TABLE 2-continued

Spin valve signal voltage (peak-to-peak amplitude) versus free layer width. The voltage is due to a single Co nanoparticle with a diameter of 11 nm and its edge is 6 nm away from the midplane of the spin valve free layer. Both in-plane and vertical mode are listed, along with the relevant bias field and tickling field amplitudes.

		Free layer width		
		1 μm	0.2 μm	0.2 μm
		Sense current		
		10 mA	2 mA	2 mA
Vertical mode	(bias field, tickling field)	(50 Oe, 50 Oe)	(50 Oe, 50 Oe)	(100 Oe, 141 Oe)
	signal voltage	0.08 μV	0.2 μV	0.8 μV

[0058] Electromagnetic Interference (EMI) Signal Rejection

[0059] Spin valve detection is typically performed with the in-plane mode (Li, et al., *J. Appl. Phys*. Vol. 93 (10): 7557 (2003)). The vertical mode, even though giving a slightly smaller signal amplitude, is extremely advantageous when the electromagnetic interference (EMI) signal due to the AC tickling field in the detection system is significant. The EMI signal tends to center at the frequency f of the AC tickling field, so it can be eliminated or greatly reduced if we perform lock-in detection at the frequency 2f. Furthermore, we can adopt a 2-bridge circuit to eliminate any remaining EMI.

[0060] Ultrathin Passivation of Detectors

[0061] The signal from the spin valve detector due to the magnetic tag depends on the distance between the magnetic tags and the free layer of the spin valve, in addition to the geometry and bias field of the spin valve itself. The detector voltage signal from a single Co particle decreases with increasing distance from the center of the particle to the midplane of the spin valve free layer.

[0062] As the sensing magnetic field from a magnetic particle drops monotonically with the distance between the sensor and the particle, it is preferred to make the free layer in the spin valves on top of the pinned layer. Furthermore, it is of utmost importance to minimize the distance between the magnetic particle and the top surface of the free layer, including the thickness of the passivation layer protecting the spin valves. However, during operation of the detector array, a solution of DNA will be flowed over the sensor surface to allow for hybridization of corresponding DNA fragments. Therefore, corrosion of the sensor surface is of major concern. Any degradation of the detector surface could sacrifice sensitivity by reducing the signal from hybridization events or by destroying the detectors altogether.

[0063] The magnetic detection schemes in the prior art have recognized this potentially catastrophic problem and consequently have added relatively thick passivation layers to their detector surfaces. If a conventional passivation layer is used, there would be a distance of greater than 1000 nm between center of the magnetic particle and the detector surface, greatly limiting the detector sensitivity. A trade-off occurs between retaining high sensitivity while sufficiently guarding against degradation. The MagArray™ detector design combines an ultrathin (less than 10 nm) layer of passivation and very small magnetic nanoparticle tags (diameter of about 20 nm or smaller), thus achieving a particle-center-to-detector distance of less than about 30 nm (including the intervening DNA fragment length of about 10 nm), which is close enough to provide the necessary sensitivity for single-tag detection. In accordance with the present disclosure, the ultrathin layers of passivation (such as Ta or Au) suitable for use with detectors such as the MagArray™ detector typically can have a thickness from about 1 nm to about 10 mm, allowing for achievement of particle-center-to-detector distances from about 6 nm to about 30 nm.

[0064] High Sensitivity MTJ Detectors

[0065] A MTJ detector is constructed similarly to a spin valve detector except that the non-magnetic spacer is replaced with a thin insulating tunnel barrier such as alumina and that the sense current flows perpendicular to the film plane. Electron tunneling between two ferromagnetic electrodes is controlled by the relative magnetization of the two ferromagnetic electrodes, i.e., tunneling current is high when they are parallel and low when antiparallel. A typical MTJ detector is composed of a bottom electrode, magnetic multilayers including a tunnel barrier, and a top electrode. MTJ detectors have magnetoresistance ratios as high as 50% and inherently large device resistances, yielding higher output voltage signals.

[0066] Conventional MTJ devices employ relatively thick (greater than 0.2 μm) top electrodes (Parkin, S. S. S. P., et al., *J. Appl. Phys.* 85: 5828 (1999)) that will greatly reduce the detected signal from a single magnetic nanoparticle, thus they are not suitable for the MagArray™ detector. To overcome this problem, we devised a double-layer top electrode. The first layer can be a thin gold layer (about 10 nm or less). Gold is desirable due to its ease for binding DNA probes. The second layer can be aluminum, copper or other conductive metals which do not bind with DNA probes, including palladium, palladium alloys, palladium oxides, platinum, platinum alloys, platinum oxides, ruthenium, ruthenium alloys, ruthenium oxides, silver, silver alloys, silver oxides, tin, tin alloys, tin oxides, titanium, titanium alloys, titanium oxides, and combinations thereof. An aperture in the second layer, slightly smaller in size than the MTJ, is created either by a lift-off process or by etching a uniform second layer. This design allows us to keep the