Miniature Magnetic Resonance Force Microscopy System

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論文内容要約

Magnetic resonance imaging (MRI), as a non-invasive 3D imaging of inside structures of objects, is a well developed and widely used instrument in biology and medicine fields for human disease detection. However, owing to the sensitivity limitations of conventional inductive techniques, the 3D imaging spatial resolution of MRI is limited to several tens to hundreds of micrometer scales. With the emergency of scanning probe microscopy (SPM) techniques including scanning tunneling microscope (STM), atomic force microscope (AFM), and so on, the information of material surface can be obtained with ultra-high precision through detecting the local interaction between the sample and a probe. Based on this ultra-high force sensitivity of the probe, which is demonstrated in AFM, the resonant magnetic force from nuclear or electronic spins can be detected by a micro-fabricated sensitive cantilever. The concept of magnetic resonance force microscopy (MRFM), as a promising MRI combined with AFM technology, was firstly proposed by Sidles in 1991. This technique utilizes a small magnetic tip and an ultra-sensitive cantilever to detect the densities of spins or radicals through a non-invasive method in a nanometer scale.

In MRFM measurement system, high sensitivity of cantilever sensor is very important to achieve high-resolution measurement result. To keep high sensitivity, low temperature to reduce thermo noise and high vacuum to reduce the air damping are two effective methods. However, the corresponding challenges need to be overcome: One is the microscanner with 3D large displacements at low temperature and another one is the limitation of test objects like cell in high vacuum. In this thesis, two aspects of challenges are realized for the miniature magnetic resonance force microscopy system, i.e., developing a comb-drive XYZ-microstage with 3D large displacements for MRFM measurement at low temperature and developing a vacuum packaged cantilever magnetic sensor for MRFM measurement at atmospheric environment.

In the first aspect, a chip-level microassembly technology is proposed to fabricate the comb-drive XYZ-microstage, which is constructed with a comb-drive XY-microstage, two comb-drive Z-actuators and silicon based substrate. The movements of the XYZ-microstage are produced by the XY-microstage into in-plane directions and by the Z-actuators with large displacement into out-of-plane direction, respectively. This assembled comb-drive XYZ-microstage with a size of $12.4\times15.6\times16.9$ mm^3 can produce large displacements of 25.2 (49.2) μm in X direction, 20.4 (27.9) μm in Y direction and 58.5 (50.5) μm Z direction. It is demonstrated that the assembled comb-drive XYZ-microstage is a promising 3D scanning stage with large displacements and less crosstalk for the application of MRFM at cryogenic environment.

In the second aspect, two kinds of bonding methods including Au-Au thermocompression bonding and anodic bonding are used to realize the vacuum packaged cantilever magnetic sensors. By contrasting the measured dependence of Q factor with pressure, the packaged vacuum of cantilever magnetic sensors based on Au-Au thermocompression bonding and anodic bonding are determined to be in the range of 1.7×10^3 ~ 2.4×10^3 Pa and 7.3×10^2 ~ 1.0×10^3 Pa, and the force sensitivity of the

cantilever sensors are estimated to be 1.4×10^{-13} N/$\sqrt{\text{Hz}}$ and 1.1×10^{-13} N/$\sqrt{\text{Hz}}$, respectively. The variations of the resonant frequency and resonant amplitude of the cantilever can be mapped to the magnetic field with a resolution of ~4×10^{-6} and 2.4×10^{-10} T, respectively. Finally, the magnetic force caused by electron spin resonance (ESR) of a standard radical polymer, DPPH, is detected at atmospheric environment.