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Micromachined Probe for High Density Data Storage

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Abstract

Near-field aperture probes with high optical transmittance efficiency for optical recording and multi-probes with a metal wire as a heater for thermal recording are batch-fabricated by silicon micromachining. The aperture with diameter sizes from 10 to 500 nm at the apex of a SiO_2 tip on a Si cantilever is fabricated using a "Low temperature Oxidation & Selective Etching" technique. The SiO_2 tip is formed by nonuniform Si wet oxidation at 950 °C. The aperture is created at the apex of SiO_2 tip by selective etching SiO_2 in a buffered-HF. The aperture shows a high optical transmittance because the SiO_2 tip has a large opening angle. This fabrication technique is extended to fabricate a metal nanowire at the apex of the SiO_2 tip by embedding a metal into the aperture. By flowing a current into the metal wire, the tip can be heated. This probe array is fabricated, and the basic characteristics are evaluated.

Micromachining technology enables to make various miniaturized sensors, actuators including MEMS (MicroElectroMechanical Systems) in a batch fabrication with low cost. One major paradigm for MEMS is the integration of micro-machines with electronics and optics. On the other hands, proximity probe techniques represented by scanning probe microprobe (SPM), scanning tunneling microscope (STM) make rapid progress. The most essential part of these techniques is a micro-probe with a sharp stylus made by micromachining. Nowadays, these probes have been utilized not only for scientific tools with a capability of visualizing a nano-world but also engineering tools such as a nano-lithography and a manipulation.

Data storage devices including magnetic memory and optical data storage play a very important role in information technology. The density of magnetic memory is drastically grown up with about 100% annually and now is approaching the limitation due to the paramagnetic effect that leads to a thermal instability of the recording bits at room temperature. The density of optical memory is also limited due to the diffraction effect. Size of the recorded optical bits (d) is decided by spot size of the laser beam that depends on the laser wavelength (λ) and numerical aperture (NA) of the optical system. To increase the density or reduce the size of recording bit, an obvious solution is to reduce the optical wavelength or increase the numerical aperture NA. However, optical storage with density of over 100 Gbit/inch^2 or with bit size of smaller than 100 nm seems too difficult to achieve.

To adapt with an increasing demand in data storage capacity in the 21st century, there is an urgent need to study and develop next generations of data storage. Several novel recording techniques have been proposed by many groups [1]. We developed near-field microprobe with a high optical transmittance for optical recording. This fabrication technique is extended to make nano-heater integrated probes for thermal recording.

High Throughput Near-field Probe

One of the most attractive applications of the near-field optics is the next generation optical data storage. The optical memory with high density and high data transfer rate is highly demanded to utilize an aperture probe array of bright nano-scaled light sources (near-field) for writing and reading bits on a medium. Incident light is converted into near-field by a metal aperture.

It is known that the thickness of oxide grown at a low temperature at convex and concave corners is thinner than that at a flat surface of Si due to the compressive stress of oxide at the corner structures. This nonuniform Si oxidation effect at a pyramidal etched pit is applied to fabricate the aperture probe array[2].

First, pyramidal etch pits are defined on Si (100) wafer by oxidation, lithography, SiO_2 patterning, and Si etching with a tetramethyl ammonium hydroxide (TMAH) (Fig.1, step b). Next, the wafer is thermally oxidized in wet oxygen at 950 °C, for about 1 μm thick (c). Using a thin Cr film of about 100 nm in thickness as a mask, the top SiO_2 is partly etched as shown in step d. The wafer is next etched in the TMAH until forming the Si diaphragm with SiO_2 tips (e). The wafer is subsequently dipped into a buffered-HF (BHF) for partly etching the SiO_2 until forming Cr protrusions at the apexes of the tip array(f). After etching-out of the Cr film, the aperture array is formed (g). Next, a thin Al film (approximately 100 nm) is entirely deposited onto the backside of the Si diaphragm to form an opaque layer (h). SEM images of the fabricated aperture array on the Si diaphragm and closed-up view of about 50 nm aperture

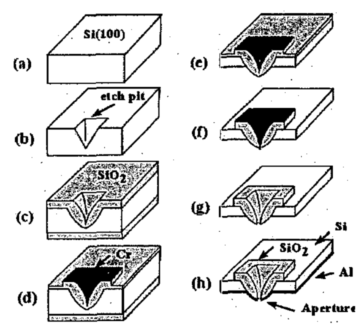
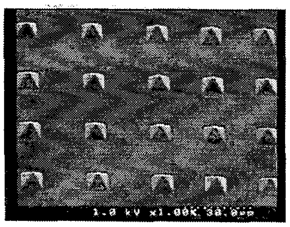
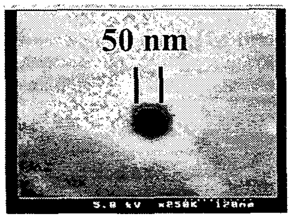


Fig.1. Fabrication sequence of the aperture probe.



(a)



(b)

Fig. 2. SEM image of the microfabricated aperture array on Si diaphragm (a), closed up view of 50 nm diameter aperture (b).

are shown in Fig. 2 a, b, respectively.

The throughput of a conventional optical fiber tip is quite low (e.g., 100 nm diameter aperture of optical fiber shows an approximately 10^{-5} ~10^{-7} throughput). The throughput of our probe is several orders of magnitude higher than that of the conventional optical fibers (100nm diameter aperture shows about 10^{-2} of optical transmittance)[3]. However, for the aperture smaller than 100 nm, the throughput is still drastically decreased.

Multi-Probe Array for Thermal Storage

As shown in Fig.3, 2D micro-thermal probe array for thermal recording based on an atomic force microscopy (AFM) are fabricated and evaluated [4]. A metal wire is formed at the apex of the probe tip, which acts as a nano-heater by flowing a current. The nano-heater with a small thermal mass will promise a quick thermal response. The silicon probe array (32×32) is bonded to a Pyrex glass substrate in which metal wires (feed-through) are formed for electrical connections from the individual probe to IC. This structure will allow operating the probes in parallel, which possibly overcomes the low data transfer rate of the AFM-based storage. As shown in Fig.4, the small metal wire for a nano-heater is fabricated at the apex of a pyramidal SiO_2 tip, which is formed by low temperature oxidation of a silicon etch-pit, consecutive metal deposition (Pt/Cr or Au/Cr) to fill the metal into the etch-pit, and etching of the SiO_2 in buffered HF solution. Another metal (Ni) is deposited on the tip to form a metal-to-metal junction that enables to measure the temperature at the tip end. The silicon substrate formed the probe array is bonded to the glass substrate.

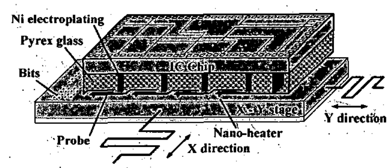


Fig. 3. Concept of the multi-probe storage.

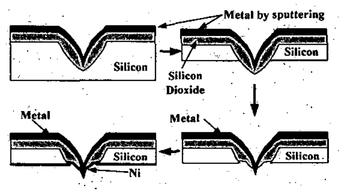


Fig. 4. Schematic fabrication sequence of the heater-integrated probe.

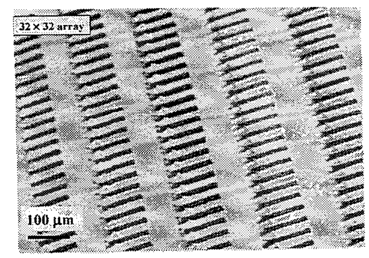


Fig. 5. SEM image of the fabricated probe

The heating capability of the nano-heater is confirmed by the resistivity change and the thermophoton emission from the nano-heater when flowing a small current into the nano-heater. Temperature of the heater predicted from a change in resistance was 800°C at the flowing current of 4 mA. The measured thermal time constant of the nano-heater was about 18 μsec. From these results, total recording speed of about 300 Mbits/sec can be expected. By using a micro-probe, preliminary experiments for data writing and reading are performed on a phase change medium. If this probe array is combined with a micro-actuator, miniature storage device with a high areal bits density possibly be realized.

References

[1] P. Vettiger et al., IBM J. Res. Develop. 44, 323 (2000)
[2] P. N. Minh, T. Ono, M. Esashi, Appl. Phys. Lett., 75, 4076 (1999)
[3] P. N. Minh, T. Ono, M. Esashi, Review Scientific Instrument, 71, 3111 (2000)
[4] D.-W. Lee, T. Ono, T. Abe, M. Esashi, IEEE technical digest of Micro Electro Mechanical Systems, 204 (2001).