

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
6 March 2003 (06.03.2003)

PCT

(10) International Publication Number
WO 03/019590 A1

(51) International Patent Classification⁷: **H01F 41/18**,
41/30, G11B 5/31

SI, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, UZ, VC,
VN, YU, ZA, ZM, ZW.

(21) International Application Number: PCT/US02/25528

(84) Designated States (regional): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

(22) International Filing Date: 12 August 2002 (12.08.2002)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/313,919 21 August 2001 (21.08.2001) US

(71) Applicant: SEAGATE TECHNOLOGY LLC [US/US];
920 Disc Drive, Scotts Valley, CA 95066 (US).

(72) Inventors: COVINGTON, Mark, W.; 6417 Kentucky Avenue, Pittsburgh, PA 15206 (US). SEIGLER, Michael, A.; 427 Arden Road, Pittsburgh, PA 15216 (US). SINGLETON, Eric, W.; 3035 Lakeshore Avenue, Maple Plain, MN 55359 (US). MINOR, Michael, K.; 1027 South Lake Drive, Gibsonia, PA 15044 (US).

(74) Agent: BORDAS, Carol, I.; Seagate Technology LLC,
1251 Waterfront Place, Pittsburgh, PA 15222-4215 (US).

(81) Designated States (national): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SD, SE, SG,

Declarations under Rule 4.17:

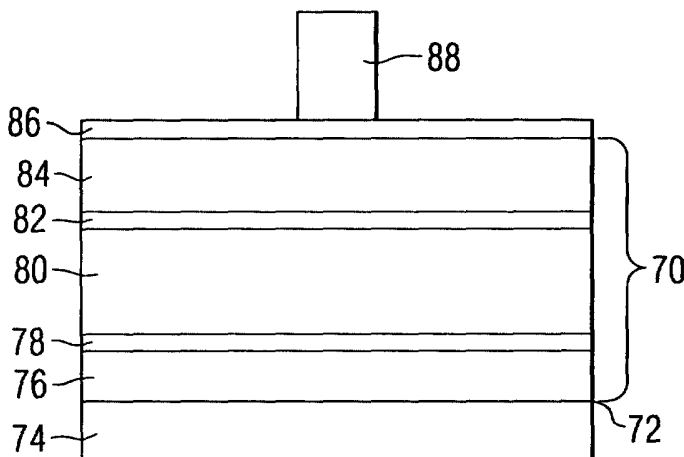
- as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii)) for the following designations AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, UZ, VC, VN, YU, ZA, ZM, ZW, ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG)
- as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii)) for all designations

Published:

- with international search report

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: ENHANCED ION BEAM ETCH SELECTIVITY OF MAGNETIC THIN FILMS USING CARBON-BASED GASES



(57) Abstract: A method of etching a structure including a magnetic material, the method includes providing a structure (70) including a magnetic material (80), applying a mask material (84) to at least a portion of the structure, and reactive ion beam etching the magnetic material using an etch process including a carbon based compound, wherein the mask material forms a material which etches slower than the magnetic material. The etch process can further include argon ions. The carbon based compound can be a compound selected from the group of C₂H₂, CHF₃, and CO₂. The etch process can alternatively include argon ions, oxygen and either C₂H₂ or CHF₃. The magnetic material can comprise a compound including a material selected from the group of Fe, Ni, and Co. The mask material can comprise a layer of Ta, W, Mo, Si, Ti or a photoresist.

ENHANCED ION BEAM ETCH SELECTIVITY OF MAGNETIC THIN FILMS USING CARBON-BASED GASES

CROSS REFERENCE TO RELATED APPLICATION

This application claims the benefit of United States Provisional Application Serial No. 60/313,919, filed August 21, 2001.

FIELD OF THE INVENTION

5 This invention relates to ion beam etching processes, and more particularly to the use of such processes in the manufacture of magnetic recording heads.

BACKGROUND OF THE INVENTION

Many disc drives use a recording head including two elements. The first element is a write head that is used for writing data to the surface of a magnetic disc.

10 The second element is a read head including a magneto-resistive element or giant magneto-resistive element ("MR element") that is used to read data from the surface of the disc. The resistance of the MR element changes in the presence of a magnetic field so the MR element is used to sense magnetic transitions on the disc that have been previously written by the write element. The recording head is typically housed within a
15 small ceramic block called a slider. The slider is positioned near the rotating disc and separated from the surface of the disc by an air bearing.

Many processes in recording head fabrication use sputtered thin films. The most critical elements of the reader are fabricated exclusively from sputtered films and it is expected that sputtering will soon replace plating as the preferred deposition
20 technique for the writer. Anisotropic dry etch processes are a key enabling technology for sputtered films. Device structures need to be fabricated with nanometer-scale accuracy and precision, and with thickness-to-width aspect ratios that are sometimes greater than one. The data storage industry currently relies on argon ion beam etching (IBE) to define the sputtered magnetic materials in recording heads. Since Ni, Fe, and
25 Co alloys tend to be physically hard materials that etch slowly, it is difficult to preferentially etch them with IBE. One consequence is that masking material must be made very thick because few materials etch more slowly than these alloys. Furthermore, the IBE process must allow for a lot of over-etching into underlying material in order to fully define the magnetic structures.

An alternative approach is to exploit chemical selectivity and use reactive ion etching (RIE) to preferentially etch certain materials over others. RIE forms volatile reaction products on the exposed wafer surface. Once formed, these reaction products desorb from the wafer surface and are pumped away. Unfortunately, it is challenging to form volatile compounds from Ni, Fe, and Co at conventional wafer processing temperatures, which are on the order of 300°C and below. Hence, these materials and their associated alloys are difficult to RIE. Past attempts at reactive etching have typically used either CO or Cl. Researchers have tried to form volatile Ni-, Fe-, and Co-carbonyls by using CO in either chemically assisted IBE or RIE processes. However, to date, there are no data that conclusively prove that carbonyls do indeed form. In contrast, a few research groups have achieved limited success using Cl-based RIE to etch NiFe and spin-valves, although the etch selectivity with respect to other materials is poor. It is well known that the introduction of reactive gases in an ion mill can reduce the etch rate of certain materials, an example of which is oxygen reactive ion beam etching (RIBE). In fact, this type of approach has been used to preferentially etch FeAlN over Ti by adding N₂ into an ion mill.

Reactive etch processes for writer processing have been disclosed for etching the gap of a longitudinal writer in a notched pole process. Those reactive processes relate to CF₄- or CHF₃-based RIBE of an Al₂O₃ gap, which is well known. The enhanced etching of various non-magnetic transition metal gap materials using noble metal gases that are different than Ar, such as Kr or Xe, has also been proposed.

The data storage industry presently has few options to dry etch magnetic materials and those that are available suffer from poor selectivity. There is a need to develop a portfolio of anisotropic dry etch processes that preferentially etch magnetic materials.

SUMMARY OF THE INVENTION

A method of etching a structure including a magnetic material, the method includes providing a structure including a magnetic material, applying a mask material to at least a portion of the structure, and reactive ion beam etching the magnetic material using an etch process including a carbon based compound, wherein the mask material forms a material which etches slower than the magnetic material. The etch process can further include argon ions. The carbon based compound can be a compound

selected from the group of C_2H_2 , CHF_3 , and CO_2 . The etch process can alternatively include argon ions, oxygen and either C_2H_2 or CHF_3 . The magnetic material can comprise a compound including a material selected from the group of Fe, Ni, and Co. The mask material can comprise a layer of Ta, W, Mo, Si, Ti or a photoresist. Magnetic
5 heads made using the process, and disc drives including such magnetic heads are also included.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a pictorial representation of a magnetic disc drive that can include magnetic heads constructed in accordance with this invention;

10 FIG. 2 is a graph showing the etch rates for various materials using argon and acetylene reactive ion beam etching;

FIG. 3 is a graph showing the relative etch selectivity for various materials using argon and acetylene reactive ion beam etching;

15 FIG. 4 is a graph showing the etch rates for various materials using argon and CHF_3 reactive ion beam etching;

FIG. 5 is a graph showing the relative etch selectivity for various materials using argon and CHF_3 reactive ion beam etching;

FIG. 6 is an air bearing surface view of an intermediate structure formed during the manufacture of a magnetic write head;

20 FIG. 7 is an air bearing surface view of another intermediate structure formed during the manufacture of a magnetic write head;

FIG. 8 is an air bearing surface view of another intermediate structure formed during the manufacture of a magnetic write head;

25 FIG. 9 is an air bearing surface view of another intermediate structure formed during the manufacture of a magnetic write head;

FIG. 10 is an air bearing surface view of an intermediate structure formed during the manufacture of a magnetic read head;

FIG. 11 is an air bearing surface view of another intermediate structure formed during the manufacture of a magnetic read head;

30 FIG. 12 is an air bearing surface view of another intermediate structure formed during the manufacture of a magnetic read head;

FIG. 13 is an air bearing surface view of another intermediate structure formed during the manufacture of a magnetic read head;

FIG. 14 is a graph showing the etch rates for various materials using argon and CO₂ reactive ion beam etching; and

5 FIG. 15 is a graph showing the relative etch selectivity for various materials using argon and CO₂ reactive ion beam etching;

DETAILED DESCRIPTION OF THE INVENTION

The process of this invention includes the combination of (1) carbon-based gases in an ion mill and (2) appropriate materials for hard masks and etch stops. For example, an ion mill with carbon-based gases in combination with Ta (and other materials) can be used to selectively etch Ni-, Fe-, and Co-alloys. The reactive IBE process proposed in this application is a physical etch process, rather than a predominantly chemically driven process like RIE. No volatile compounds are formed. The invention modifies the physical etch rates of various materials to permit preferential etching of one material with respect to another.

This invention encompasses processes that can be used in the manufacture of magnetic heads for use with magnetic recording media, as well as magnetic recording heads made by the processes and disc drives that include the heads. FIG. 1 is a pictorial representation of a disc drive 10 that can utilize magnetic heads constructed in accordance with this invention. The disc drive includes a housing 12 (with the upper portion removed and the lower portion visible in this view) sized and configured to contain the various components of the disc drive. The disc drive includes a spindle motor 14 for rotating at least one magnetic storage medium 16 within the housing, in this case a magnetic disc. At least one arm 18 is contained within the housing 12, with each arm 18 having a first end 20 with a recording and/or reading head or slider 22, and a second end 24 pivotally mounted on a shaft by a bearing 26. An actuator motor 28 is located at the arm's second end 24, for pivoting the arm 18 to position the head 22 over a desired sector of the disc 16. The actuator motor 28 is regulated by a controller that is not shown in this view and is well known in the art.

30 This invention provides anisotropic dry etch processes that can preferentially etch materials and can be used in the manufacture of magnetic recording heads. In one example, the invention provides a reactive ion beam etch (RIBE) process

that uses carbon-containing gases. The invention seeks to achieve the highest possible etch selectivity of common magnetic materials and alloys by introducing reactive gases into an ion mill to form hard surface layers on potential masking materials. This is accomplished by using materials that form carbides that etch more slowly than Ni, Fe, Co, and their respective carbides. The likelihood of forming volatile compounds with this approach is remote, but this is of secondary importance since the ion mill can remove redeposited material from sidewalls by etching at an oblique angle.

This invention encompasses various processing schemes, which use a combination of a reactive etch gas and selected materials for hard masks and etch stops. The reactive gases can be introduced into the Kaufman source of a standard ion mill, which creates ions in an inductively coupled plasma and accelerates them through a set of voltage-biased grids.

In one example, the process uses a mixture of acetylene (C_2H_2) and Ar in a RIBE process. Experimental data for the absolute etch rate of several materials as a function of the relative C_2H_2 flow rate are shown in FIG. 2. For the sake of clarity, only etch rate data for FeCoB, Ta, and AZ1505 photoresist are shown. The data for other materials follow roughly the same trend, but have been omitted from the figure. The total flow rate was 14, 15, and 17 SCCM for the relative flow rates of 0.714, 0.8, and 0.882, respectively. The "medium" ion beam parameters used an acceleration voltage of 600 V, beam current of 300 mA, RF power of ~400 W, and a suppressor voltage of 400 V. In FIG. 2, line 40 represents the etch rate for FeCoB, line 42 represents the etch rate for Ta, and line 44 represents the etch rate for AZ1505 photoresist. FIG. 2 illustrates the etch rate for a fixture angle of 45° but these data reflect the behavior observed for all fixture angles. The data in FIG. 2 are representative of the overall trend we have observed in that the etch rate decreases as the relative amount of C_2H_2 increases. Despite the overall decrease in the etch rate of FeCoB, the etch rates for Ta and photoresist decrease even faster.

FIG. 3 shows the etch selectivity of FeCoB with respect to Ta and AZ1505 photoresist, which is defined as the quotient of the etch rates of FeCoB and either Ta or photoresist. The dashed line 46 indicates the best selectivity we have achieved using conventional Ar IBE and either W or high-quality Al_2O_3 . In FIG. 3, line 48 represents the selectivity for FeCoB/Ta, and curve 50 represents the selectivity for

FeCoB/AZ1505. For the highest relative C_2H_2 flow rates studied, we observe a remarkable etch selectivity of almost nine-to-one. Note that the highest relative flow rate caused severe degradation in the photoresist that is reminiscent of when resist overheats and consequently “burns”.

5 Another example process combines CHF_3 and Ar, and the data for the absolute etch rate and selectivity are shown in FIGs. 4 and 5, respectively. The parameters used to generate the data in FIG. 4 are the same as those used to generate the data of FIG. 2 except that CHF_3 has been used in place of acetylene. In FIG. 4, curve 52 represents the etch rate for FeCoB, curve 54 represents the etch rate for NiFeCr, curve 56
10 represents the etch rate for W, and curve 58 represents the etch rate for AZ1505 photoresist.

FIG. 5 shows etch selectivity as a function of relative CHF_3 flow rate. The dashed line 46 in FIG. 5 is the same as in FIG. 3. In FIG. 5, curve 60 represents the relative etch rate for FeCoB:W, curve 62 represents the selectivity for NiFeCr:W, curve
15 64 represents the relative etch rate for FeCoB:AZ1505, and curve 66 represents the relative etch rate for NiFeCr:AZ1505. For this process, we observed an improvement when using W and a relative CHF_3 flow rate of 0.357, in which case the selectivity is approximately 45% better than Ar IBE with W or Al_2O_3 . Photoresist AZ1505 also exhibits improved selectivity by adding CHF_3 , although its selectivity remains below the
20 best Ar IBE performance. For this process, there is a small “window” of CHF_3 flow rate in which the selectivity improves. The relative flow rate of the CHF_3 to (CHF_3 + Ar) is preferably between 0.27 and 0.43, and more preferably between 0.3 and 0.4. While these data indicate that there is little latitude for process variations, it nevertheless illustrates that the process allows the use of different materials. This can be useful if, for example,
25 W is a better choice than Ta as a mask or etch stop.

Both of these processes improve upon the best selectivity performance we have achieved using standard Ar IBE. Using FeCoB as a benchmark magnetic material, the best selectivity with Ar IBE at a 45° fixture angle is achieved by using either W or high-quality Al_2O_3 as masking material. This selectivity is indicated by curve 46 in
30 FIGs. 3 and 5. For the C_2H_2 RIBE process, we observe significantly better selectivity using either Ta or photoresist. Other non-magnetic materials, such as W, Al_2O_3 , and SiO_2 , show either no change or worse selectivity with increasing C_2H_2 flow rate. For the

CHF₃ RIBE process, we observe better selectivity using W or AZ1505 photoresist. In contrast, Ta shows no improvement and the selectivity of Al₂O₃ and SiO₂ gets worse with increasing CHF₃ flow rate.

We have also evaluated the performance of these two processes with other
5 technologically important materials, such as NiFe and a top spin valve structure [for example, 55NiFeCr/50CoFe/30Cu/30CoFe/4Ru/25CoFe/70IrMn/60Ru, where the numbers indicate the layer thicknesses in Å]. We observed an improvement in selectivity that is comparable to that observed with the benchmark performance of FeCoB, shown in FIGs. 2-5. Furthermore, we have also measured the selectivity using
10 higher voltage beam parameters that etch more quickly. For the C₂H₂ RIBE process with the highest C₂H₂ flow rate, we have observed a selectivity of approximately four-to-one.

The diametric performance of Ta and W, and their dependence on the type of reactive gas used, suggest that there are subtle details in how carbides form on the surface. In addition, previously published data show that carbides will form when
15 using C-based etch gases and TaC and WC would be expected to etch more slowly than Ta and W.

Although we have primarily investigated Ta and W as hard mask materials, the C-based RIBE processes included in this invention are not limited to these materials alone. Carbon-based RIBE can also be extended to a wider range of materials
20 that form slower etching carbides, such as Mo, Si, and Ti.

Finally, one benefit of using C₂H₂ or CHF₃ in a reactive etch is that they are safer than other reactive gases, such as CO, CH₄, and Cl, and thus are more consistent with the desire to eliminate hazardous materials from disk drive production. There are no safety provisions required for CHF₃. Acetylene is flammable but not toxic
25 and, therefore, only requires a gas cabinet. Unlike a toxic gas, there is no need for expensive double-walled plumbing and gas monitors. Furthermore, the reactive by-products we form on the wafer surface are presumably carbides, which are much safer than carbonyls and corrosive Cl by-products. Hence, there are no special safety provisions required for the ion mill exhaust.

30 We now illustrate the applicability of these RIBE processes by outlining two processes for defining a sputtered top pole in a magnetic write head, and the track width of a current-perpendicular-to-the-plane (CPP) giant magneto-resistance (GMR)

reader. The C-based RIBE can be applied to many processes other than the ones described here. For example, two other applications include the definition of a current-in-plane (CIP) GMR reader and a tunnel junction read head.

A process using this invention to define a sputtered top pole of a magnetic write head is illustrated schematically in FIGs. 6-9. FIGs. 6-9 show the application of carbon-based RIBE to writer fabrication. The figures are schematics showing the air bearing surface (ABS) view for a fabrication sequence to build a top pole in a perpendicular writer. FIG. 6 is a cross-section of the thin film multilayer with lithographically defined resist. An Ar IBE process defines the resist pattern into the RIE mask (not shown). A thin film multilayer structure 70 is deposited onto a planarized surface 72 in which a fraction of the surface contains an exposed portion of a write yoke. All of the material and structures fabricated before this top pole step lie below surface 72 and they are represented by layer 74. The roles of each layer in the structure 70 are as follows. A bottom layer 76 of Ta or W will serve as an etch stop. A buffer layer 78 is optional but can be included if it promotes good magnetics in the high-moment material and if it can serve as a sacrificial layer that helps to eliminate "feet" in the high-moment layer during the RIBE process. A high moment magnetic layer 80 is positioned on the buffer layer. Cap layer 82 is positioned on the high moment magnetic layer. A hard mask layer 84 of Ta, or W is positioned on the cap layer. A reactive ion etch mask 86 is positioned on hard layer. A resist 88 is positioned on reactive ion etch mask.

At one point in the process, it is desirable to open a via through layers 76 and 78 of FIG. 6 down to the yoke so that the high-moment layer in this example will be exchange-coupled to the rest of the yoke. The high-moment layer will form the top pole of a perpendicular writer. We use the example of FeCoB but other high-moment materials can be used. The cap layer is a non-magnetic material that protects the trailing edge of the write pole. This layer is both resistant to F-based RIE and readily etches with C-based RIBE, an example of such material is non-magnetic NiFeCr. The top Ta or W layer will act as a hard mask for the high-moment layer. Finally, the RIE mask is used to define the top pole structure into the Ta or W during the first RIE step.

FIG. 7 shows the definition of the device pattern into a Ta or W hard mask by F-based RIE. The top pole structure is transferred from the resist to the RIE mask by a standard Ar IBE step. We note that the RIE mask can also be defined in a lift-

off process where some material that is resistant to F-based RIE, such as NiFe or Al, is deposited through resist with a directional technique, like evaporation or ion beam deposition. Once the RIE mask is defined, the pattern can be transferred to the Ta or W layer by F-based RIE. This will then serve as the top pole mask during the C-based RIBE of the high-moment layer. FIG. 8 shows that a Ta or W hard mask is then used to define the device structure during the C-based RIBE of the high-moment top pole, which is FeCoB for this example. FIG. 9 shows the final step of using a second F-based RIE to remove the Ta or W etch stop layer. The last step, illustrated in FIG. 9, is a clean-up process that removes the Ta or W etch stop layer from the field.

The process can also be applied to the manufacture of CPP readers as shown in FIGs. 10-13. These figures show an ABS view for a proposed process for track width definition of a CPP reader. FIG. 10 is a cross-sectional view of the thin film multilayer with lithographically defined resist. A thin film multilayer structure 100 is deposited onto a planarized surface 102 of a Cu lead or NiFe shield 104. The roles of each layer in the structure 100 are as follows. A bottom layer 106 of Ta or W will serve as an etch stop. A buffer layer 108 is optional but can be included if it promotes good magnetics in the GMR stack and if it can serve as a sacrificial layer that helps to eliminate "feet" in the GMR stack during the RIBE process. A GMR stack 110 is positioned on the buffer layer. Cap layer 112 is positioned on the GMR stack. A resist 114 is positioned on cap layer.

C-based RIBE then defines the track width of the CPP sensor by removing portions of the cap layer, GMR stack and bottom layer is not protected by the resist, as shown in FIG. 11. An insulator 116 is then deposited on the structure using a directional deposition process as shown in FIG. 12. The insulator and resist are then lifted off to leave the structure shown in FIG. 13.

The methodology of the process shown in FIGs. 10-13 is very similar to that described for the writer. In this case, we used a resist to define the track width rather than a metal hard mask so that one can use lift-off to remove the insulator. One important difference from the writer process is the constraint on the resistivity of the Ta or W etch stop layer. Stray resistance from leads and other miscellaneous layers in the CPP stack must be minimized. This is potentially a problem since Ta typically forms a body centered tetragonal phase that has very high resistivity of $\sim 180 \mu\Omega\text{-cm}$. It is

possible to form the low resistivity body centered cubic phase of Ta that has a resistivity of around $20 \mu\Omega\text{-cm}$, but this is not guaranteed to occur. In contrast, W thin films typically have a resistivity of around $20 \mu\Omega\text{-cm}$ and may be a better choice for the CPP reader application.

5 Whether one chooses to use resist or a metal hard mask, the C-based RIBE process will help to relax the constraints on the dry etch process. The enhanced selectivity can allow thicker layers to be etched for the same thickness of resist or hard mask. Conversely, the same thickness can be etched with a thinner mask. C-based RIBE, when incorporated into the writer process described above, can substantially
10 improve upon our current sputtered top pole etch process. Finally, another key benefit of using Ta and W as masks is the fact that both materials can be readily etched with F-based RIE.

 This invention provides a new C-based RIBE process for selective etching of Ni, Fe, and Co alloys used in recording heads. This process is a substantial
15 improvement over standard Ar IBE and is a potentially better alternative than Cl-based RIE for dry etching magnetic materials. While we present data for just two sets of ion beam parameters, the principle behind this disclosure can be extended to any set of beam parameters, if necessary.

 Data have been presented for the field etch rates of various materials
20 when subjected to reactive ion beam etch (RIBE) processes that use either C_2H_2 or CHF_3 . Two examples are given to illustrate the application of these processes during recording head fabrication.

 The accumulation of the carbon-rich material during the carbon-based etch can be prevented by including elements or compounds in the gas mixture that
25 readily react with carbon to form fast-etching compounds that may or may not be volatile. One way to accomplish this is to incorporate oxygen into the gas mixture used during carbon-based RIBE. The oxygen in the ion beam will then form carbon monoxide or carbon dioxide from the residual carbon that accumulates on the sidewalls. In general, molecular oxygen can be mixed with carbon-containing gases that do not
30 contain oxygen, such as acetylene and methane. Another approach is to use a gas that has both carbon and oxygen. Since carbon monoxide is flammable and toxic, we chose carbon dioxide.

FIG. 14 shows measured field etch rates for various materials used in recording head fabrication as a function of the relative flow rate of CO₂. The combined flow rates of Ar and CO₂ vary from 10 to 16 SCCM. The measured values are the absolute etch rates. FIG. 15 shows the etch selectivity of NiFe and FeCo with respect to various materials. The selectivity is computed from the data in FIG. 14. Pure CO₂ RIBE yields a selectivity of NiFe and FeCo that is approximately 6 to 7 times higher than that for pure Ar IBE. This carbon-based etch process leads to structures with clean sidewalls that are free of the carbon-rich build-up.

The data in FIGs. 14 and 15 show the measured field etch rates as a function of the relative amount of CO₂ mixed with Ar. The absolute etch rates of most materials exhibit an overall gradual decline with increasing concentration of CO₂, but the etch selectivity of NiFe and FeCo with respect to Ta exhibits a remarkable enhancement. This behavior is similar to that observed with C₂H₂ RIBE. Pure CO₂ RIBE produces an etch selectivity of the benchmark materials NiFe and FeCo that is six to seven times larger than that for pure Ar IBE. This is a significant enhancement and comes with only a small compromise in absolute etch rate, which is about 2.3 times smaller than that for pure Ar IBE.

The key test of CO₂ RIBE is whether it can eliminate the accumulation of carbon-rich material. Patterned structures have been constructed in which the magnetic material in the surrounding field has been etched solely by CO₂ RIBE. The structures exhibit clean sidewalls.

Overall, CO₂ RIBE is able to match the etch selectivity produced by C₂H₂ RIBE. Furthermore, CO₂ RIBE is able to do so while at the same time offering several improvements and advantages. In particular, CO₂ and C₂H₂ are both non-toxic. However, CO₂ is even safer because it is non-flammable, which means that no gas cabinet is required. Pure CO₂ can be run through the ion beam source. This is in contrast to the behavior observed with C₂H₂ RIBE, in which a finite amount of Ar is required in order for the ion beam source to generate the required currents. CO₂ leads to less carbon build-up in the vacuum chamber and in the turbo pump. Thus, running CO₂ will lead to fewer maintenance issues than when using C₂H₂. CO₂ can be used beyond just a clean-up step because it leads to clean sidewalls.

The addition of oxygen helps keep sidewalls clean when using a carbon-based RIBE process. We have accomplished this by using CO₂, but other ways of achieving the same results are through the use of CO or using a mixture of O₂ with carbon-containing gases that do not have oxygen, such as C₂H₂ and CH₄. The selectivity of magnetic materials to photoresist goes down with increasing relative CO₂ flow rate. This is in contrast to C₂H₂ RIBE in which the relative etch rate of photoresist with respect to magnetic alloys goes down with increasing relative C₂H₂ flow. This can be compensated for by adding a gas, such as CHF₃ or C₂H₂, to CO₂ that induces slower etch rates for photoresist.

The etch selectivity is a function of the ion energy, where the selectivity increases with decreasing beam voltage. This can be exploited to minimize the amount of over-etching into underlying material by employing a multi-step CO₂ RIBE process. In such a process, higher beam energies are used to clear material from the field for the first step. Then, a second step that employs lower beam energies can be used for the over-etching necessary to clean up corners and straighten sidewalls. CO₂ RIBE in combination with a Ta etch stop layer can also be used as a clean-up or via opening step in a manner similar to that described above for C₂H₂ RIBE.

While the present invention has been described in terms of several examples, it will be apparent to those skilled in the art that various changes can be made to the disclosed examples without departing from the scope of the invention as defined by the following claims.

What is claimed is:

1. A method of etching a structure including a magnetic material, the method comprising:

providing a structure (70) including a magnetic material (80);
applying a mask material (84) to at least a portion of the structure; and
reactive ion beam etching the magnetic material using an etch process including a carbon based compound, wherein the mask material forms a material which etches slower than the magnetic material.

2. The method of claim 1, wherein the etch process further includes argon ions.

3. The method of claim 2, wherein the carbon based compound comprises a compound selected from the group of:

C_2H_2 , CHF_3 , and CO_2 .

4. The method of claim 2, wherein the etch process further includes oxygen and either C_2H_2 or CHF_3 .

5. The method of claim 1, wherein the carbon based compound comprises a compound selected from the group of:

C_2H_2 , CHF_3 , and CO_2 .

6. The method of claim 1, wherein the magnetic material comprises an alloy including a material selected from the group of:

Fe, Ni, and Co.

7. The method of claim 6, wherein the mask material comprises a material selected from the group of:

Ta, W, Mo, Si, Ti and a photoresist.

8. The method of claim 1, wherein the mask material forms an etch stop.

9. The method of claim 1, wherein the mask material is applied to at least a portion of a surface of the magnetic material.

10. The method of claim 1, wherein the structure comprises:
a portion (74) of a write pole;
an etch stop layer (76) supported by the portion of the write pole, wherein the etch stop layer supports the magnetic material;

a cap layer (82) supported by the magnetic material, wherein the cap layer supports the mask material;

a layer of reactive ion etch mask (86) supported by the mask material; and

a resist (88) supported by the reactive ion etch mask.

11. The method of claim 10, wherein the structure further comprises:

a buffer layer (78) between the etch stop layer and the magnetic material.

12. The method of claim 1, wherein the magnetic material forms a layer in a magneto-resistive stack.

13. The method of claim 1, wherein the magnetic material forms a write pole.

14. The method of claim 1, wherein the material which etches slower than the magnetic material comprises a carbide.

15. A magnetic head made using the process of claim 1.

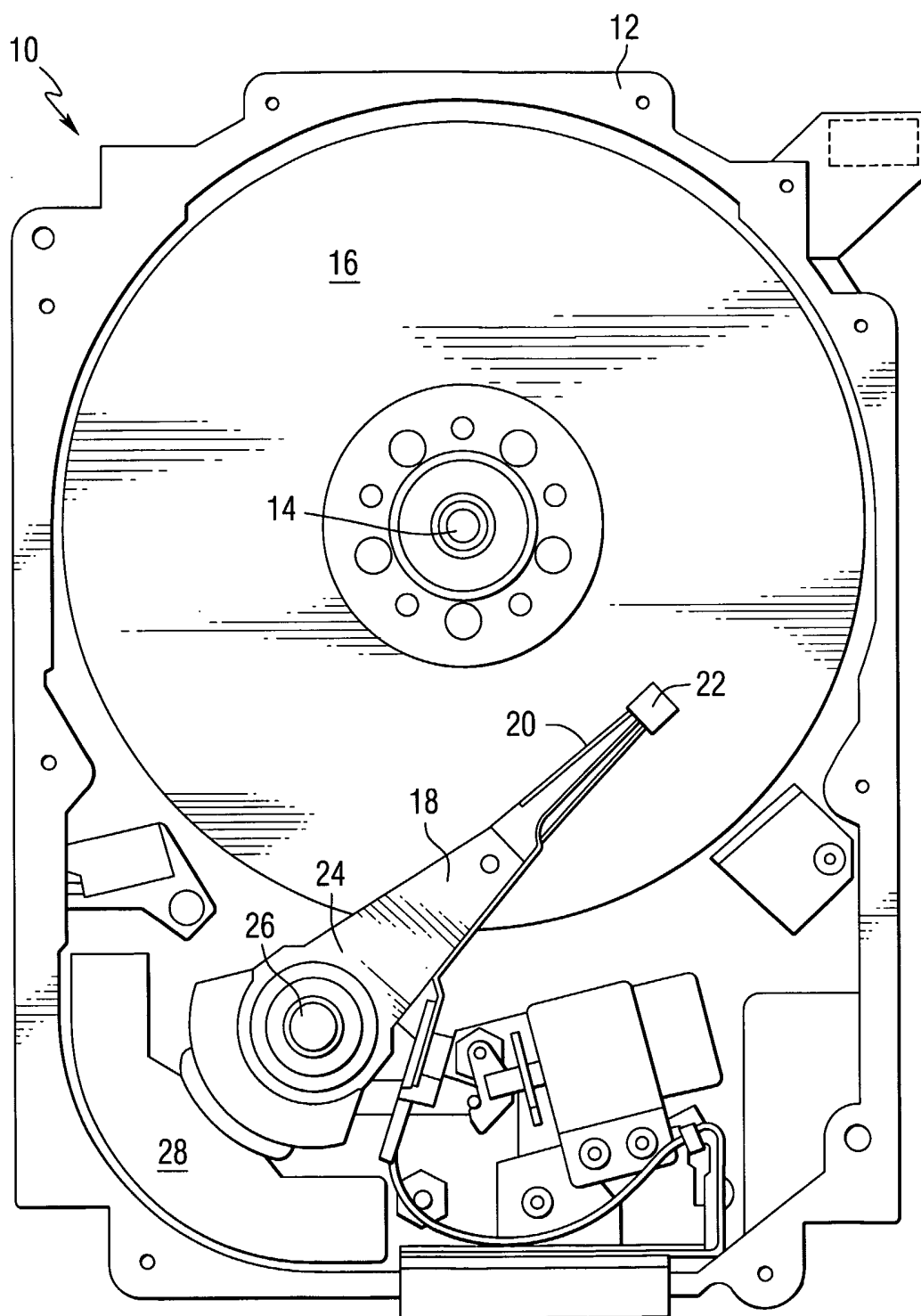
16. A disc drive (10) comprising:

a magnetic head (22) made using the process of claim 1;

means (14) for rotating a magnetic storage medium (16); and

means (18) for positioning the magnetic head adjacent to a surface of the magnetic storage medium.

1/6

**FIG. 1**

2/6

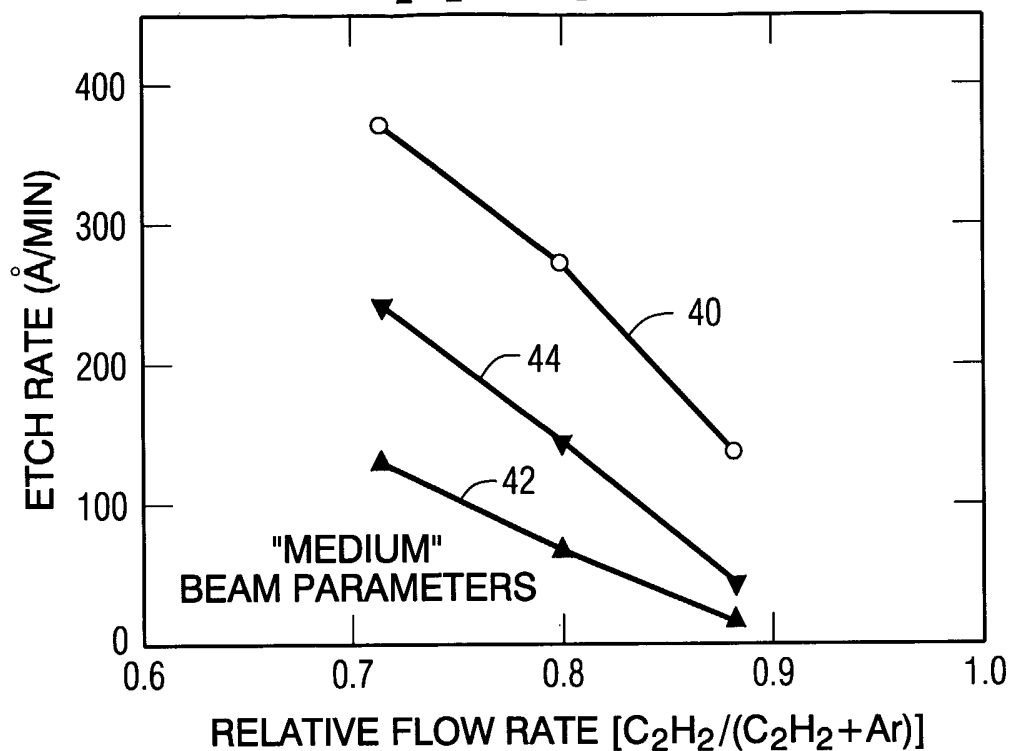
Ar:C₂H₂ RIBE @ 45° ANGLE

FIG. 2

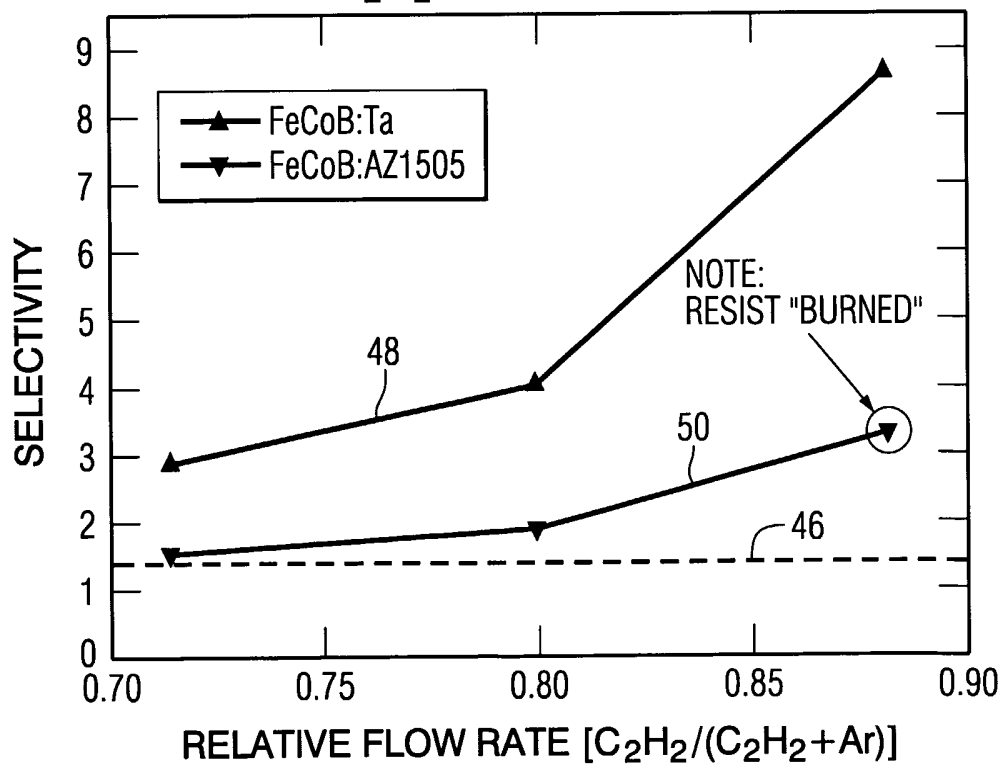
Ar:C₂H₂ RIBE @ 45° ANGLE

FIG. 3

3/6

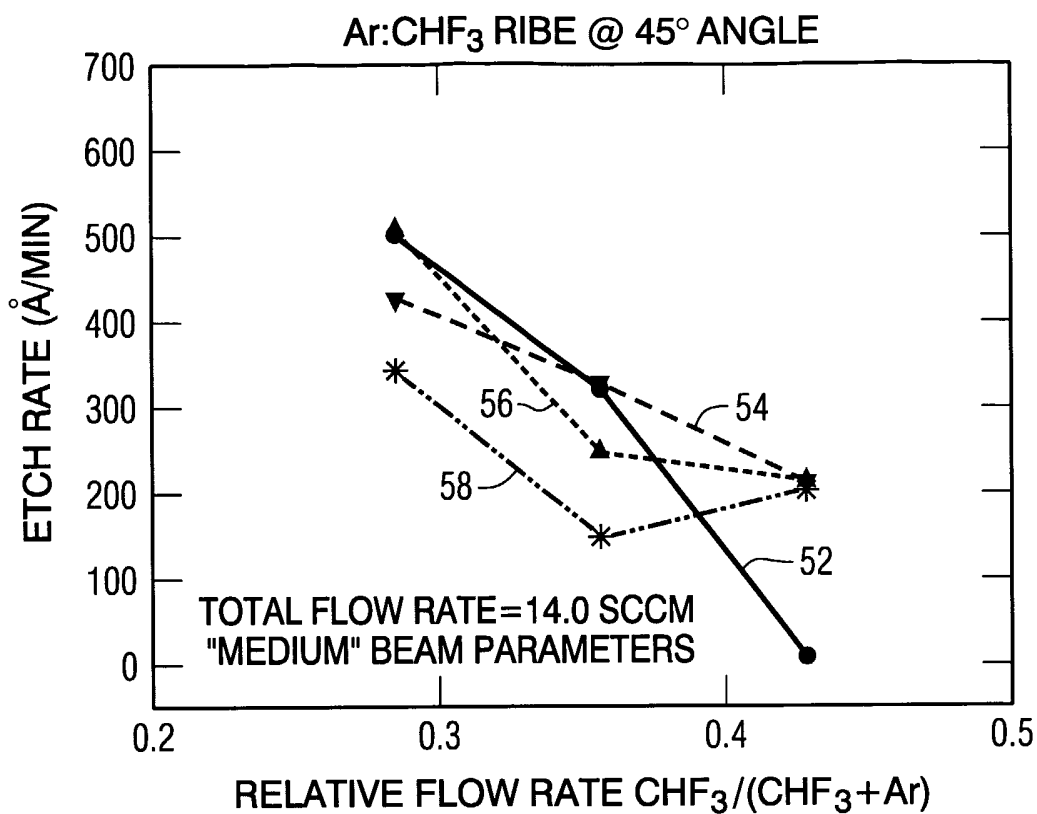


FIG. 4

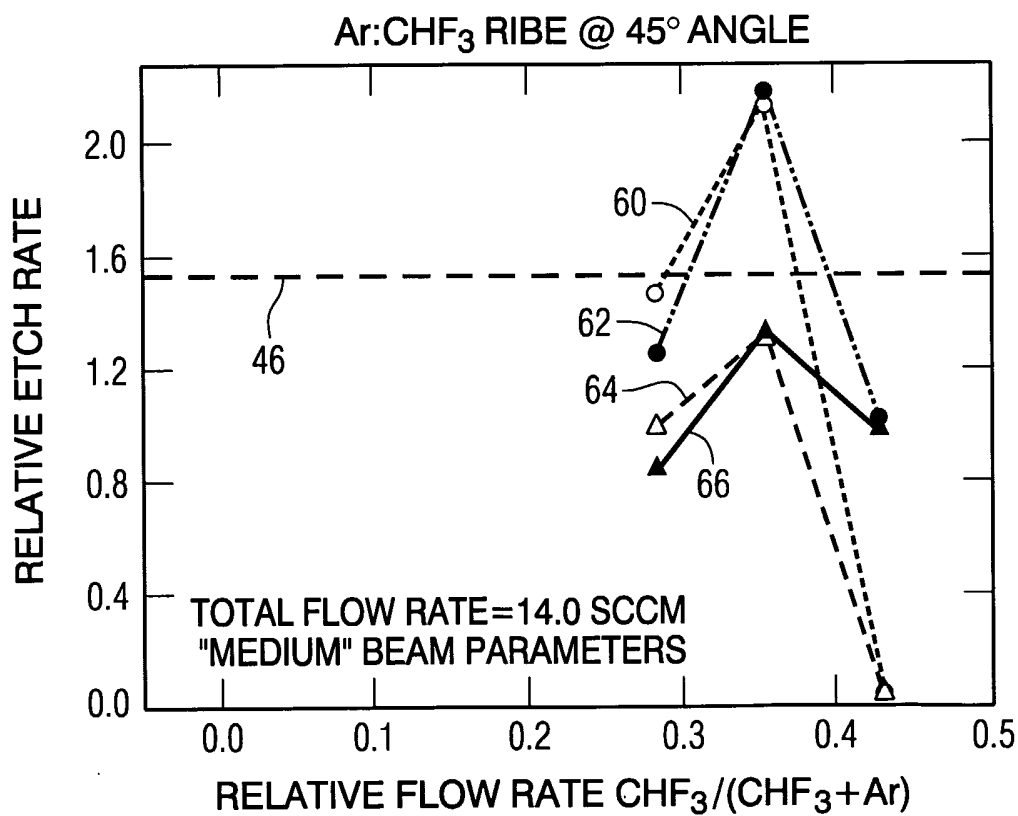


FIG. 5

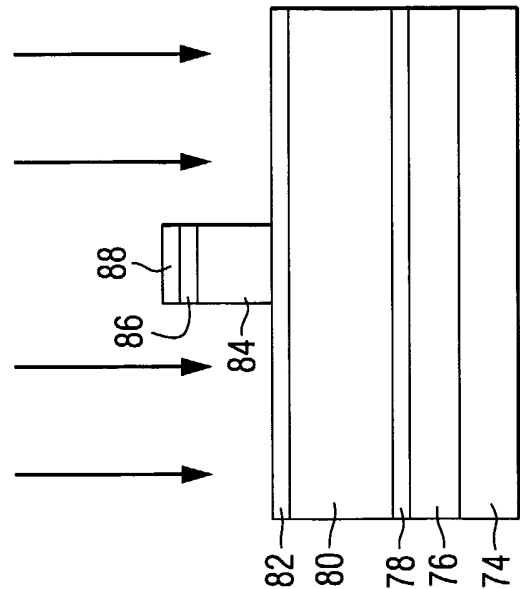


FIG. 7

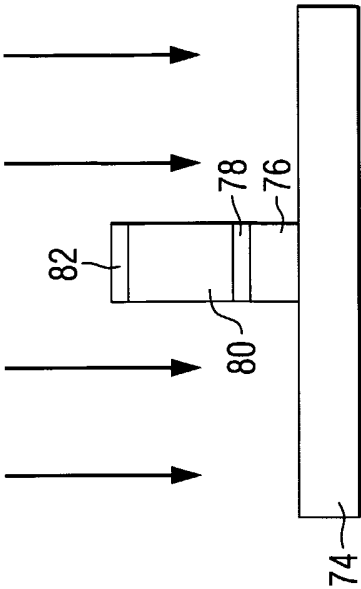


FIG. 9

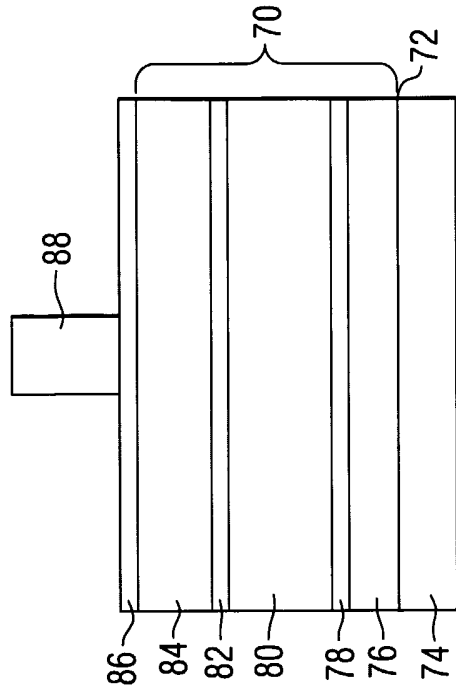


FIG. 6

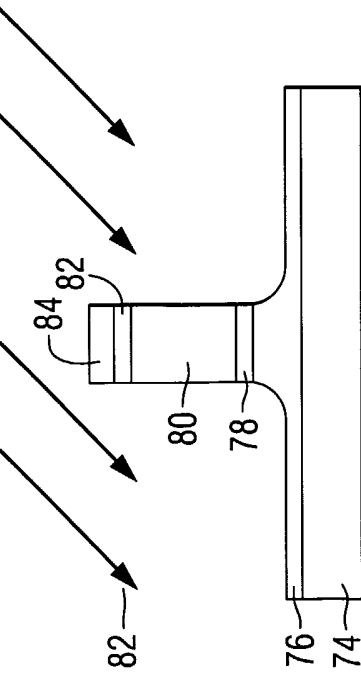


FIG. 8

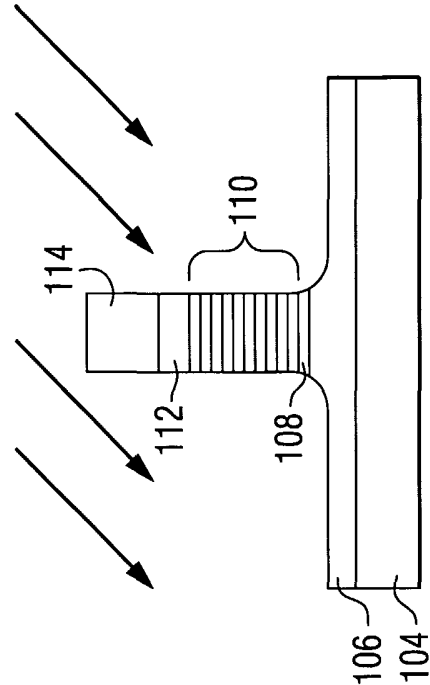


FIG. 11

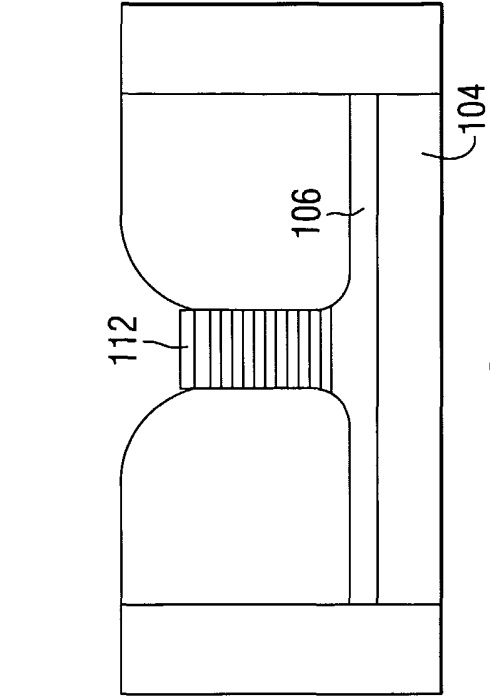


FIG. 13

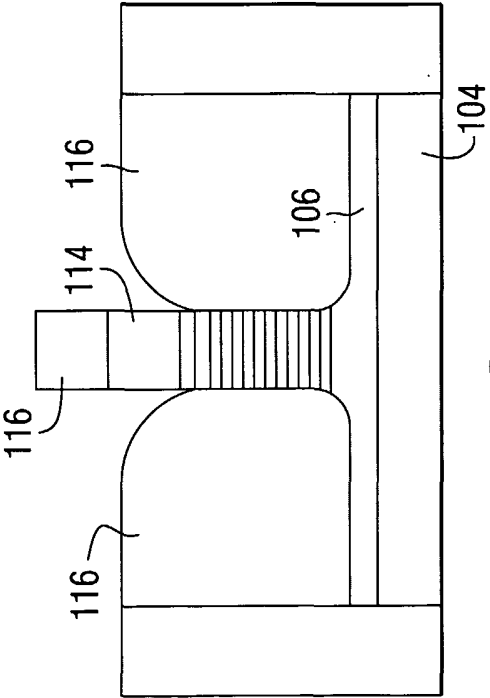


FIG. 12

6/6

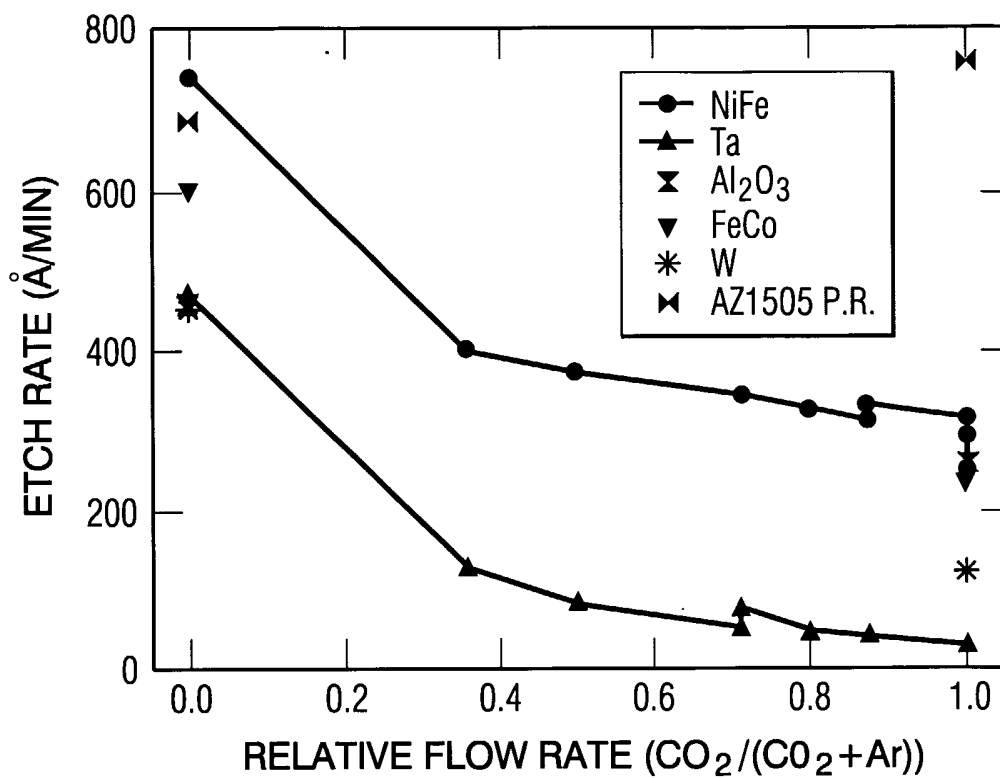


FIG. 14

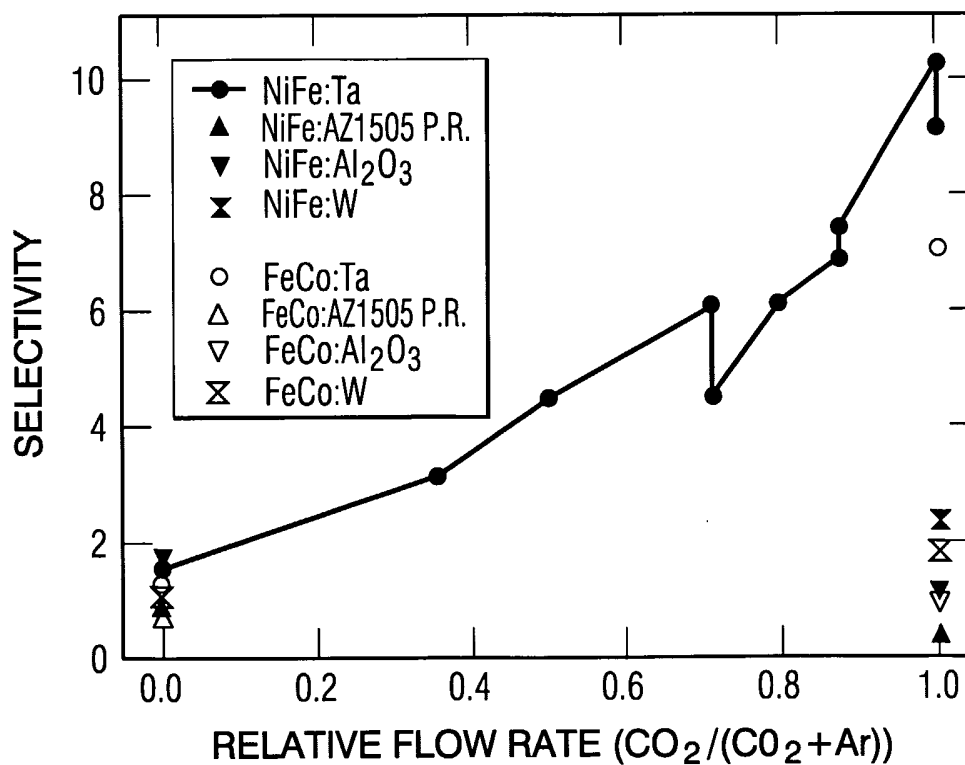


FIG. 15

INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 02/25528

A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 H01F41/18 H01F41/30 G11B5/31

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)

IPC 7 H01F 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 practical, search terms used)

EPO-Internal, PAJ, WPI Data, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A A	US 6 238 582 B1 (DRUZ BORIS L ET AL) 29 May 2001 (2001-05-29) column 9, line 32 -column 10, line 3; claims 36-38,42,52,53,85,86; figures 2H-2J --- PATENT ABSTRACTS OF JAPAN vol. 2000, no. 20, 10 July 2001 (2001-07-10) & JP 2001 084535 A (TDK CORP), 30 March 2001 (2001-03-30) abstract -----	1-6,8,9, 13,15 10 1,12



Further documents are listed in the continuation of box C.



Patent family members are listed in 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 document 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.
- *G* document member of the same patent family

Date of the actual completion of the international search

10 December 2002

Date of mailing of the international search report

18/12/2002

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer

Decanniere, L

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/US 02/25528

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 6238582	B1	29-05-2001	AU 4047500 A 16-10-2000
			EP 1183684 A2 06-03-2002
			WO 0058953 A2 05-10-2000
JP 2001084535	A	30-03-2001	US 6315875 B1 13-11-2001