ferromagnetic material. The material may be a pure element (e.g., nickel or cobalt) or it may be a ferromagnetic alloy such as an alloy of copper, manganese and/or tin. Examples of suitable ferromagnetic alloys include Heusler alloys, (e.g., 65% copper, 25% manganese and 10% aluminium), Permalloy (55% iron and 45% nickel), Supermalloy (15.7% iron, 79% nickel, 5% molybdenum and 0.3% manganese) and μ-metal (77% nickel, 16% iron, 5% copper and 2% chromium). Nickel-cobalt alloys may also be used. In some embodiments, non-metallic ferromagnetic materials including ferrites which are mixture of iron and other metal oxides may be used. However, it may be challenging to fabricate MFGs from these materials for microfluidic devices.

[0052] In the embodiment of FIG. **1**, the MFG is an array of thin nickel stripes micro-patterned on a glass substrate, which becomes magnetized under the influence of an external permanent magnet. Because the nickel possesses much higher permeability than the surrounding material (i.e., the buffer), a strong gradient is created at the interface. Although the magnetic flux density from the MFGs may not be strong compared to the surface of the external magnet, the gradient of the magnetic field is very large within a short distance (e.g., a few microns in some embodiments) of the line edges (See FIG. **2**). As a result, the MFGs allow precise shaping of the field distribution in a reproducible manner inside microfluidic channels. The MFG element may include one or more individual magnetizable elements. As shown in the FIG. **1**, the MFG may include a plurality of magnetizable elements, e.g., 2 or more, 4 or more, 5 or more, 10 or more, 15 or more, 25 or more, etc.

[0053] In designs where the magnitude of the gradient decreases rapidly with distance from the MFG, the MFG may be formed within or very close to the flow channel where sorting takes place. Therefore, in some microfluidic examples, an MFG should be located within a few micrometers of the sorting region where magnetic particles are to be deflected (e.g., within about 100 micrometers (or in certain embodiments within about 50 micrometers or within about 5 micrometers of the sorting region, such as within about 2 micrometers of the sorting region). However, when large external fields are employed, the MFG design need not be so limited. Generally speaking, the MFG may be located as far away from the sorting region as about 10 millimeters. This may be the case when, for example, the external magnetic field is in the domain of about 1 Tesla or higher. Note that the large gradients afforded by such MFGs allow one to design very high throughput sorting stations with relatively large channels and consequently the capability to support large volumetric flow rates.

[0054] In certain embodiments, the MFG is provided within the sorting region channel; i.e., the fluid contacts the MFG structure. In certain embodiments, some or all of the MFG structure is embedded in channel walls (such as anywhere around the perimeter of the channel (e.g., top, bottom, left, or right for a rectangular channel)). Some embodiments permit MFGs to be formed on top of or beneath the microfluidic cover or substrate.

[0055] The pattern of material on or in the microfluidic substrate may take many different forms. In one embodiment it may take the form of a single strip or a collection of parallel strips. The example depicted in FIG. **1** shows four parallel strips comprising an MFG. Note that there are two MFGs in FIG. **1**, one for the magnetic particles entering the sorting region from sample channel **107***a* and the other for magnetic particles entering the region from sample channel **107***b*.

[0056] Examples of suitable dimensions for line-type MFG structures will now be presented. In certain embodiments employing ferromagnetic strips for use in sorting particles in a conventional buffer medium, the strips may be formed to a thickness of between about 1000 Angstroms and 100 micrometers. The widths of such strips may be between about 1 micrometer and 1 millimeter; e.g., between about 5 and 500 micrometers. The length, which depends on the channel dimensions and the angle of the strips with respect flow direction, may be between about 1 micrometer and 5 centimeters; e.g., between about 5 micrometers and 1 centimeter. The spacing between individual strips in such design may be between about 1 micrometer and 5 centimeters. The number of separate strips in the MFG may be between about 1 and 100. The angle of the strips with respect to the direction of flow may be between about −90° and +90°. For fractionation applications, it has been found that angles of between about 2° and 85° work well. Obviously, one or more dimensions of the MFG pattern may deviate from these ranges as appropriate for particular applications and overall design features.

[0057] In certain embodiments, the pattern of ferromagnetic material may take the form of one or more pins or pegs in the flow channel or on the substrate beside the flow channel or embedded in the substrate adjacent the flow channel. FIGS. **3**A to **3**E present arrangements of ferromagnetic elements for MFGs in accordance with certain embodiments of the invention. In each case, the elements are provided within or proximate a flow channel in a magnetophoretic sorting region.

[0058] FIGS. **3**A and **3**B present two arrangements (rectangular and offset) of pin-type MFG elements depicted with respect to a direction of flow. The heights and widths of these elements may be in the same ranges as presented for the strip MFG elements presented herein. For comparison, FIGS. **3**C-**3**E present arrangements of MFG elements taking forms of layers of linear strips (FIG. **3**C), layers of curved strips (FIG. **3**D), and layers of chevrons (FIG. **3**E).

[0059] As indicated an external magnet may provide the magnetic field that is shaped by an MFG to produce a strong magnetic field gradient in a sorting region. Typically the external magnet is a permanent magnet, but it may also be an electromagnet (e.g., a Helmholtz coil). Generally, electromagnets produce smaller magnetic fields (in comparison to permanent magnets), but they may be designed to produce very uniform fields, which may be advantageous.

[0060] The position and orientation of the permanent magnet(s) with respect to the sorting region may be determined by the magnetic field strength produced by the permanent magnets, the homogeneity of the field (i.e., the uniformity of the field across the sorting region absent the MFG), the dimensions and shape of the magnet, etc. It generally desirable to have a uniform field produced by the external magnet(s) in the region of the MFG—assuming that the MFG is not present. In a typical case, two permanent magnets are employed, one located above the sorting region and the other located below the sorting region. In a specific embodiment, the magnets may be located above and below an MFG. In certain embodiments, two permanent magnets straddle a sorting region (i.e., the permanent magnets are located in the same plane as the sorting region or in a plane parallel to the plane of the sorting region). Certain embodiments employ a single magnet with one pole located above or below the sorting region. Still other embodiments employ generally U-shaped magnets in which