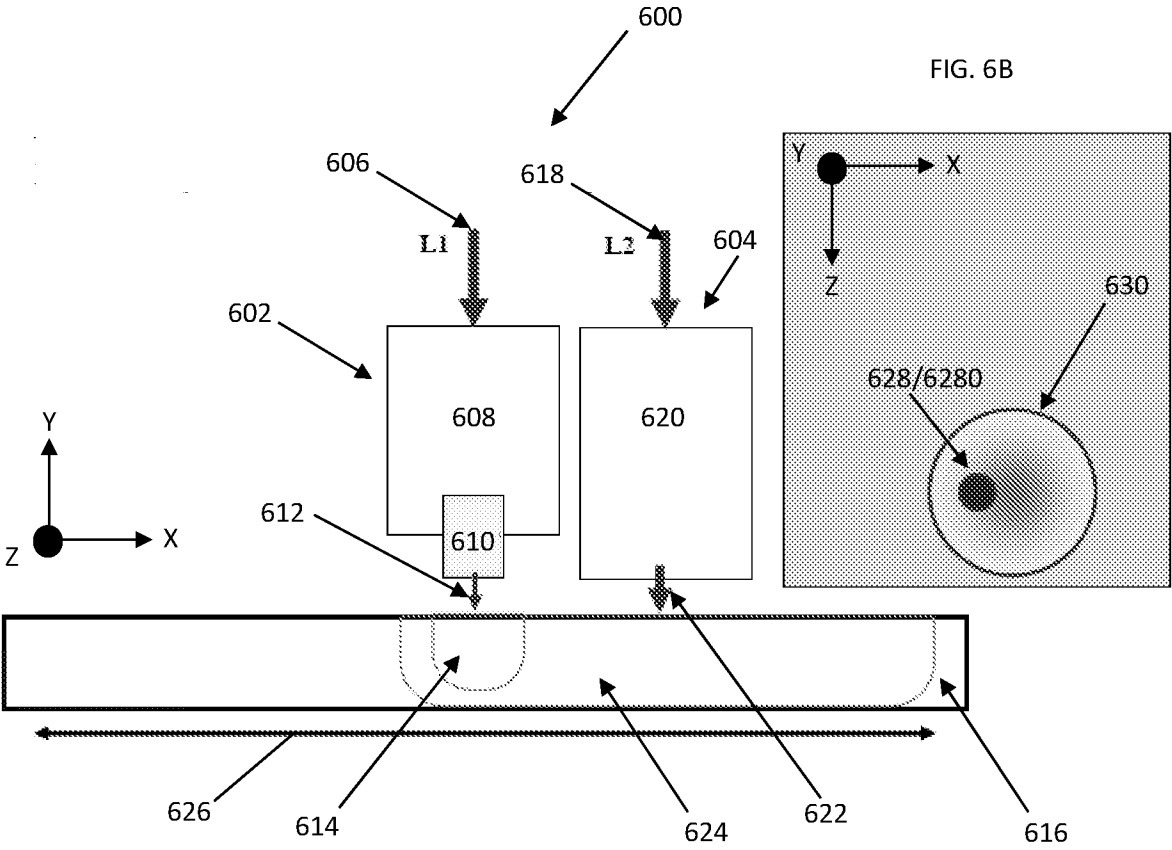


FIG. 6A

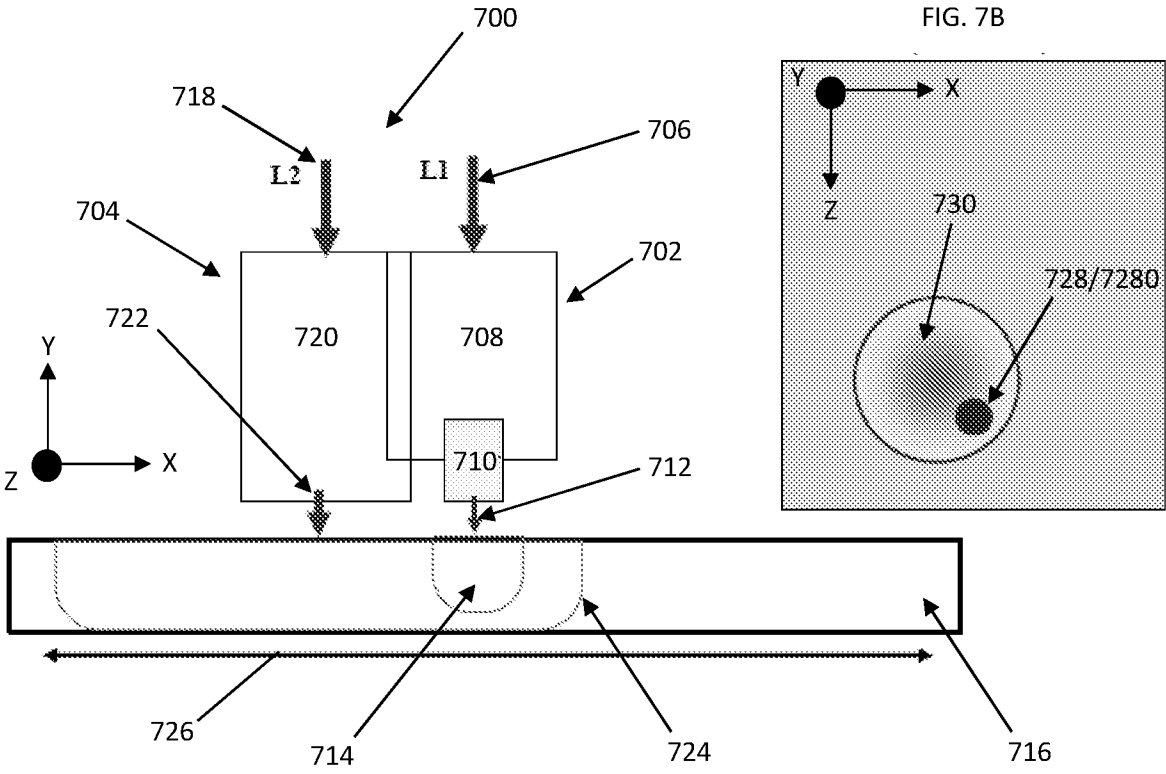


FIG. 7A

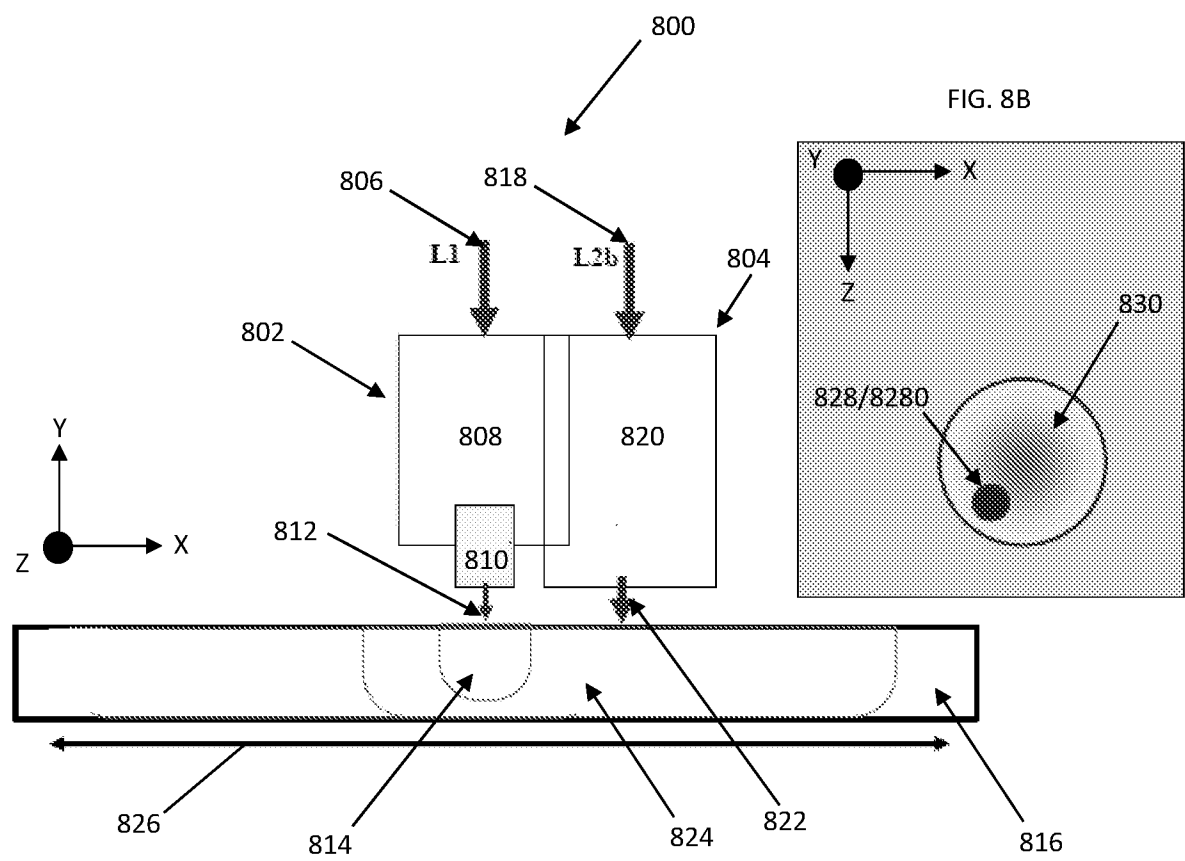


FIG. 8A

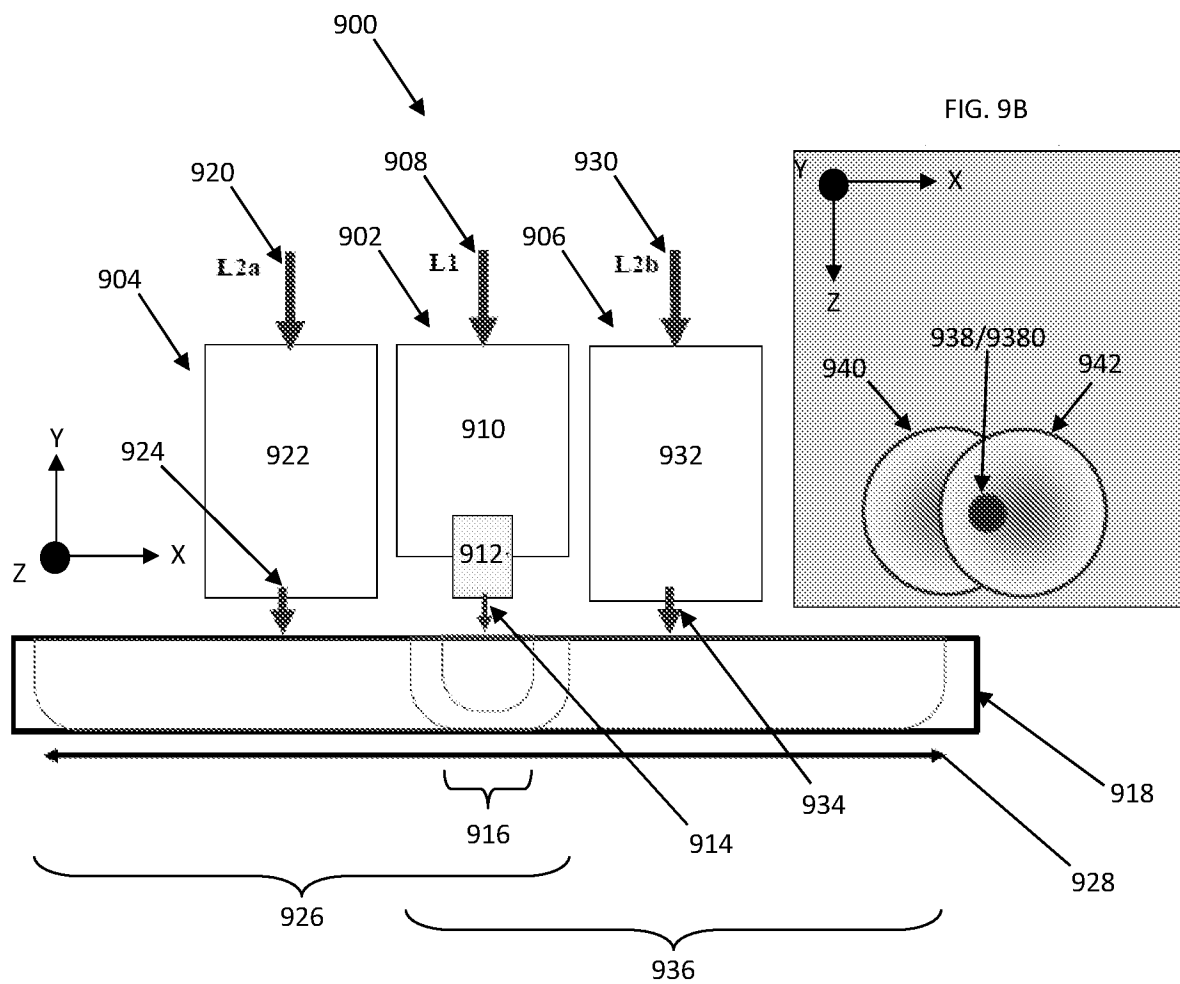


FIG. 9A

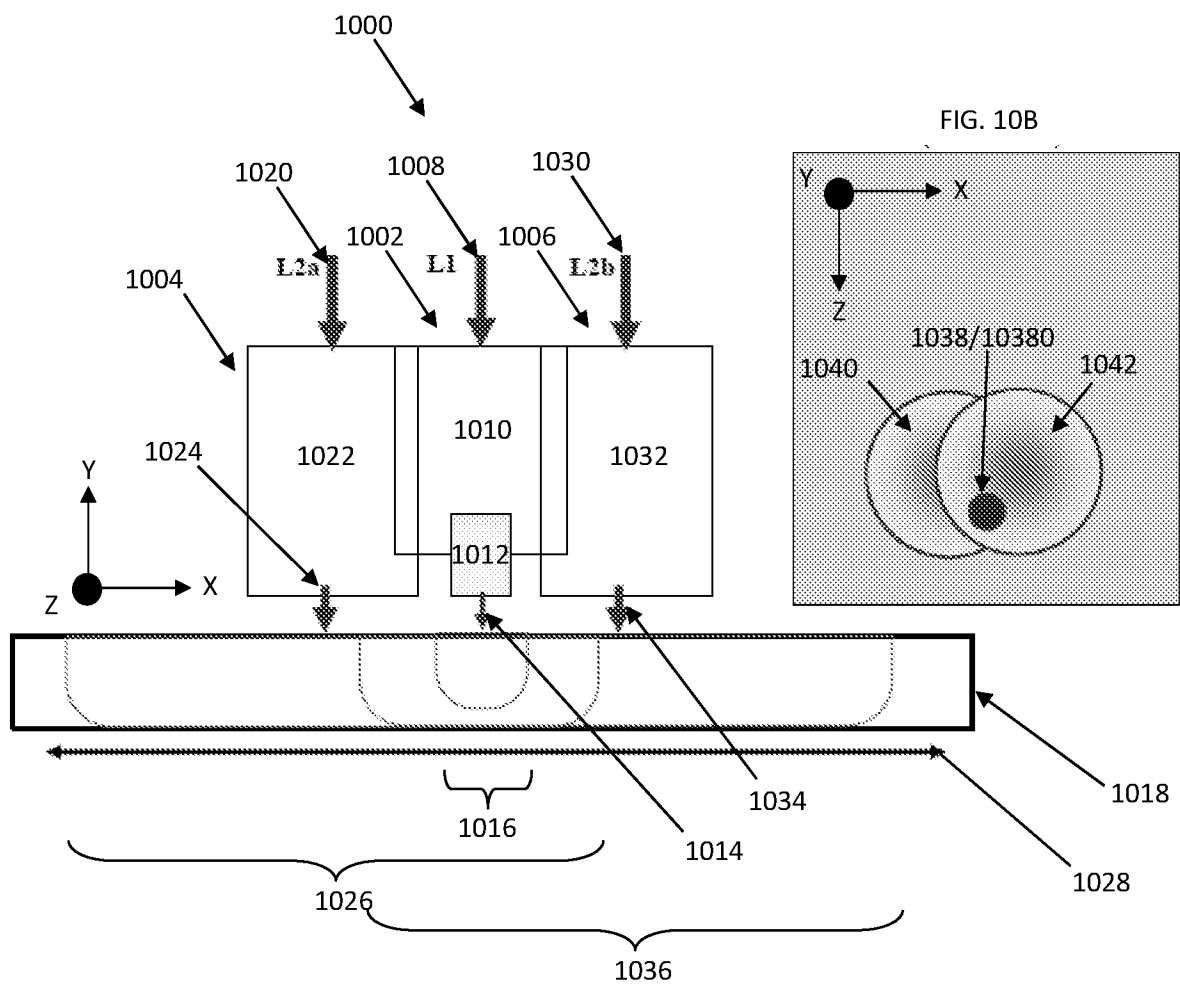


FIG. 10A

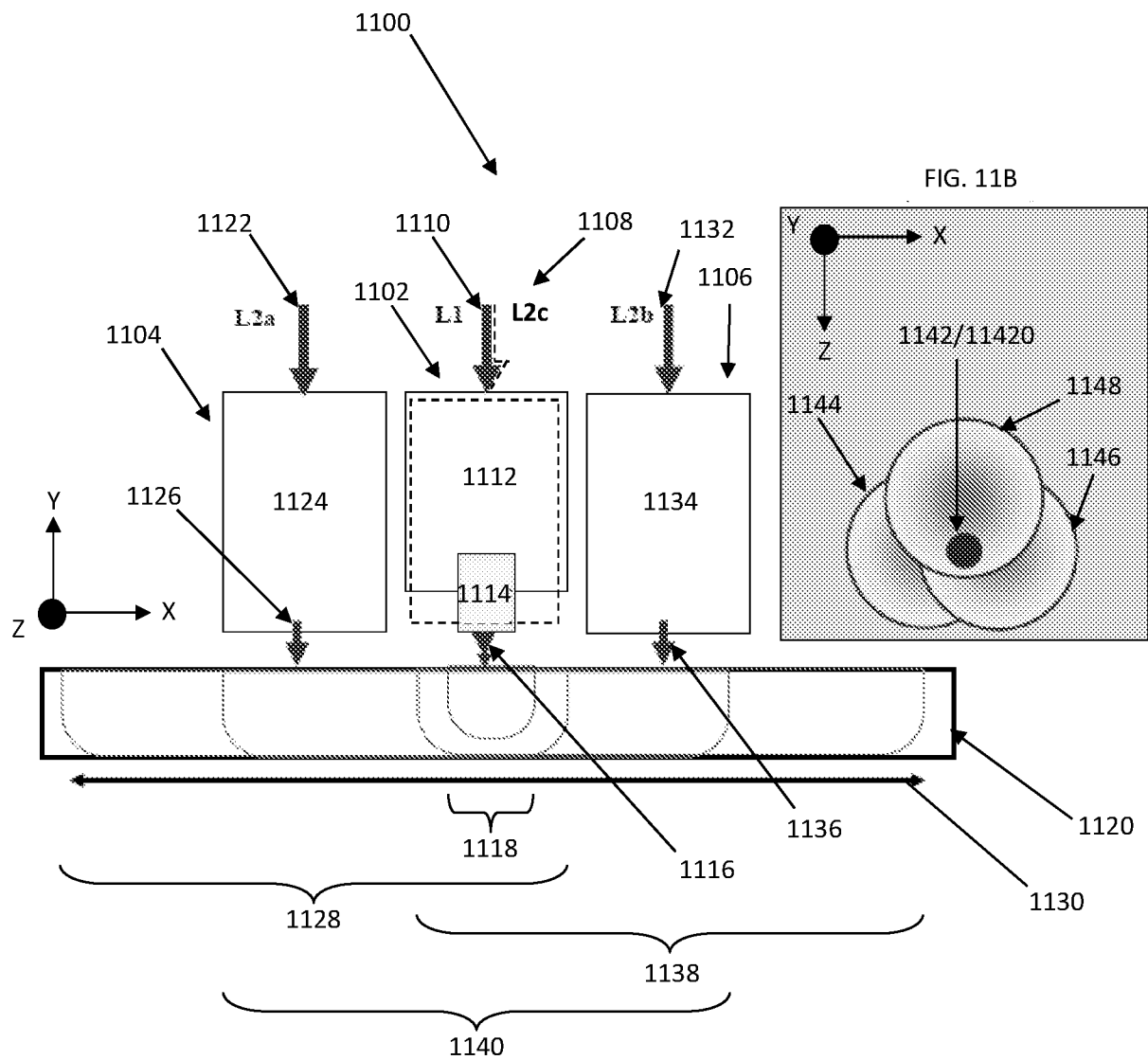


FIG. 11A

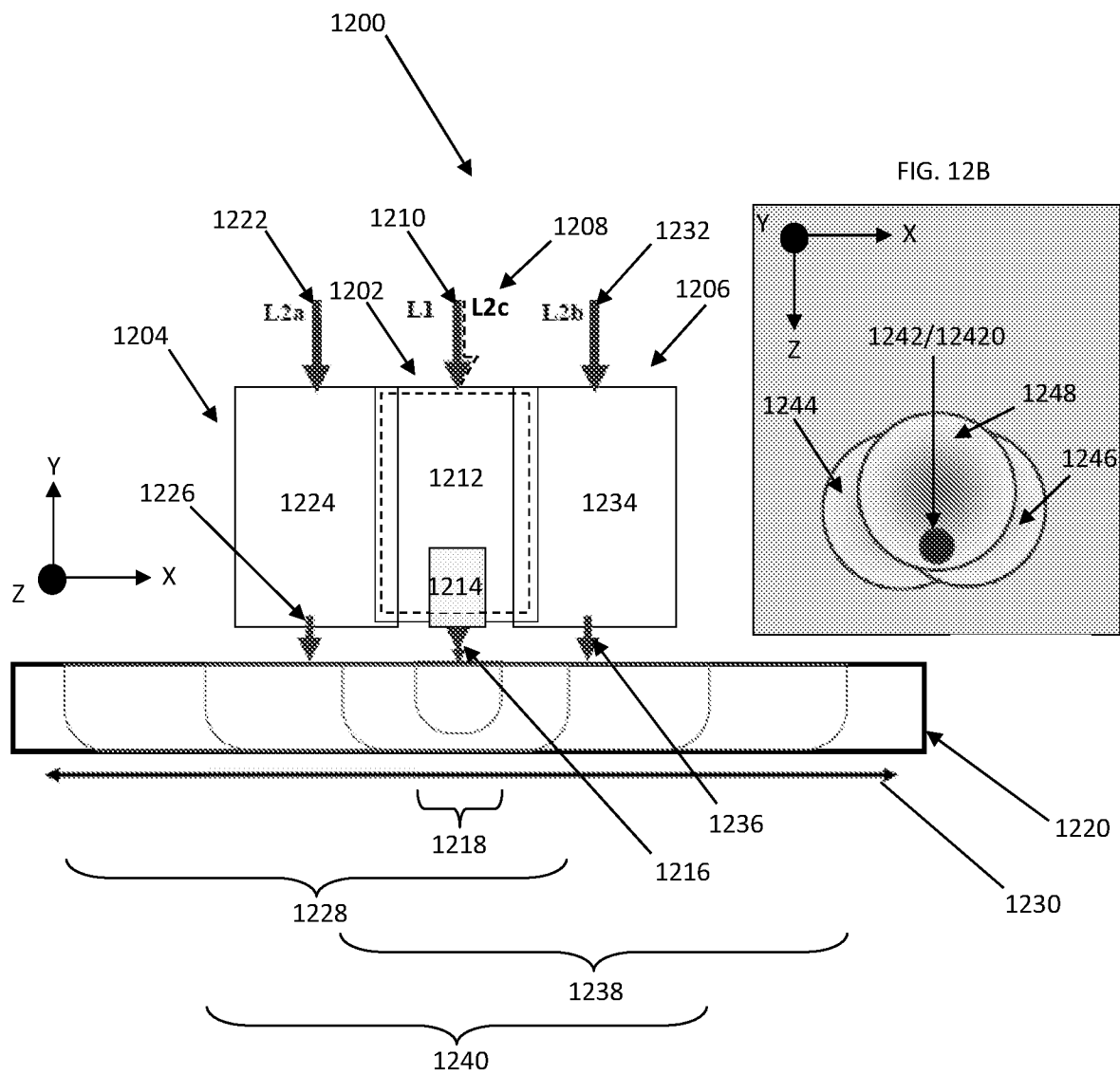


FIG. 12A

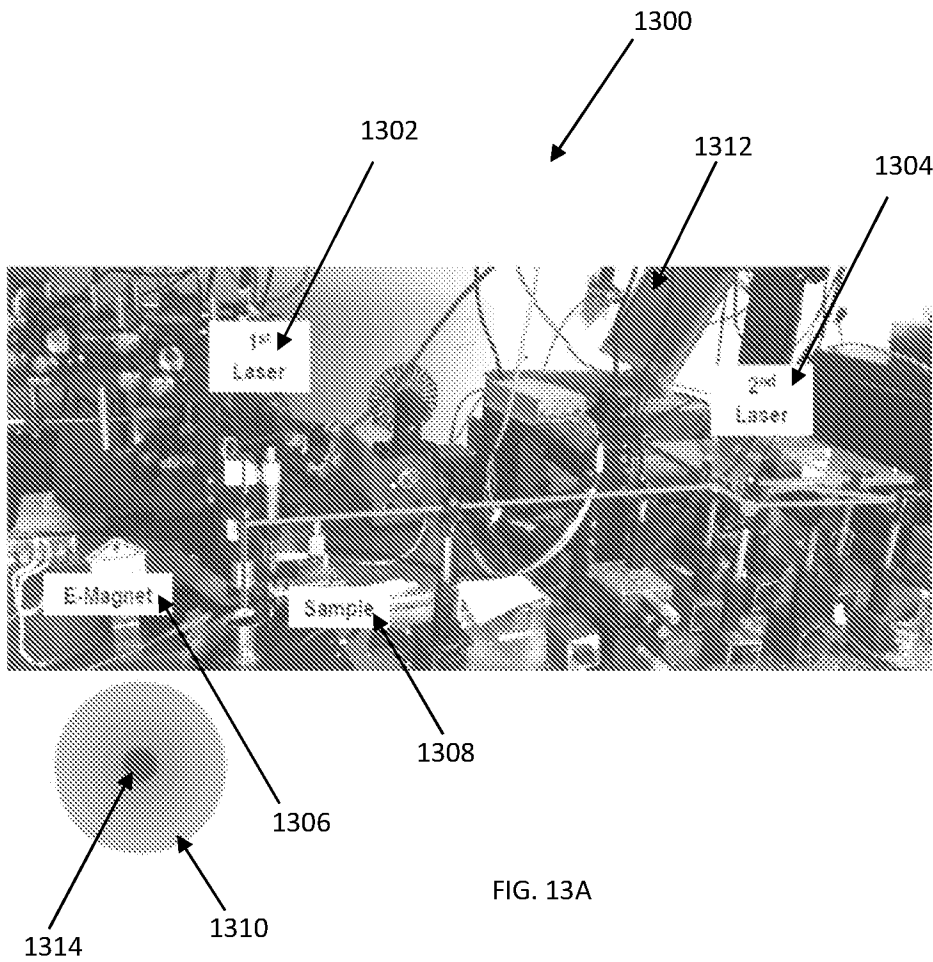


FIG. 13A

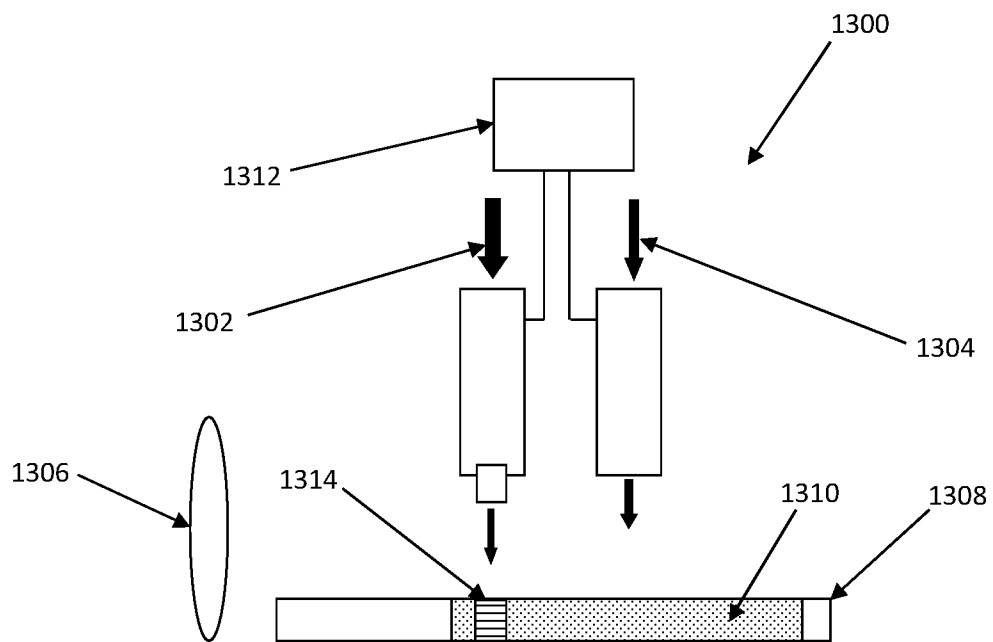


FIG. 13B

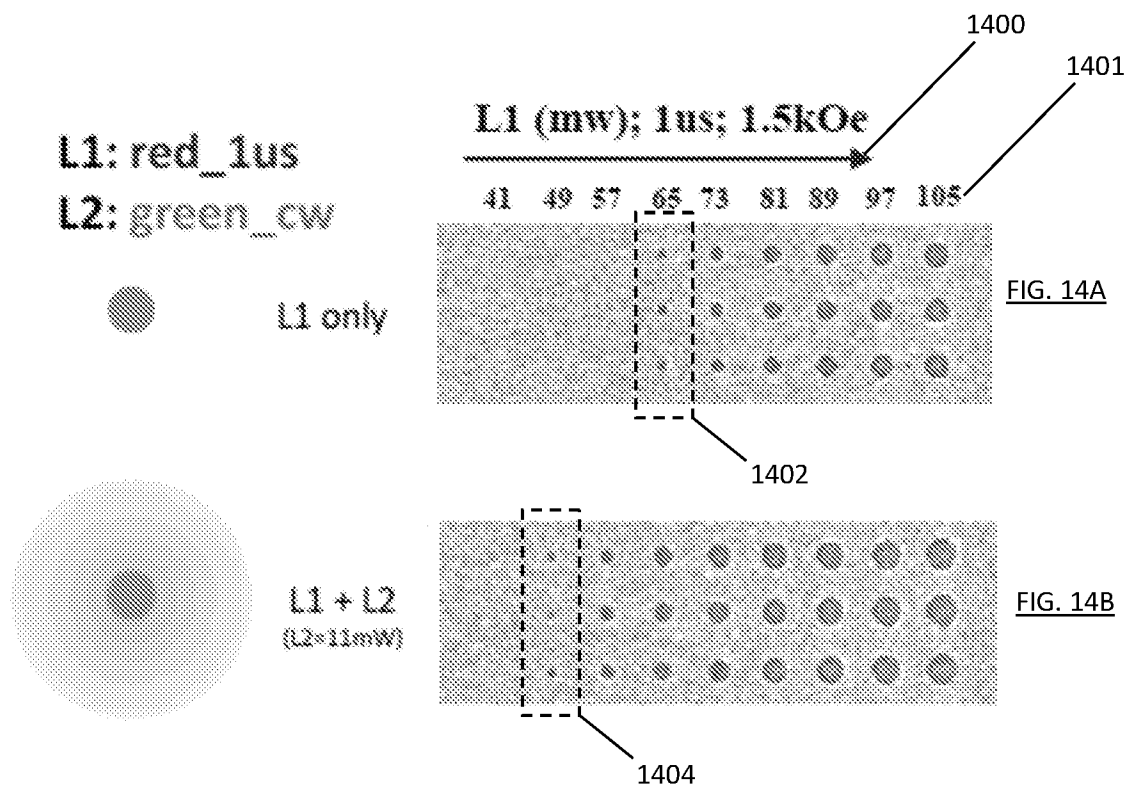


FIG. 14

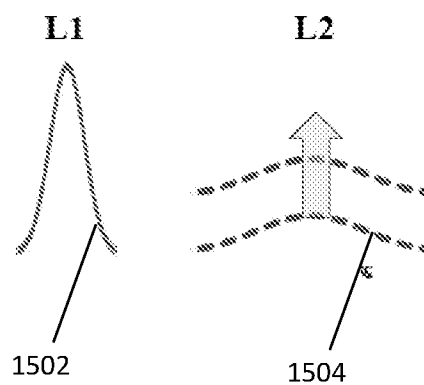
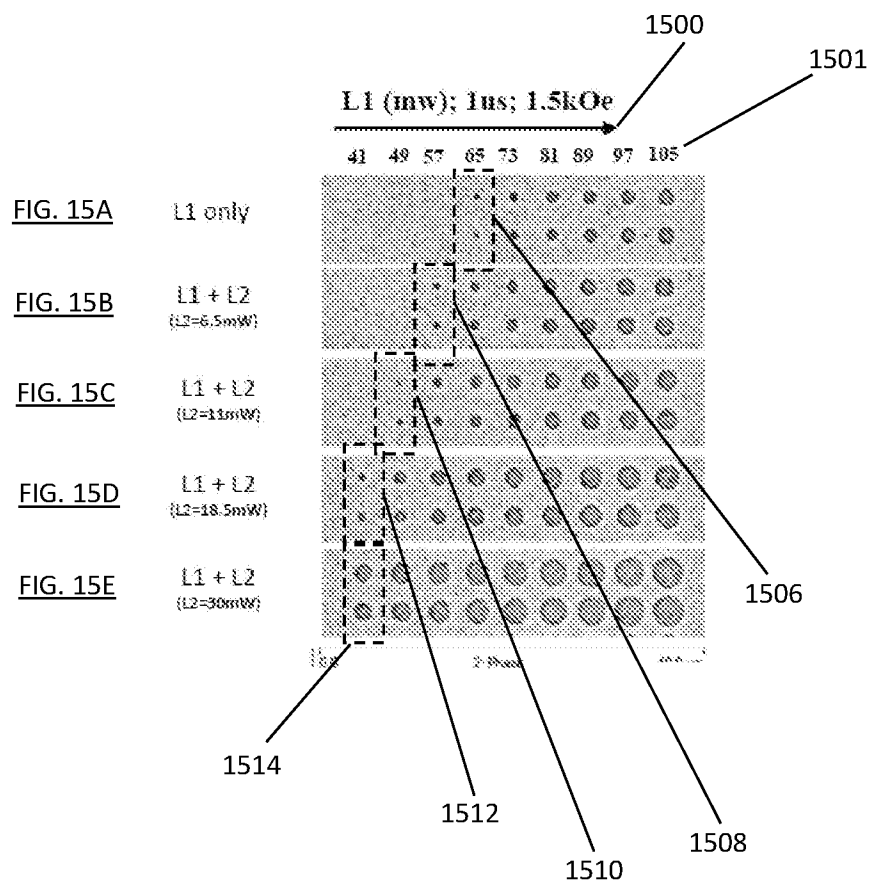


FIG. 15F

FIG. 15G

FIG. 15

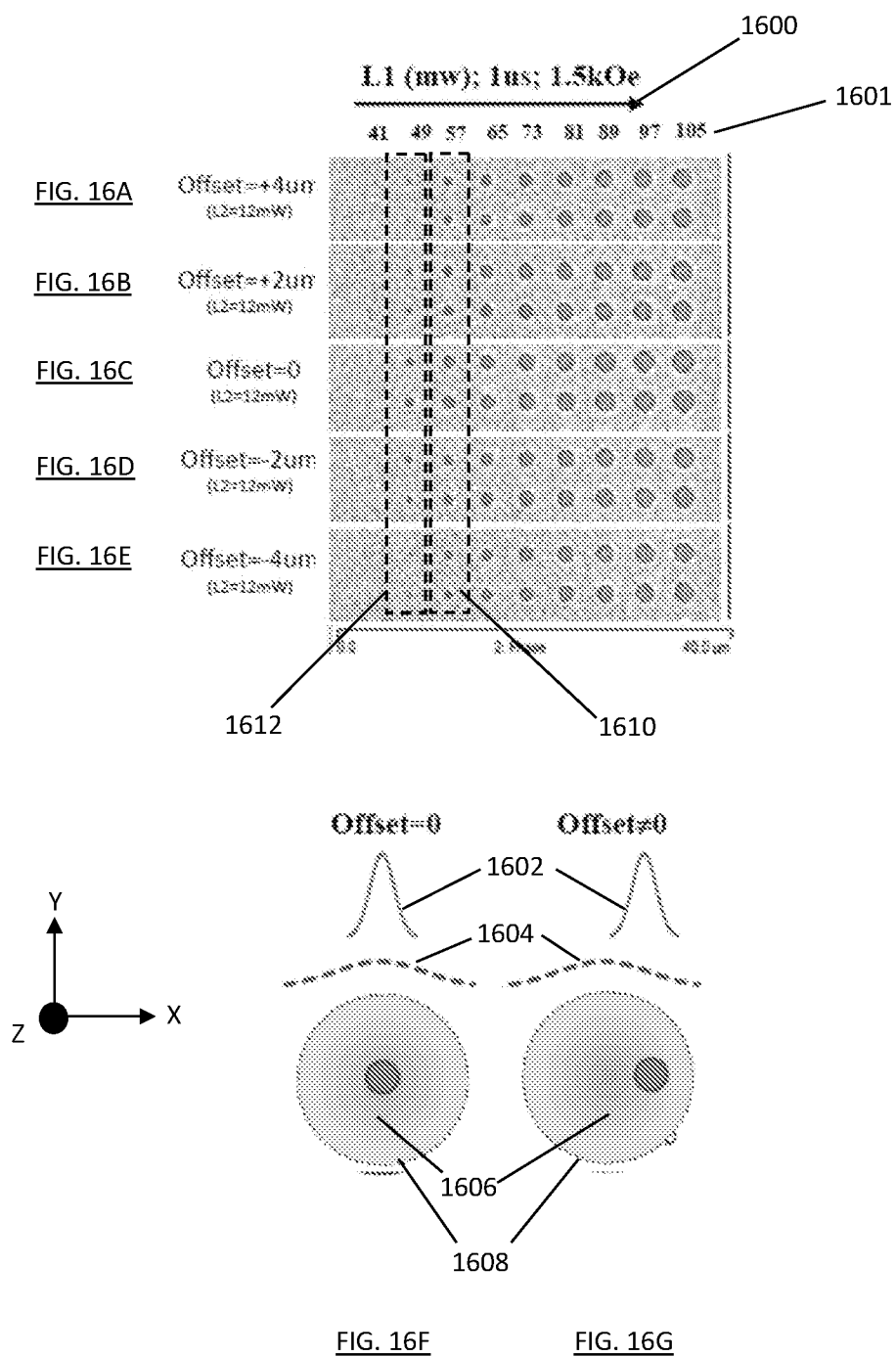


FIG. 16

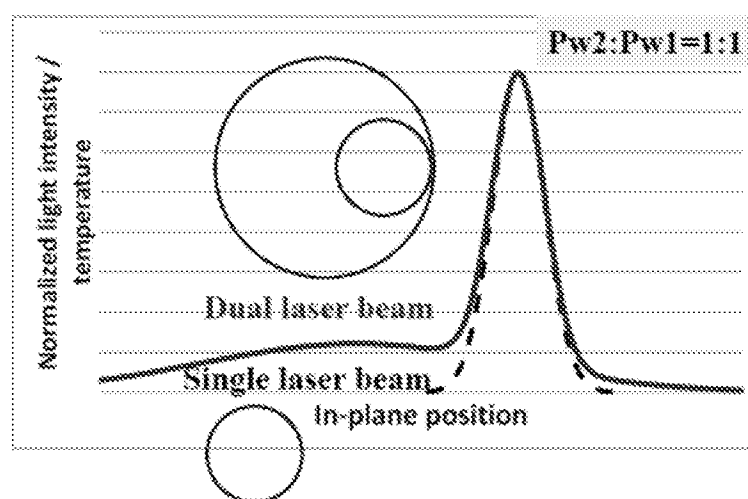


FIG. 17

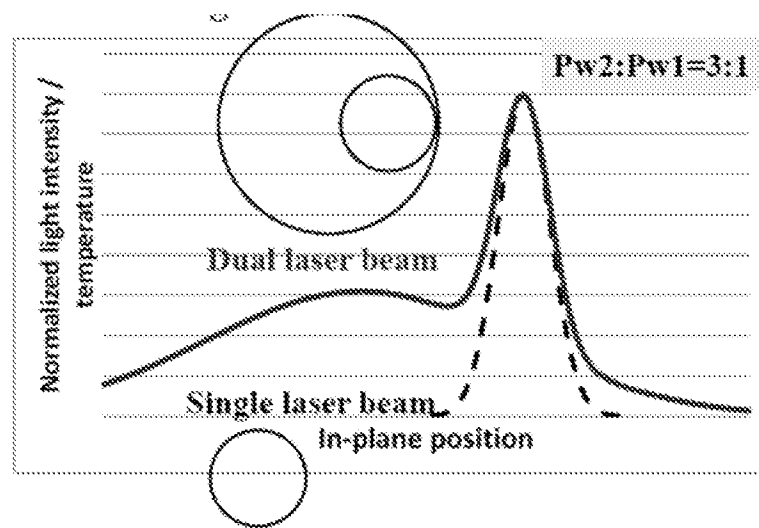


FIG. 18

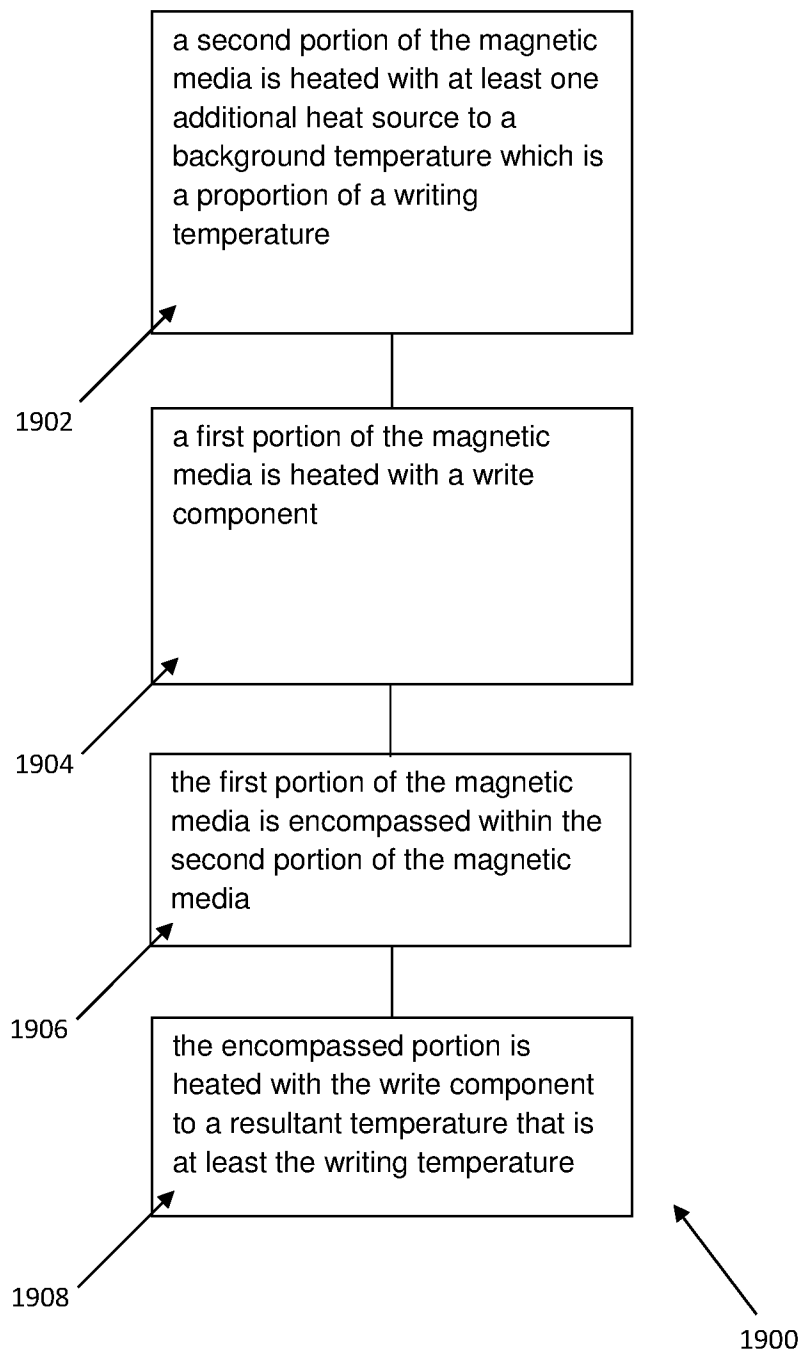


FIG. 19

INTERNATIONAL SEARCH REPORT

International application No.

PCT/SG2017/050103

A. CLASSIFICATION OF SUBJECT MATTER

G11B 5/02 (2006.01) G11B 5/012 (2006.01) G11B 7/127 (2012.01)

According to International Patent Classification (IPC)

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G11B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

IEEE Xplore, EPODOC, WPI, English full-text patent databases, FAMPAT: additional, auxiliary, dual, second, two, multiple, heat, laser, diode, light, optical, beam, waveguide, channel, temperature, 辅助, 附加, 光, 热 and related search terms

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6950385 B1 (CHIBA N. ET AL.) 27 September 2005 Figures 7, 8, column 8, line 28-67, column 9, line 5-20	1-17
A	US 2010/0002330 A1 (LILLE J. S.) 7 January 2010 Whole document	
A	US 2011/0205861 A1 (ERDEN M. F. ET AL.) 25 August 2011 Whole document	
A	US 2012/0092971 A1 (SCHRECK E. ET AL.) 19 April 2012 Whole document	
A	US 2015/0340051 A1 (TATAH K. ET AL.) 26 Nov 2015 Whole document	

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

*Special categories of cited documents:

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

15/05/2017 (day/month/year)

Date of mailing of the international search report

24/05/2017 (day/month/year)

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/SG2017/050103

Note: This Annex lists known patent family members relating to the patent documents cited in this International Search Report. This Authority is in no way liable for these particulars which are merely given for the purpose of information.

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 6950385 (B1)	27/09/2005	EP1063641 (A1) JPH11296897(A) WO9941741 (A1)	27/12/2000 29/10/1999 19/08/1999
US 20100002330 (A1)	07/01/2010	NONE	NONE
US 20110205861 (A1)	25/08/2011	US2013294207 (A1)	07/11/2011
US 20120092971 (A1)	19/04/2012	JP2012089230 (A)	10/05/2012
US 20150340051 (A1)	26/11/2015	NONE	NONE