



(51) International Patent Classification:

G01R 33/00 (2006.01) G11B 5/31 (2006.01)

G01R 33/09 (2006.01) G11B 5/39 (2006.01)

(21) International Application Number:

PCT/IB2021/054647

(22) International Filing Date:

27 May 2021 (27.05.2021)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

20315270.7 28 May 2020 (28.05.2020) EP

(71) Applicant: CROCUS TECHNOLOGY SA [FR/FR]; 3

avenue Doyen Louis Weil, 38025 Grenoble (FR).

(72) Inventors: **TIMOPHEEV, Andrey**; 19, Avenue General de Gaulle, 38450 Vif (FR). **STRELKOV, Nikita**; 82 rue des Aiguinards, 38240 Meylan (FR). **CHILDRRESS, Jeffrey**; 5700 Village Oaks Drive, San Jose, California 95123 (US).

(74) Agent: **P&TS SA (AG, LTD.)**; Av. J.-J. Rousseau 4, P.O. Box 2848, 2001 Neuchâtel (CH).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, IT, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW,

(54) Title: MAGNETIC SENSOR COMPRISING MAGNETORESISTIVE ELEMENTS AND SYSTEM FOR PROGRAMMING SUCH MAGNETIC SENSOR

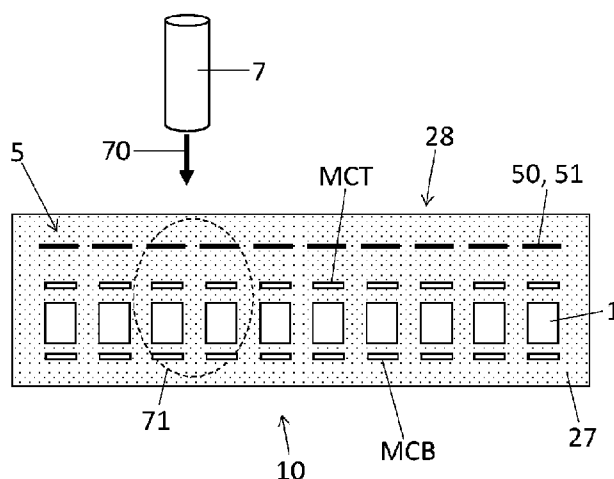


Fig. 1

(57) Abstract: The present disclosure concerns a magnetic sensor (10) comprising a plurality of magnetoresistive elements (1); each magnetoresistive element comprising a ferromagnetic layer (21) having a magnetization (210) that is orientable at or above a threshold temperature; the magnetic sensor further comprises a plasmonic structure (5) destined to be irradiated by electromagnetic radiation (70) and comprising a spatially periodic plasmonic array (50) of metallic structures (51). The period of the plasmonic array and the lateral dimension of the metallic structures are adjusted to obtain plasmon resonance of the plasmonic structure for a given wavelength of the electromagnetic radiation (70). The plasmonic array is arranged in the magnetic sensor such as to heat the first ferromagnetic layer at or above the threshold temperature, from the enhanced absorption of the electromagnetic radiation by plasmon resonance. The present disclosure further concerns a system comprising the sensor and an emitting device (7) configured to emit electromagnetic radiation.



SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN,
TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) Designated States (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

- *with international search report (Art. 21(3))*
- *in black and white; the international application as filed contained color or greyscale and is available for download from PATENTSCOPE*

Magnetic sensor comprising magnetoresistive elements and system for programming such magnetic sensor

Field

[0001] The present invention relates to magnetic sensors comprising magnetoresistive elements and a system for programming such magnetic sensors.

5 Description of related art

[0002] Magnetic sensor based on magnetic tunnel junction (MTJ) technology outperforms GMR, AMR and Hall effect sensors by several essential parameters such as sensitivity, die size etc. Full performance of TMR sensor can be reached with a Wheatstone bridge configuration where
10 diagonal branches are programmed in the same direction while those constituting each half bridge - in the opposite. Therefore, Wheatstone bridge configuration requires a sequential programming of different sensor branches under different magnetic field directions.

[0003] Among other technologies, laser programming is an effective
15 tool to deliver high energy densities on a micron sized spot. Another advantage is that it allows to program entire wafer in a few tens of minutes. All this has direct impact on the final product cost and therefore at least partially defines its success on the market.

[0004] However, effectiveness of laser programming is strongly
20 dependent on a complete sensor layout design. Usual tunnel magnetoresistive (TMR) sensor contains an array of MTJ stacks connected with certain serial to parallel ratio. Metallic layers serve as interconnectors within MTJ array and as well as electric leads to outer periphery. They therefore partially or completely hide an MTJ stack from the direct
25 exposure to a laser beam. Moreover, metals do not absorb much in the visible/near infrared region. Therefore, all the metallic layers work as mirrors reflecting the laser energy rather than absorbing it. This makes the

absorption of the energy non uniform (in the first approximation it depends on surface density of metal) over the sensor area and quite inefficient.

[0005] Document US201111133 discloses a method by which portions
5 of a wafer level fabrication can be selectively heated by means of the formation of a plasmon generating layers of specific size, shape, orientation and material on the fabrication and then illuminating the formation with electromagnetic radiation of such wavelength and polarization as will optimally be absorbed by the plasmon generating layers
10 so as to generate plasmons therein. The generated plasmons thereupon produce thermal energy which is transferred to portions of the fabrication with which the plasmon generation layer has thermal contact.

[0006] Document US2015132503 discloses methods of forming a near field transducer, the method including depositing a plasmonic material;
15 and laser annealing the plasmonic material.

Summary

[0007] Plasmonic resonance is well-known and established effect which happens in metallic structures with developed micron to sub-micron texture. The effect has overcome the in-lab environment and gets
20 employed in real life applications, namely heat-assisted programming of high-coercive recording media, absolute or selective absorber layers for optical sensing, laser color printing on the metal, etc. Resonance absorption in plasmonic structure can be adjusted to laser beam polarization and its wavelength by design of the texture characteristic
25 dimensions, such as size of the elements, their shape and their relative distance.

[0008] The present disclosure concerns a magnetic sensor comprising a plurality of magnetoresistive elements. Each magnetoresistive element comprises an MTJ including a first ferromagnetic layer having a first
30 magnetization switchable in accordance to an external magnetic field

above a threshold temperature.

[0009] The magnetic sensor further comprises a plasmonic structure destined to be irradiated by electromagnetic radiation. The plasmonic structure comprises a spatially periodic plasmonic array of metallic
5 structures, the period of the plasmonic array and the lateral dimension of the metallic structures being adjusted to obtain plasmon resonance of the plasmonic structure for a given wavelength of the electromagnetic radiation. The plasmonic array is arranged in the magnetic sensor such as to heat the first ferromagnetic layer at the threshold temperature, from
10 the enhanced absorption of the electromagnetic radiation by plasmon resonance.

[0010] The magnetic sensor comprises an array of sensor branches, each sensor branch comprising a plurality of magnetoresistive elements. The plasmonic structure comprises a plurality of plasmonic subarrays, each
15 plasmonic subarray comprising a periodic array of metallic structures and being arranged in alternance with the sensor branches.

[0011] The present disclosure further concerns a system comprising the magnetic sensor and an electromagnetic radiation emitting device configured to emit electromagnetic radiation that irradiates an illuminated
20 region of the magnetic sensor and that has a wavelength adapted to generate plasmon resonance of the plasmonic structure.

[0012] The magnetic sensor disclosed herein can be programmed by using an electromagnetic radiation and provide efficient absorption of the light energy at the MTJs. The different metallic layers can be used for
25 absorbing the light energy. Absorption of the light energy is also more uniform.

Brief Description of the Drawings

[0013] The invention will be better understood with the aid of the description of an embodiment given by way of example and illustrated by the figures, in which:

5 Fig. 1 shows a side view of a magnetic sensor comprising a plurality of magnetoresistive elements and a plasmonic structure, according to an embodiment;

 Fig. 2 shows a side view of an isolated magnetoresistive element, according to an embodiment;

10 Fig. 3 represents a topology of the magnetic sensor showing one MTJ atop a silicon-based CMOS front-end circuit;

 Figs 4a to 4c show periodic plasmonic arrays comprising rectangular-shaped metallic structures (Fig. 4a), disc-shaped metallic structures (Fig. 4b) and elliptically shaped metallic structures (Fig. 4c),
15 according to an embodiment;

 Fig. 5 shows the plasmonic structure located on top of the magnetoresistive elements and on top of the top metal connector layer, according to an embodiment;

 Fig. 6 shows a top view of an arrangement of the magnetic
20 sensor comprising the plasmonic structure located at the level of the top metal connector layer, according to an embodiment;

 Fig. 7 shows the plasmonic structure comprising a plasmonic array and an auxiliary plasmonic structure, according to an embodiment;

 Fig. 8 shows the magnetic sensor wherein the plasmonic structure
25 comprises a first plasmonic subarray and a second plasmonic subarray, according to an embodiment.

Detailed Description of possible embodiments

[0014] **Fig. 1** shows a side view of a magnetic sensor 10 comprising a plurality of magnetoresistive elements 1, according to an embodiment. **Fig.**

2 shows a side view of an isolated magnetoresistive element 1, according to an embodiment.

[0015] As shown in Fig. 2, the magnetoresistive element 1 can comprise a MTJ 2 including a first ferromagnetic layer 21 having a first magnetization 210, a second ferromagnetic layer 23 having a second magnetization 230 that can be switched relative to the first magnetization 210. A tunnel barrier layer 22 is comprised between the first ferromagnetic layer 21 and the second ferromagnetic layer 23. The first magnetization 210 can be switchable in accordance to an external magnetic field when the MTJ 2 is heated at a temperature equal or above a threshold temperature such as a blocking temperature, a Neel temperature, or another threshold temperature. The first magnetization 210 becomes pinned at a temperature below the threshold temperature. The threshold temperature can be above 150°C or 200°C or at least above temperature of normal conditions of use of the magnetoresistive element 1. Below the threshold temperature, the first magnetization 210 is pinned and its direction remains stable for temperatures and external magnetic fields corresponding to normal conditions of use of the magnetoresistive element 1.

[0016] The MTJ 2 can further comprise a pinning layer 24, such as an antiferromagnetic layer, adjacent to the first ferromagnetic layer 21. The pinning layer 24 pins the first magnetization 210 along a pinned direction through exchange coupling at a temperature below the threshold temperature. Here, the threshold temperature can correspond to a temperature close to the Neel temperature and, at the same time, above the blocking temperature of the antiferromagnetic material of the antiferromagnetic layer 24.

[0017] As illustrated in Fig. 1, the magnetoresistive element 1 can be embedded in a dielectric layer 27.

[0018] Fig. 3 represents a topology of the magnetic sensor 10 showing a top surface 28, a top metal connector layer MCT, a first current line 3, the

MTJ 2, a second current line 4 and a silicon based complementary metal oxide semiconductor (CMOS) front-end circuit 80.

[0019] The magnetoresistive element 1 can further comprise metallic conductors to provide write and read functionality. In the example of Fig. 3, the first current line 3 can be electrically coupled to the magnetoresistive element 1. The second current line 4 can extend substantially perpendicular (or parallel) to the first current line 3 and being magnetically coupled to the magnetoresistive element 1. The magnetoresistive element 1 can further include a selection transistor (not show) electrically connected to the magnetoresistive element 1. The magnetoresistive element 1 can further include a top metal connector layer MCT on top of the MTJ 2 and connected to it by a metal via VM, and a bottom metal connector layer MCB below the MTJ 2. The top metal connector layer MCT electrically connect the bottom metal connector layer MCB can be used as a field line.

[0020] The magnetoresistive element 1 further comprises a plasmonic structure 5 configured to enhance and localize electromagnetic radiation 70 energy absorption emitted from an electromagnetic radiation emitting device 7.

[0021] In one aspect, the plasmonic structure 5 comprises a spatially periodic plasmonic array 50 of metallic structures 51. As shown in Figs 4a to 4c, the periodic plasmonic array 50 can comprise a spatially periodic arrangement of rectangular-shaped metallic structures 51 (Fig. 4a), disc-shaped metallic structures 51 (Fig. 4b) or elliptically shaped metallic structures 51 (Fig. 4c). Other shapes of the metallic structures 51 can be also contemplated.

[0022] The metallic structures 51 comprised in the plasmonic array 50 may all have substantially the same shape. However, the plasmonic array 50 may comprise metallic structures 51 having different shapes.

Principle of the plasmonic structure

[0023] During a programming operation of the magnetic sensor 10, the first magnetization 210 is switched from an initial orientation to a programmed orientation. The programmed orientation can be any
5 direction in accordance to the external magnetic field direction. The programming operation can be performed on all the magnetoresistive elements 1 in the magnetic sensor 10 or a selected sub-ensemble of the magnetoresistive elements 1.

[0024] During the programming operation, the electromagnetic
10 radiation 70 emitted by the electromagnetic radiation emitting device 7 irradiates an illuminated region 71 of the magnetic sensor 10. As shown in Fig. 1, the illuminated region 71 can cover a surface area encompassing two adjacent magnetoresistive elements 1. However, the illuminated region 71 could cover a surface area encompassing a single magnetoresistive element
15 1, a sub-ensemble of the magnetoresistive elements 1 or all the magnetoresistive elements 1 in the magnetic sensor 10.

[0025] In conditions of plasmon resonance of the plasmonic structure 5
at the wavelength of the electromagnetic radiation 70, the plasmonic structure 5 provides enhanced absorption of the electromagnetic radiation
20 70. Consequently, in the illuminated region 71, the the plasmonic structure 5 provides enhanced heat generation. The enhanced heat is transmitted to the selected magnetoresistive elements 1 in the illuminated region 71 allowing the first ferromagnetic layer 21 of the selected magnetoresistive elements 1 to be heated at or above the threshold temperature. Since the
25 enhanced heating occurs only in the illuminated region 71, selective and mask-free programming of the magnetic sensor 10 can be achieved.

[0026] The plasmonic structure 5 can further provide a uniform heat generation within the illuminated region 71.

[0027] The radiation emitting device 7 may comprise a laser emitting
30 device directing a focused laser beam 70 to the illuminated region 71 of the

magnetic sensor 10 (see Fig. 1). The focusing of the laser beam 70 may be achieved by using near-field optics such as a solid immersion lens.

Arrangement of array of metallic structures

[0028] The arrangement of the metallic structures 51 in the periodic plasmonic array 50 can be optimized such as to obtain plasmonic resonance at the wavelength of the electromagnetic radiation 70. This can be achieved by varying lateral dimension d of the metallic structures 51 and the periodic arrangement of the metallic structures 51. The plasmonic array 50 can comprise a two-dimensional lattice having substantially equal the distance L between two adjacent metallic structures 51. The plasmonic array 50 can comprises any one of a square lattice (as shown in Fig.4), rectangular lattice, hexagonal lattice or rhombic lattice of metallic structures 51, or any other type of lattice.

[0029] For example, the distance L between two adjacent metallic structures 51 in the periodic plasmonic array 50 should be equal or smaller than the wavelength of the electromagnetic radiation 70 (subwavelength plasmonic array 50). The lateral dimension d of the metallic structures 51 should also be smaller than the wavelength of the electromagnetic radiation 70 (subwavelength metallic structures 51).

[0030] Under resonance conditions, i.e., when the wavelength of the electromagnetic radiation 70 matches the plasmonic resonance of the metallic structures 51, the power absorption in metallic structures 51 can be increased by at least one order of magnitude. Under resonance conditions, the heat generation within the illuminated region 71 can reach up to 9 times the heat generation without plasmonic resonance.

Location of the plasmonic structure

[0031] The plasmonic structure 5 should be arranged in the magnetic sensor 10 in order to be near the magnetoresistive element 1 such that the heat absorbed by the plasmonic structure 5 in the illuminated region 71 can

be transmitted to the MTJ 2 such that the reference magnetization at can be the high temperature threshold. Here, near the magnetoresistive element 1 can comprise a distance between 50 nm and 5000 nm.

5 [0032] The plasmonic structure 5 should further be arranged in the magnetic sensor 10 such as to be easily illuminated by the radiation emitting device 7. Ideally, the plasmonic structure 5 should not be masked from the radiation emitting device 7 by metal connector layers or other structures not participating in the plasmon resonance.

10 [0033] In one embodiment, the plasmonic structure 5 is provided between the top surface 28 of the magnetic sensor 10 and at least one of the MTJs 2.

15 [0034] Fig. 5 shows a partial view of the topology representation of Fig. 4. In the example shown of Fig. 5, the plasmonic structure 5 is provided between the top surface 28 and the top metal connector layer MCT. The plasmonic structure 5 can be embedded in the dielectric layer 27. The dielectric layer 27 should be optically transparent to the electromagnetic radiation 70. The dielectric layer 27 can comprise a dielectric material such as SiO₂, SiN, etc.

20 [0035] An advantage of the configuration of Fig. 5, where the plasmonic structure 5 is located on top of the magnetoresistive elements, is that the plasmonic structure 5 is not shadowed by metallic layers on a higher level. The configuration of Fig. 5 ensures uniform illumination over the whole surface of the plasmonic structure 5.

25 [0036] The lateral dimension of the metallic structures 51 can correspond to about the ratio of the wavelength of the electromagnetic radiation 70 to the refractive index of the dielectric layer 27, .i.e. wavelength λ of the electromagnetic radiation 70 in the dielectric layer 27, or a fraction of this ratio.

[0037] For example, in case the dielectric layer 27 comprises SiN, an incident wavelength λ_i of 1064 nm of the emitted electromagnetic radiation 70 decreases in the dielectric layer 27 and the wavelength in SiN λ_{SiN} is equal to the incident wavelength λ_i divided by the refraction index of SiN $\lambda_i/1.885 = 564$ nm. Thus, the lateral dimension of the metallic structures 50 may be substantially equal to half the wavelength in SiN λ_{SiN} and the distance L between two adjacent metallic structures 50 can be substantially equal to the wavelength in SiN λ_{SiN} .

[0038] In another embodiment, the plasmonic structure 5 is located at the level of the top metal connector layer MCT.

[0039] Fig. 6 shows a top view of an arrangement of the magnetic sensor 10 comprising the plasmonic structure 5 located at the level of the top metal connector layer MCT, i.e. in the plane of the top metal connector layer MCT. The magnetic sensor 10 comprises an array of sensor branches 40, each sensor branch 40 comprising a plurality of interconnected magnetoresistive elements 1. The plasmonic structure 5 can comprise a plurality of plasmonic subarrays 52, wherein each plasmonic subarray 52 comprises a periodic array of metallic structures 51. Each plasmonic subarray 52 can be arranged in alternance with the sensor branches 40.

[0040] In one aspect, a plasmonic subarray 52 has a width W_P that is twice the width W_S of a sensor branch 40. In other words, the surface area occupied by the plasmonic subarray 52 corresponds to the surface area of two sensor branches 40. The plasmonic resonance of each plasmonic subarray 52 depends on the periodicity of the array of metallic structures 51 and on the lateral dimension d of the metallic structure 51.

[0041] In an example, the plasmonic subarray 52 is about 5.0 μm in width. The lateral dimension d of the metallic structures 51 is about 0.4 μm . However, other arrangements of the plasmonic subarrays 52 relative to the sensor branches 40 can be contemplated.

[0042] Other arrangements of the plasmonic structure 5 are also possible. For example, the plasmonic structure 5 can be located at the levels (in the plane) of any one of the metal layers, such as at the levels of the second current line 4 or the metal connector layer MCB. Such
5 arrangements can include a plurality of plasmonic subarray 52 arranged in alternance with the sensor branches 40, as described above.

[0043] Configurations of the magnetic sensor 10 where the plasmonic structure 5 is provided in the plane of the top metal connector layer MCT, bottom metal connector layer MCB, or other metal connector layers or
10 metal vias, may result in lowering the density of magnetoresistive elements 1 per area in the magnetic sensor 10. Indeed, the available surface area of the magnetic sensor 10 must be shared between the surface area occupied by the plasmonic structure 5 and the surface area occupied by the magnetoresistive elements 1.

15 [0044] The resonance frequencies were modelled for the plasmonic structure 5 located at the level of the top metal connector layer MCT and arranged according to the configuration shown in Fig. 6. The resonance frequencies were modelled for spatially periodic arrangement of metallic structures 51 having a rectangular shape (see Fig. 4a), a disc shape (see Fig.
20 4b). The resonance frequencies were modelled for multiple lateral dimension d of the metallic structures 51 and multiple distance L between two adjacent metallic structures 51.

[0045] **Table 1** reports the plasmonic resonance values obtained from the modelling for the plasmonic structure 5 located at the level of the top
25 metal connector layer MCT. The modelling was performed for the plasmonic array 50 having rectangular-shaped (sq) and disc-shaped (circ) metallic structures 51 being spaced by a distance L between 500 nm and 700 nm and having a lateral dimension d between 200 nm and 300 nm.

L/d (nm/nm)	Resonances (sq., μm)	Resonances (circ, μm)
500/200	1.12; 0.74; 0.66; 0.57; 0.51	1.08 ; 0.75; 0.65; 0.57; 0.5
600/200	1.32; 0.79; 0.7; 0.6	1.27; 0.96 ; 0.67; 0.6; 0.57; 0.52
500/250	0.89; 0.73; 0.63; 0.54	1.09 ; 0.62; 0.6; 0.52; 0.5
500/300	0.95 ; 0.89; 0.65; 0.6; 0.56; 0.51	0.93 ; 0.71; 0.66; 0.54
600/300	1.27; 0.97 ; 0.86; 0.69; 0.56; 0.52	1.02 ; 0.75; 0.57; 0.52; 0.51
700/300	0.82; 0.71; 0.75; 0.64; 0.54; 0.5	1.49; 1.13; 1.07 ; 0.84; 0.6; 0.5

Table 1

[0046] **Table 2** reports the plasmonic resonance values obtained from the modelling for the plasmonic structure 5 located at the level of the bottom metal connector layer MCB. The modelling was performed for the plasmonic array 50 having rectangular-shaped (sq) and disc-shaped (circ) metallic structures 51 being spaced by a distance L between 500 nm and 880 nm and having a lateral dimension d between 200 nm and 400 nm.

[0047] Simulations have shown that the resonant absorption can happen both in the metallic structures 51 and in metallic layer beneath, for example, both in the metallic structures 51 and in the top metal connector layer MCT or both in the metallic structures 51 and in the bottom metal connector layer MCB.

[0048] Depending on the configuration and of the location of the plasmonic structure 5 in the magnetic sensor 10, reflectance of the electromagnetic radiation 70 emitted by the emitting device 7 can drop below 20%. Frequency corresponds to laser wavelength 1064nm

L/d (nm/nm)	Resonances (sq., μm)	Resonances (circ, μm)
500/200	0.88; 0.62; 0.53	0.83; 0.66; 0.63; 0.53
600/200	0.68; 0.65; 0.55; 0.52	0.76; 0.6; 0.54
500/250	0.91; 0.52; 0.5	0.66; 0.53; 0.52
500/300	0.69; 0.51; 0.5	0.61
600/300	0.63; 0.54; 0.51	0.74
700/300	1.15; 0.7; 0.63; 0.6; 0.57; 0.5	1.15; 0.72; 0.61; 0.53
880/400	0.97 ; 0.75; 0.67; 0.61; 0.57; 0.54	1.38; 1.03 ; 0.87; 0.6

Table 2

[0049] Other configurations of the plasmonic structure 5 can be contemplated. For example, the plasmonic structure 5 can be located at the level of the top metal connector layer MCT and the metallic structures 51 can be spaced by a distance L between 400 nm and 700 nm and have a lateral dimension d between 200 nm and 300 nm.

[0050] In another configuration, the plasmonic structure 5 can be located at the level of the bottom metal connector layer MCB and the metallic structures 51 can be spaced by a distance L between 500 nm and 900 nm and have a lateral dimension d between 200 nm and 400 nm.

[0051] In yet another configuration, the plasmonic structure 5 is located at the level of the second current line 4 below the MTJ 2 and the metallic structures 51 can be spaced by a distance L between 450 nm and 850 nm and have a lateral dimension d between 200 nm and 450 nm.

[0052] For the plasmonic array 50 comprising the rectangular-shaped and disc-shaped metallic structures 51, the simulations have shown that the resonance frequencies are determined by the lateral dimension d and the distance L between adjacent metallic structures 51.

[0053] In yet another configuration, the metallic structures 51 can have an elliptical shape (Fig. 4c). For the plasmonic structure 5 comprising the

elliptical metallic structures 51, the simulations have shown that the resonance frequencies are determined by the long axis (a) and short axis (b) of the elliptical metallic structures 51. The elliptical metallic structures 51 can have a long axis between 230 nm and 470 nm and a short axis between
5 470 nm and 230 nm, respectively.

[0054] Other configurations of the plasmonic structure 5 can also be considered. In an embodiment shown in **Fig. 7**, the plasmonic structure 5 comprises the plasmonic array 50 and an auxiliary plasmonic structure 53 configured for adjusting absorption of the electromagnetic radiation
10 energy. In other words, under resonance conditions, the plasmonic array 50 and the auxiliary plasmonic structure 53 resonate simultaneously because of electromagnetic coupling between them. The auxiliary plasmonic structure 53 may result in an amplification of the power absorption by a factor of 3 or even more. The plasmonic array 50 can be
15 comprised between the auxiliary plasmonic structure 53 and the electromagnetic radiation emitting device 7. The auxiliary plasmonic structure 55 can comprise a spatially periodic arrangement of metallic structures or a continuous metallic layer.

[0055] In yet another embodiment shown in **Fig 8**, the plasmonic
20 structure 5 comprises at least a first plasmonic subarray 52a and a second plasmonic subarray 52b. The first plasmonic subarray 52a is configured to transmit the heat generated by plasmon resonance to a first subset of magnetoresistive elements 1 of the magnetic sensor 10 and the second plasmonic subarray 52b is configured to transmit the heat generated by
25 plasmon resonance to a second subset of magnetoresistive elements 1. In Fig. 8, the first subset is represented as two sensor branches 40 comprising magnetoresistive elements 1 and the second subset comprises one such branch 40. Other configurations of the subsets should be considered as well as of the number of plasmonic subarrays and subsets.

30 [0056] The plasmonic subarrays 52a, 52b can be located on top of the magnetoresistive elements 1 and on top of the top metal connector layer MCT.

[0057] The at least first plasmonic subarray 52a has a different resonance response from the second plasmonic subarray 52b with respect to the polarization or wavelength λ of the electromagnetic radiation 70.

[0058] The wavelength and/or the polarization of the electromagnetic radiation 70 emitted by the electromagnetic radiation emitting device 7 can be adjusted in order to correspond to the resonant condition of one of the first or second plasmonic subarray 52a, 52b such that plasmon resonance occurs only for one of the first or second plasmonic subarray 52a, 52b. Thus, only the sensor branches 40 corresponding to the resonant plasmonic subarray 52a or 52b are heated at the high temperature threshold.

[0059] This latter configuration allows for programming selectively sensor branches 40 without requiring a mask for illumination beam windowing in the case the whole magnetic sensor 10 is completely illuminated. There are also fewer positioning constraints since the electromagnetic radiation emitting device 7 (such as a laser) can be moved over the top surface 28 of the magnetic sensor 10 such as to selectively heat the one or several magnetoresistive elements 1 encompassed by the illuminated region (71).

Reference numbers and symbols

	1	magnetoresistive element
	10	MRAM based sensor
5	2	magnetic tunnel junction
	21	reference layer
	210	reference magnetization
	22	tunnel barrier layer
	23	sense layer
10	230	sense magnetization
	24	pinning layer
	27	dielectric layer
	28	top surface
	3	first current line
15	4	second current line
	40	sensor branch
	5	plasmonic structure
	50	plasmonic array
	51	metallic structure
20	52	plasmonic subarray
	53	auxiliary plasmonic structure
	7	electromagnetic radiation emitting device
	70	electromagnetic radiation
	71	illuminated region
25	80	front-end circuit
	λ	wavelength
	d	lateral dimension
	L	distance
30	MCB	bottom metal connector layer, field line
	MCT	top metal connector layer
	VM	metal via
	W_P	width of plasmonic substructure
	W_S	width of sensor branch
35		

Claims

1. A magnetic sensor (10) comprising a plurality of magnetoresistive elements (1); each magnetoresistive element (1) comprising a MTJ (2) including a first ferromagnetic layer (21) having a first magnetization (210) being pinned below a threshold temperature and free at or above the threshold temperature, such that the first magnetization (210) can be switched when first ferromagnetic layer (21) is at the high temperature threshold during a programming operation;
- the magnetic sensor (10) further comprising a plasmonic structure (5) destined to be irradiated by electromagnetic radiation (70), the plasmonic structure (5) comprising a spatially periodic plasmonic array (50) of metallic structures (51), the period of the plasmonic array (50) and the lateral dimension (d) of the metallic structures (51) being adjusted to obtain plasmon resonance of the plasmonic structure (5) for a given wavelength (λ) of the electromagnetic radiation (70);
- wherein the plasmonic array (50) is arranged in the magnetic sensor (10) such as to heat the first ferromagnetic layer (21) at or above the threshold temperature, from the enhanced absorption of the electromagnetic radiation (70) by plasmon resonance;
- characterized in that the magnetic sensor (10) comprises an array of sensor branches (40), each sensor branch comprising a plurality of magnetoresistive elements (1); and
- in that the plasmonic structure (5) comprises a plurality of plasmonic subarrays (52), each plasmonic subarray (52) comprising a periodic array of metallic structures (51) and being arranged in alternance with the sensor branches (40).
2. The magnetic sensor, according to claim 1, wherein the period of the plasmonic array (50) and the lateral dimension (d) of the metallic structures (51) are adjusted to obtain plasmon resonance of the plasmonic structure (5), for a given wavelength (λ) of the electromagnetic radiation (70).

3. The magnetic sensor, according to claim 1 or 2,
wherein the MTJ (2) is between a top surface (28) and a front-end circuit
(80) of magnetic sensor (10); and
wherein the plasmonic structure (5) is provided between the top surface
5 (28) and the front-end circuit (80).

4. The magnetic sensor, according to claim 3,
wherein the magnetoresistive element (1) includes a top metal connector
layer (MCT) between the MTJ (2) and the top surface (28); and
wherein the plasmonic structure (5) is provided in the plane of the top
10 metal connector layer (MCT).

5. The magnetic sensor, according to claim 3,
wherein the magnetoresistive element (1) includes a bottom metal
connector layer (MCB) between the MTJ (2) and the front-end circuit (80);
and
15 wherein the plasmonic structure (5) is provided in the plane of the bottom
metal connector layer (MCB).

6. The magnetic sensor, according to any one of claims 1 to 5,
wherein the plasmonic structure (5) is embedded in a dielectric layer (27);
and
20 wherein the period of the plasmonic array (50) and the lateral dimension
(d) of the metallic structures (51) are adjusted to obtain plasmon resonance
of the plasmonic structure (5), for a given ratio of the wavelength (λ) of the
electromagnetic radiation (70) to the refractive index of the dielectric layer
(27).

25 7. The magnetic sensor, according to any one of claims 1 to 6,
wherein the plasmonic structure (5) comprises at least a first plasmonic
subarray (52a) and a second plasmonic subarray (52b) having a different
resonance response from the first plasmonic subarray (52b) with respect to
the polarization or wavelength (λ) of the electromagnetic radiation (70).

8. The magnetic sensor, according to any one of claims 1 to 7, wherein the plasmonic structure (5) further comprises an auxiliary plasmonic structure (53) configured to adjust absorption of the electromagnetic radiation (70).
- 5 9. The magnetic sensor, according to claim 8, wherein the auxiliary plasmonic structure (53) comprises a spatially periodic arrangement of metallic structures or a continuous metallic layer.
- 10 10. The magnetic sensor, according to any one of claims 3 and claim 8 or 9, wherein the auxiliary plasmonic structure (53) and the plasmonic array (50) are between the magnetoresistive elements (1) and the top surface (28).
- 15 11. A system comprising the magnetic sensor, according to any one of claims 1 to 10 and an electromagnetic radiation emitting device (7) configured to emit electromagnetic radiation (70) that irradiates an illuminated region (71) of the magnetic sensor (10) and that has a wavelength (λ) adapted to generate plasmon resonance of the plasmonic structure (5).
- 20 12. The system according to claim 11, wherein illuminated region (71) encompasses at least one magnetoresistive element (1).
13. The system according to claim 11 or 12, wherein the electromagnetic radiation emitting device (7) comprises a laser emitting device directing a focused laser beam (70) to the illuminated region (71) of the magnetic sensor (10).
- 25 14. The system according to any one of claims 11 to 13, wherein the electromagnetic radiation emitting device (7) is movable over the surface (28) of the magnetic sensor (10) such as to selectively heat the one or several magnetoresistive elements (1) encompassed by the illuminated region (71).

15. The system according to any one of claims 11 to 14,
wherein the plasmonic structure (5) comprises at least a first plasmonic
subarray (52a) and a second plasmonic subarray (52b) having a different
resonance response from the first plasmonic subarray (52b) with respect to
5 the polarization or wavelength (λ) of the electromagnetic radiation (70);
and
wherein the wavelength and/or the polarization of the electromagnetic
radiation (70) is adjustable in order to correspond to the resonant condition
of one of the first or second plasmonic subarray (52a, 52b).

10 16. The system according to any one of claims 1 to 15,
wherein the plasmonic array (50) comprises a two-dimensional lattice
having substantially equal the distance (L) between two adjacent metallic
structures (51) and wherein the plasmonic array (50) comprises any one of a
square lattice rectangular lattice, a hexagonal lattice or a rhombic lattice.

15

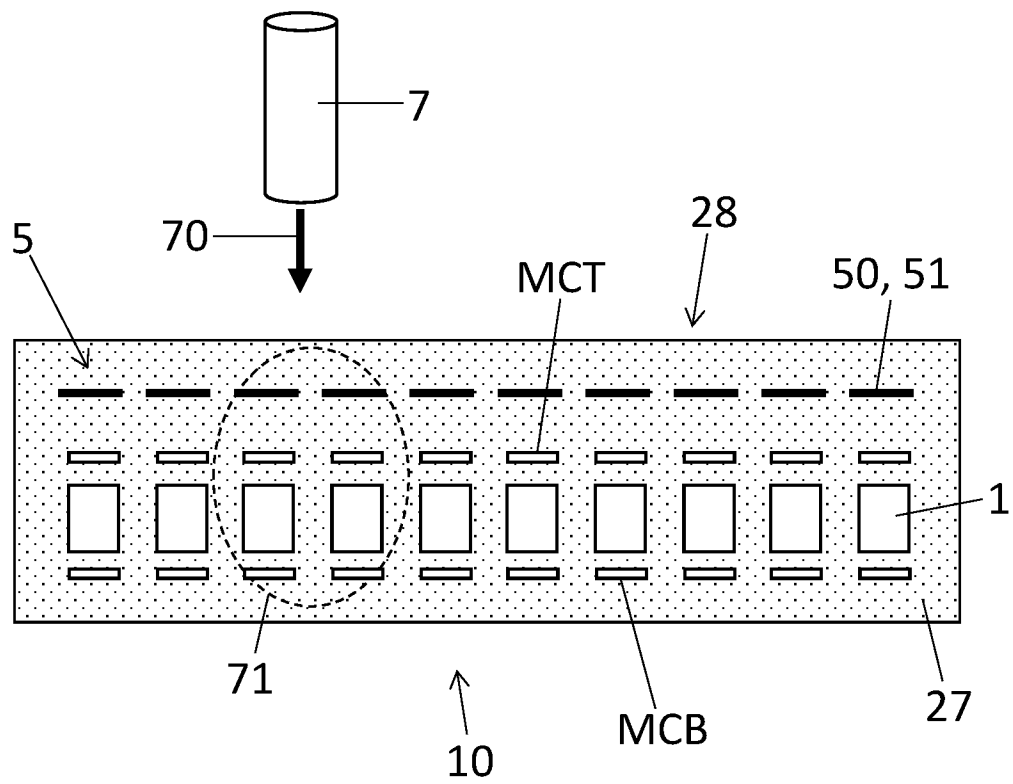


Fig. 1

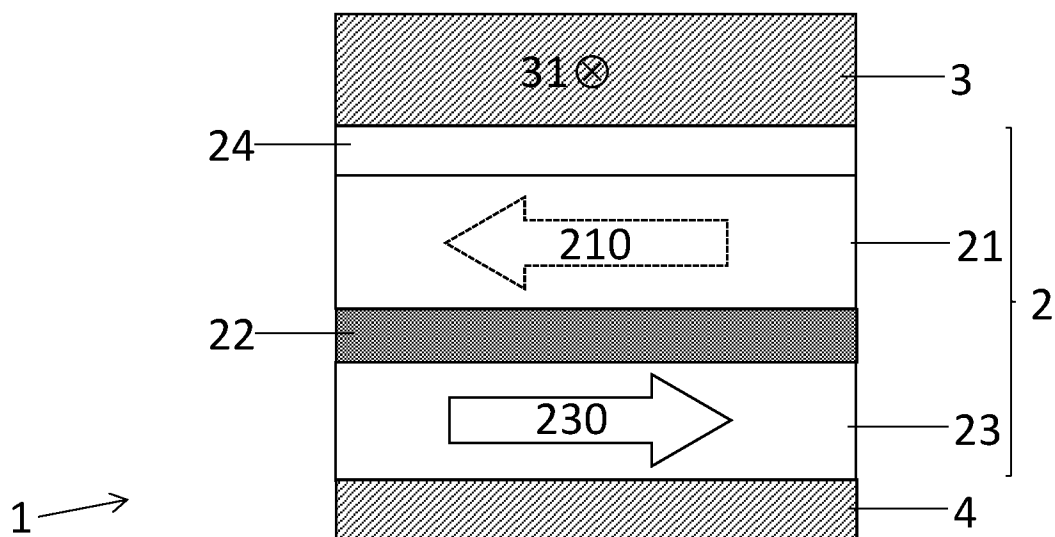


Fig. 2

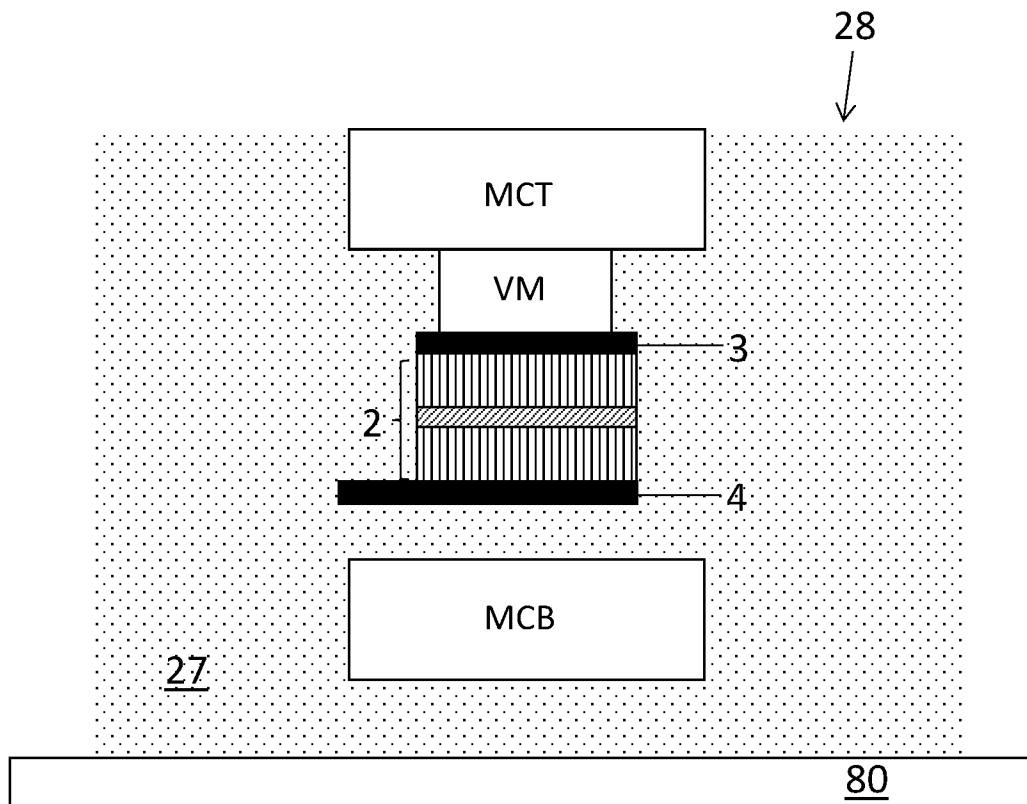


Fig. 3

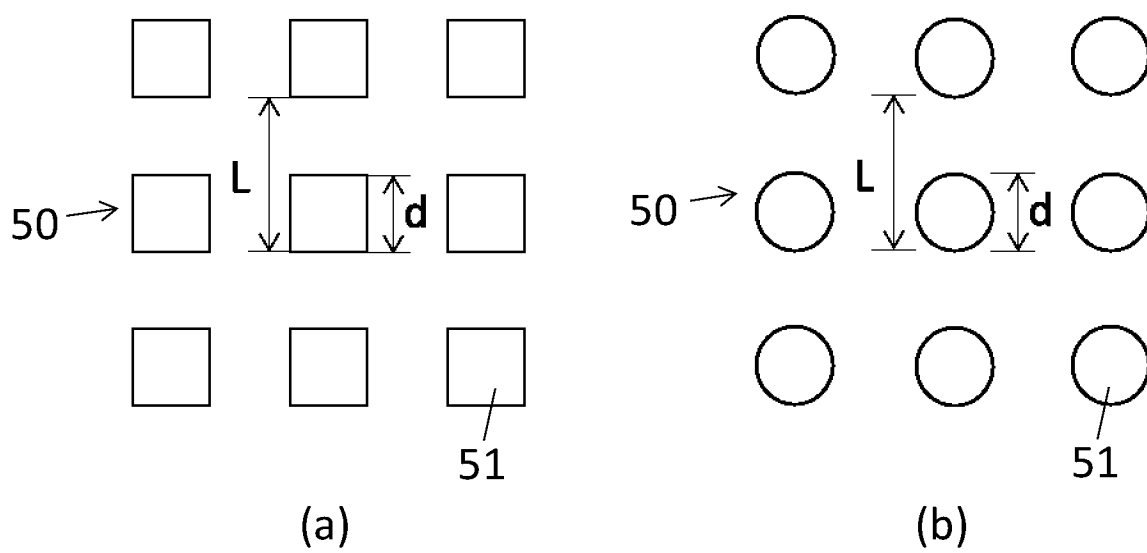


Fig. 4

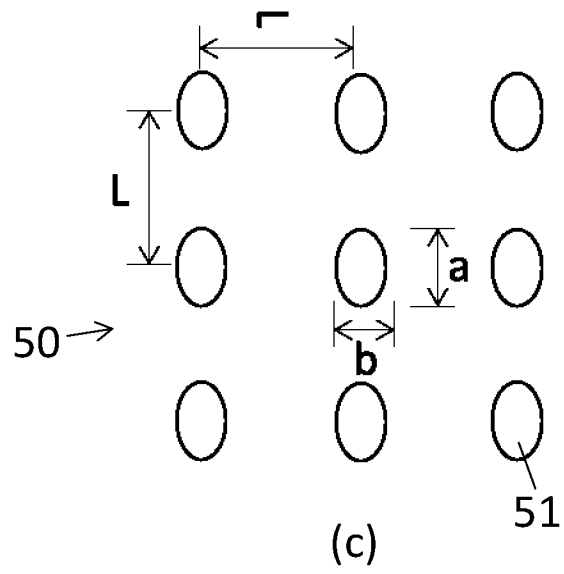


Fig. 4

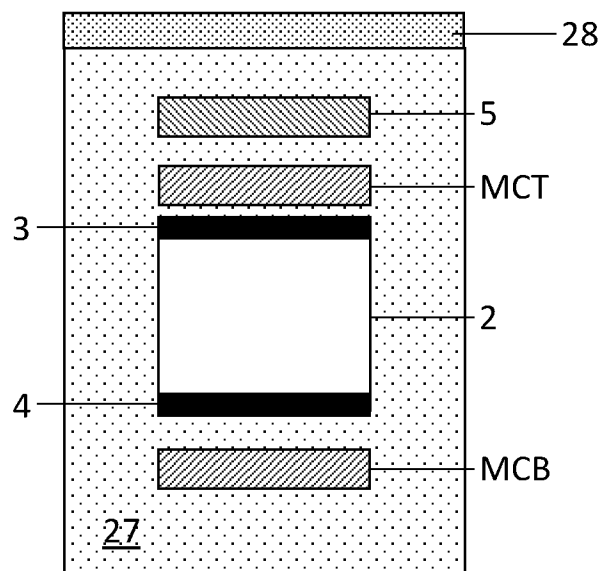
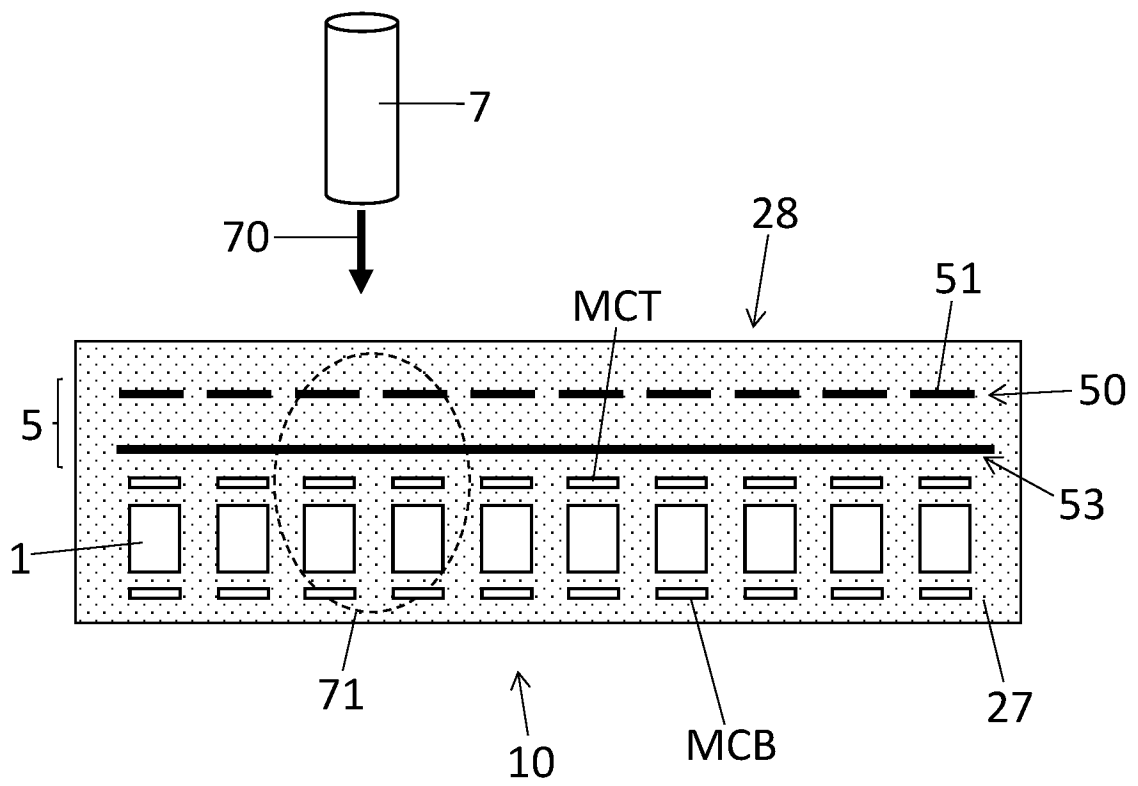
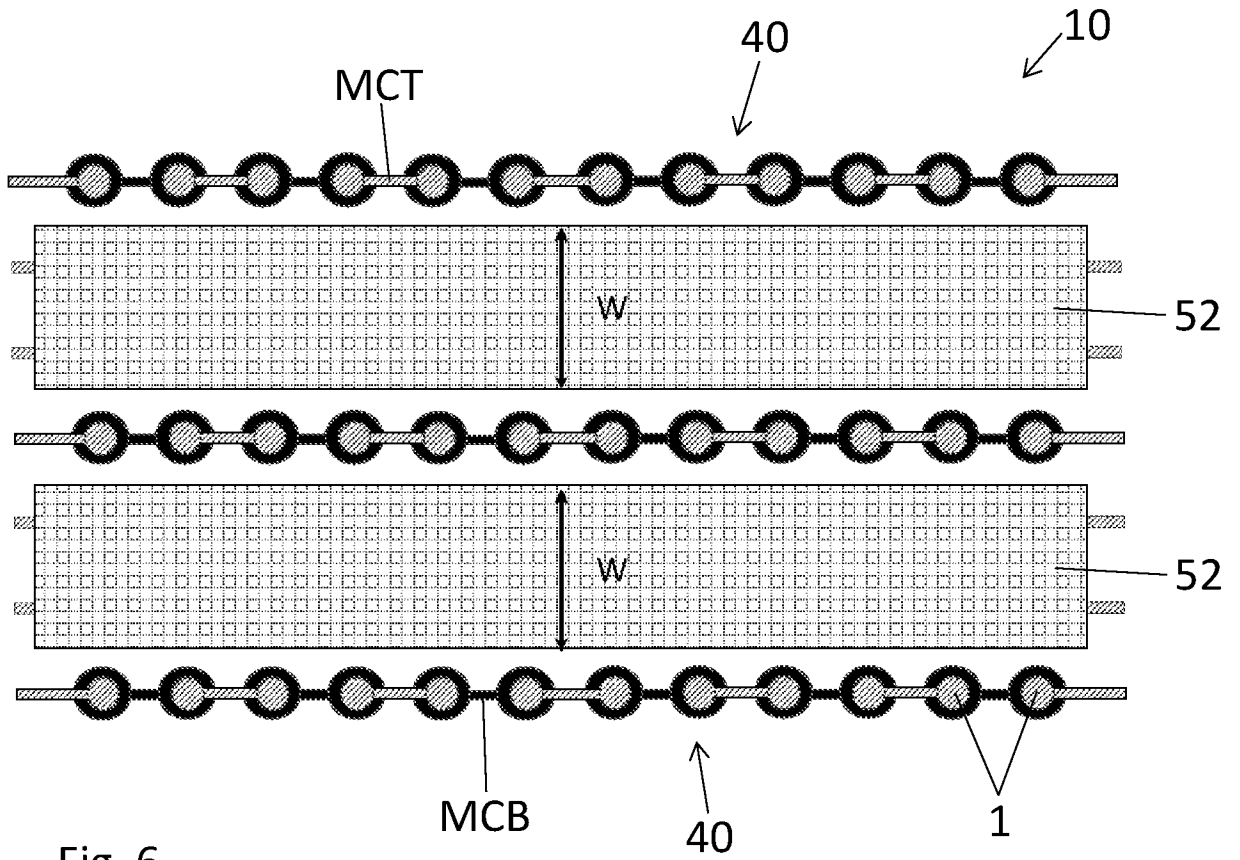


Fig. 5



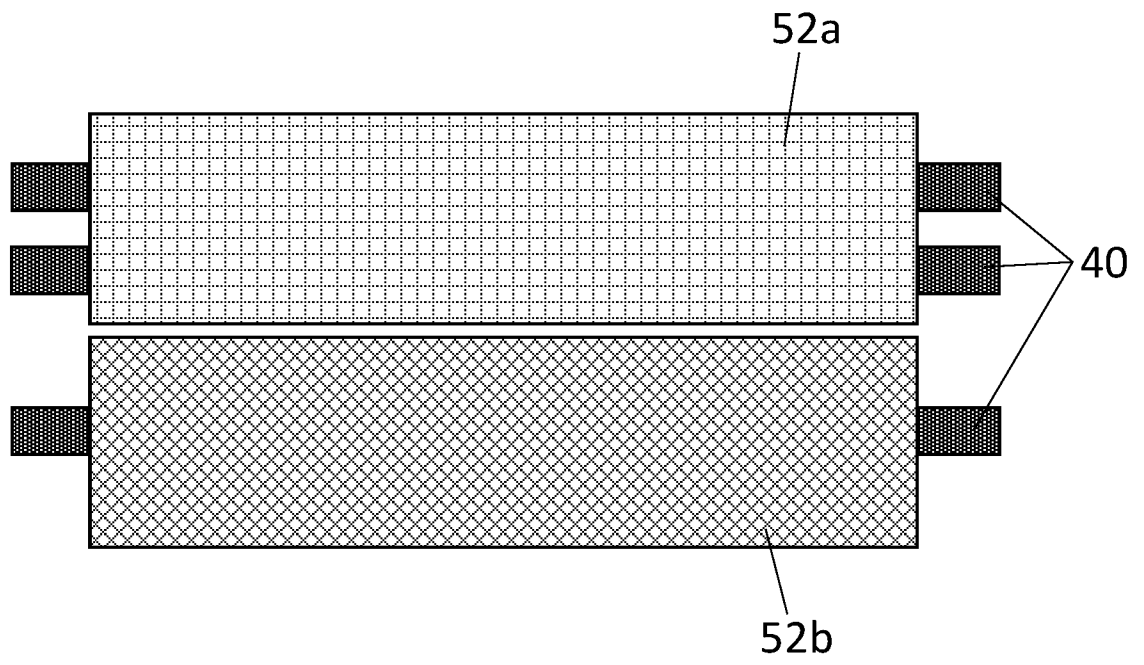


Fig. 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2021/054647

A. CLASSIFICATION OF SUBJECT MATTER

INV. G01R33/00 G01R33/09
ADD. G11B5/31 G11B5/39

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G01R G11B H02N H01L H01F

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)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2011/111133 A1 (ZHOU YUCHEN [US] ET AL) 12 May 2011 (2011-05-12)	1,2,4,5, 8,9, 11-14,16
Y	the whole document	3,6
A		7,10,15
Y	----- US 2015/132503 A1 (KAUTZKY MICHAEL C [US] ET AL) 14 May 2015 (2015-05-14) paragraphs [0026], [0034], [0037], [0038], [0044], [0070] -----	3,6



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"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

30 July 2021

Date of mailing of the international search report

09/08/2021

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Philipp, Peter

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/IB2021/054647

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2011111133	A1	12-05-2011	NONE

US 2015132503	A1	14-05-2015	NONE
