行政院國家科學委員會補助專題研究計畫成果報告

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※ Fabrication of Sub-Micro Aperture by ※

※ Micro Electroplating ※

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計劃編號 : NSC 90-2212-E-009 –033 -

.執行期間 : 90 年 8 月 1 日至 91 年 7 月 31 日

計劃主持人 : 徐文祥

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中 華 民 國 91 年 7 月 31 日

行政院國家科學委員會專題研究計畫成果報告

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計劃主持人 : 徐文祥　國立交通大學機械系教授

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一、中文摘要

本案提出利用精密電鍍的方式來產生微小孔穴。可應用於近場光學資料儲存技術，以減低資料儲存點的尺寸。等與前述各項技術相較，電鍍法具有成本較低、耗能較少、可批次生產等優點。只需利用光阻製程在金屬板上製作出孔穴的圖樣，隨後便可電鍍出具有孔穴的金屬薄片。此製程不需使用離子束蝕刻或高溫爐管等昂貴的設備，而且完全在接近室溫的狀態下進行，因此成本低廉、耗能省，而深具潛力。經由對電鍍製程中，各項參數的改良與精確控制，已可將電鍍生產的微小孔穴直徑降至165奈米。

英文摘要

An optical aperture made by electroplating is proposed. The aperture can be applied in the SNOM (Scanning Near-field Optical Microscopy) data storage technique, provides small data pits beyond the limit of the light wavelength. The aperture is initially defined by semiconductor lithography process, formed by electroplating, and shrunk by over-plating phenomenon. Fabrication of sub-micron apertures is realized. The aperture can be as small as a diameter of 165 nm, and the smallest aperture that is already proved open through is about 165 nm in diameter.

二、計劃緣由與目的

In last ten years, the density was improved by about 100 times, and the growing rate seems not to decay nowadays. However, the magnetic data storage technique will reach its physical limit in a few years. And the conventional optical data storage is limited by the light wavelength, too. But the near-field optical technology eliminates impressive potential in high-density data storage, specially the region beyond 100 Gbits/in^2 (林盈熙, 1999).

The SNOM (Scanning Near-field Optical Microscopy) technique combines the near-field optics and the AFM (Atomic Force Microscopy) technique. By this technique, the light is not lens focused, but limited by a tiny aperture to the data pits. So that the data pit size is no longer limited by the wavelength of the light, but the size of the tiny aperture.

The most popular SNOM approach taken is using the stretched optical fiber tips, usually in pipette shape, with a sharp end. At the end of the tip, a layer of metal material was coated. Then, by some special methods, the metal at the apex of the tip was removed, so that a tiny aperture was formed.

Another way to sharpen an optical fiber is using chemical etching (Takuya et al. 1996). The metal layer at the apex of the tip is removed by special lithography process. The photoresist is exposed by the evanescent wave generated over the prism surface into which light from a He-Cd laser is incident at the total reflection angle. The diameter of the aperture can be about 30 nm, if the exposing process were well controlled.

Another way to make a tiny aperture is adopting the FIB milling (Focused Ion Beam) technique. A focused ion beam is raster scanned to remove the metal film and form an aperture at the end of the tip. This process takes 2~3 minutes for each tip. Typically, the opening hole has a diameter of smaller than 100 nm (Saeed et al. 1999).

The methods above are not suitable to batch production. An example of tiny aperture made by silicon micromachining process that is batch producible was realized (PHAN et al. 1999). In which a SiO2 layer was thermally grown on the pyramidal etch pit and then released to be used as the structure of the tip. Due to the locally compressive intrinsic stress, the oxide layer at the bottom of the pyramidal pit is relatively thinner than the other part of the oxide layer, and will be etched through in the etching steps, left a tiny hole. The diameter of the hole can be controlled by the etching time, and can be 100 nm or smaller. These etching and oxidation are all batch processes, which make the mass production of small apertures possible.

Controlling the gap between the media disk and the pickup head becomes critical while adopting the near-field optics. If the gap is too large, the data density will go down seriously. As the gap distance decreases, the control becomes more and more difficult and drags down the data transfer speed. A solution to control the gap is using the air-bearing effect between the pickup head and the running surface of the media disk. An aperture has 4 pieces of sliders to produce air-bearing effect (F. Issiki et al. 2000) can achieve a gap of about 100 nm. A high data transfer rate of 1.5 Mbit/s is realized, two order faster than any existing SNOM systems that use sharpened fiber probes without air-bearing gap control.

The approaches discussed above are all tend to make an aperture by removing metal. Here, a novel approach is proposed to make metallic tiny aperture—electroplating. This approach don't remove metal but add metal material, to shrink a hole defined by standard lithography processes to a smaller size, which means, a hole of the size beyond the resolution limit of the lithography process. The hole can be used as an aperture to limit the laser light to the data pit on the surface of the media disk. The backside of the plated metal film can be used as a slider to control the gap by the air bearing effect. Electroplating process is easy, low-cost, and relate safe to operate, furthermore, it is suitable to batch production.

三、研究方法

To use an aperture to realize the near-field optical data storage, the media light can be guided by an optical fiber, and limited by a tiny aperture to a data pit on the disk. The aperture is on the pickup head, which is attached to a swinging positioning arm. The arm moves the head and positions the aperture to the data track on the disk. The tiny aperture is the key point of the pickup head. The way we make an optical aperture here is to use the selective plating property of the electroplating technique: an un-conductive spot on the conductive surface will result to a hole on the plated metal film. The un-conductive spot defined by standard lithography process can't excess the limit of the light. So we apply some over-plating in the electroplating process, to get a hole smaller than the spot defined by the lithography process (Fig. 1). The typical spot size in the lithography is about 1 μm in diameter. By the overplating technique, an aperture diameter bellow 0.3 μm or smaller is expected. The surface under the aperture plate is supposed to be flat and can be used as a slider.

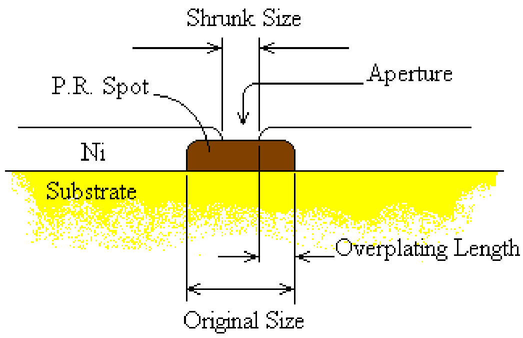

Fig. 1 Make an aperture by electro overplating

There are three types of patterns designed for the fabrication of the aperture plate. All the three types are put together on one mask alternately to make a multi purpose mask, saving the cost of the masks. The size of the aperture plate is 2000 um x 1000 um. The aperture is positioned on the upper middle of the plate. 10 P.R. spots in different sizes are defined, diameters range from 1 to 10 um, with a difference of 1 um. The different sizes of the spots ensure that there will be at least one spot useful under the errors of the fabrication processes, including mask generating, lithography, and the electroplating. There is no releasing hole on pattern type "A", this type is only suitable to fabrication process with backside etching. Releasing holes are added on the pattern type "B". The releasing holes are 10 um x 10 um in size, and space 50 um to each other. This type is suitable to front-side etching process. The releasing holes are replaced by groups of holes on pattern type "C". Every group contains spot sizes range from 1 um to 10 um, 10 spots for every size, total 100 spots for each group, and every group spaces 50 um to others. These spot groups can be used as releasing holes and testing patterns for the over-plating process simultaneously. A sputtered copper layer is used as the electroplating seed layer and the sacrificial layer. The substrate is a silicon wafer, which provides a flat surface for the lithography process. First, the surface of the silicon wafer is cleaned and covered by a layer of P.R. by spin-coating process as a separating layer. Then the copper seed layer is sputtered onto the surface of the P.R. layer. Above the seed layer, the second P.R. layer is spun on and patterned by using photolithography process. After that, the electroplating of the Nickel layer follows. When the electroplating process is finished, immerge the whole wafer into the ACE solvent to solve the P.R. layers away, and the Nickel layer with the copper seed layer will peer off from the silicon wafer. The seed layer is then etched away by wet etching. The etchant is a solution of ammonia water with a little H_2O_2. The etching time is about 40 seconds, and the copper layer will disappear throughout, leaving the wanted nickel layer with the apertures. This approach eliminates backside etching of the silicon wafer, and the silicon wafer can be recycled, reducing the cost. The thickness of the sputtered copper layer is very thin. So, as being a sacrificial seed layer, the etching time can be reduced, and minimize the damage to the electroplated Nickel layer due to the etchant. The type of the photoresist used is FH6400. It is spin coated on to the wafer. The spinning speed is 4000 rpm. Spin time is 25 seconds. While the coating finished, 1 minute of soft bake at 90 ℃ is applied. The separating layer is hard baked for 10 minutes at 120 ℃ after the soft bake, to make it stronger, prevent the damage of the following sputtering process. The second layer of photoresist, which is for the patterning, is coated following the sputtered copper seed layer. The exposing time is 20 seconds. The developing time is 20 seconds, too. Then another 20 seconds of gentle rinse in water is applied. The smallest photoresist spot survived is about 0.5 um in diameter. The sputtering is proceeded in constant power mode. The power is controlled at 150 watt. If the power is too strong, the separating layer of P.R. will be damaged and broken. The sputtering time is 10 minutes, results a copper layer of about 1000 angstrom.

A conventional low-stress nickel electroplating solution is used in the electroplating process. The container is a 5-liter cup. The quantity of the solution is 4 liter. The positive electrode is a Ni metal board special made for electroplating usage, and is contained in a cotton bag. The positive electrode and the wafer (negative electrode) are both vertically put into the cup. A hotplate and a PID temperature controller with a thermal couple are used to heat up and maintain the temperature of the solution. Both the electrodes are connected to the power supply by clip wires. An air-stirring device is applied to remove the generated bubbles generated on the surface of the wafer quickly and evenly. The electroplating current is controlled at 0.1 Amp, and the electroplated area is about 60 mm x 60 mm. The current density is about 0.3 Amp/dm^2. Since the current is controlled at 0.1 Amp, the voltage is about 0.6 ~ 0.8 volt normally. The temperature of the solution should be controlled at 50° C, and the thickness of the plated nickel layer is mainly controlled by the electroplating time.

四、結果與討論

An experiment is taken to observe the shrinking speed of the aperture throughout the shrinkage in the overplating process. There are P.R. spots of different sizes on the same die. Under the same electroplating time, these apertures will be on different extent of shrinkage, so that the variation of the shrinking speed along the shrinkage can be observed indirectly.

Three samples on the same wafer are measured to observe the relation between the overplating length and the P.R. spot size. The measurements are taken on the SEM photos. Sample 1 is taken from the edge of the electroplating area. Sample 2 is taken from the center of the area. And sample 3 is on the middle of sample 1 and 2. The electroplating time is 60 minutes, current density is 3.0 Amp/dm^2.

The measured parameters are the size of the P.R. spot and the shrunk size of the aperture. Then the overplating length is calculated. The curves in Fig.2 show that the overplating length gets longer if the P.R. spot size is smaller. Suppose the overplating phenomenon begins at the same time on all the apertures on the same sample, this result implies that the shrinking speed is gradually increasing throughout the overplating process. This means that the smaller the aperture is, the more difficult to control it's size. However, the experiment did not touch to the aperture size bellow 0.3 um, the shrinking behavior is still unknown in that region.

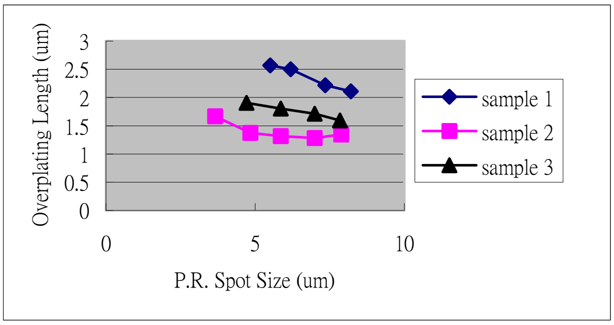

Fig. 2 Overplating length V.S. original pattern size

Since the overplating phenomenon is used as the method to shrink the apertures, the uniformity of overplating length draws more attention than that of the plated thickness. An experiment is taken to observe the uniformity of overplating length. The sample is electroplated for 2 hours at 0.1 Amp, equals to about 0.3 amp/dm^2 of current density.

The light coming through the aperture is shown in Fig.3. The SEM image of the samllest aperture is shown in Fig.4. The P.R. spot size is about 3.8 um, the diameter of the aperture is 0.165 um, directly measured from the SEM image.

The SEM shows only the opening region of the aperture. The aperture is so deep that the SEM can't see the inner region. So that the apertures can't be proved whether it is open through or not in the SEM photos. Light eliminates through the aperture proves that the aperture is open, but if the diameter is smaller than the wavelength of the light, the light beam will diffract and be too weak for the optical microscope to detect. For these reasons, a set of special equipments including powerful laser and highly sensitive photo detector will be much useful to exam the sub-micro apertures.

Fig. 2 Light coming through the apertures

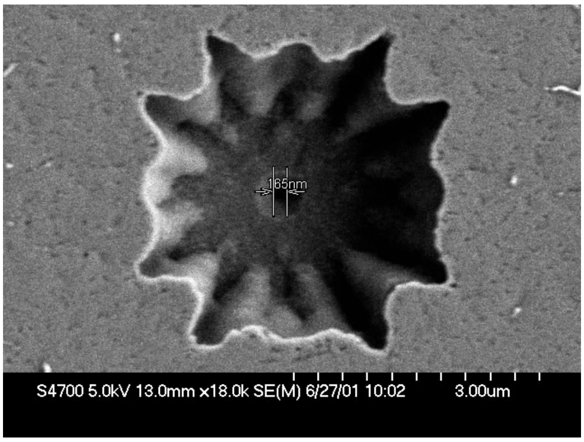

Fig. 3 A shrunk aperture observed, P.R. spot size = 3.8 um, Shrunk size = 165 nm

If an aperture shrunk from a smaller P.R. spot can remain open through, it will have the potential to achieve a smaller size because of easier diffusion for the electroplating solution to the deep bottom of the shrinking aperture. But the thickness of the electroplated nickel film should be enough to prevent the damages due to the surface tension of the etchant. Because of the thickness, the smaller P.R. spots (0.5 ~ 2 um) are always fully covered, and the apertures remain open are all shrunk from larger P.R. spots (< 3um). This makes the achievement of a smaller aperture difficult. To reduce the nickel film thickness, some means should be taken to reinforce the nickel film before releasing it off from the wafer. For example: reducing the die area to make the nickel film more survivable, or plate a second nickel layer, which is much thicker than the aperture layer, provides better structural strength.

五、 參考文獻

1. F. Issiki, K. Ito, K. Etoh, and S. Hosaka, "1.5-Mbit/s direct readout of line-and-space patterns using a scanning near-field optical microscopy probe slider with air-bearing control," Applied Physics Letters, Vol. 76, No. 7, 14 February 2000, pp.804-806.
2. PHAN Ngoc Minh, Takahito ONO, and Masayoshi ESASHI, "A novel fabrication method of the tiny aperture tip on silicon cantilever for near field scanning optical microscopy," Micro Electro Mechanical Systems, 1999. Twelfth IEEE International Conference on 1999, pp. 360-365.
3. Saeed Pilevar, Klaus Edinger, Walid Atia, Igor Smolynianov, Christopher Davis, "Near-field scanning optical microscopy probe fabrication using focused ion beam milling technique," Lasers and Electro-Optics, 1999. CLEO '99. Summaries of Papers Presented at the Conference on , 1999, pp.68-69.
4. Takuya Matsumoto and Motoichi Ohtsu, "Fabrication of a fiber probe with a nanometric protrusion for near-field optical microscopy by a novel technique of three-dimensional nanophotolithography," Journal of Lightwave Technology, Vol. 14, No.10, October 1996, pp.2224-2230.
5. 蔡定平, "近場光碟機最近的發展," 科儀新知, Vol. 19, No. 4, February 1998, pp.28-37.
6. 林盈熙, "奈米級之資料儲存技術," 第二屆奈米工程既系統技術研討會, pp.2-31~2-39.