RIKEN Review No. 43 (January, 2002): *Focused on* 2nd International Symposium on Laser Precision Microfabrication (LPM2001)

An overview of laser microprocessing in data storage industry

Tow-Chong Chong and Yong-Feng Lu

Data Storage Institute, 5 Engineering Drive 1, National University of Singapore, Singapore

Laser technologies have been applied to material processing for data storage industry in a number of areas: laser cleaning of magnetic heads, laser cleaning of magnetic media, laser microtexturing of magnetic media, laser microbumping and disk tagging, laser-induced periodic structures and laser nano-etching and nanolithography by tip-enhanced laser irradiation.

Introduction

In data storage industry, head flying height has been continually reduced to increase the recording density. There are many engineering issues associated with this requirement. Laser microprocessing technologies have been widely used to address these issues to achieve high recording density and better reliability. For example, laser surface cleaning has been used to remove microparticles and microcontaminations from magnetic media and magnetic head sliders which has the potential to achieve better cleaning efficiency than those conventional cleaning methods. Laser surface processing can also be used to improve the tribology performance at the head-media interface. Lasers can be used to create microtextures at the landing zone of the magnetic disks to avoid microstiction and microfriction with minimum wearing issues. Meanwhile, the similar technique can be used to create microbumps on media surface as calibration reference for glider test. Microbumps can also be used as contamination-free laser tagging which provides better traceability and indentification of single-side disks. With the requirement of even higher recording density, laser processing has been developed to address engineering issues within nanometer order. Lasers, in combination of scanning probe microscopes (SPM), have demonstrated to be capable for nanoprocessing and nanolithography.

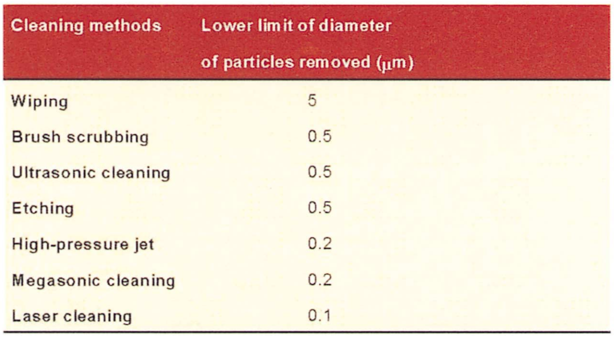
Technical details

Laser surface cleaning

As micro-device fabrication technology advances toward higher densities and smaller dimensions, contamination control becomes one of the most critical problems in the industry.$^{1,2)}$ In disk drive industry, head flying height has been continually reduced to increase the recording density. This implies that tiny particles on the slider or disk surfaces can damage both the slider and disk surfaces and hence lead to the failure of the disk drive system. Consequently, there have been significant efforts to develop effective techniques to remove surface contaminants,$^{1,2)}$ such as high-pressure jet; mechanical wiping and scrubbing; etching and ultrasonic cleaning. Some of them such as ultrasonic cleaning require the immersion of a sample into a liquid bath, which has a number of serious drawbacks. Firstly, it is widely known that the wet techniques could add contaminants due to insufficient cleaning and filtering of the liquid at the submicron level. Secondly, the usage of hazardous chemicals and solvents becomes undesirable for environmental and industrial reasons such as causing cancers in humans and depleting ozone layer. Other problems associated with the wet techniques are rinsing/drying difficulties and incompatibility with other processes. Hence, dry cleaning techniques have emerged in order to overcome these drawbacks.

Recently, laser cleaning was demonstrated to be an efficient cleaning method for removal of particulate and organic film contamination from solid surfaces.$^{3-20)}$ Two types of laser cleaning have been reported, relying on pulsed-laser heating of the solid surfaces without or with the presence of a thin liquid coating. We shall refer to these two types as dry laser cleaning and steam laser cleaning, respectively. For dry laser cleaning, particles can be ejected from particulate-contaminated surfaces by short-pulse laser irradiation. The proposed mechanism of the ejection is fast thermal expansion of the particle and/or solid surfaces, which induces large cleaning force to overcome the adhesion force between particles and solid surfaces.$^{16-20)}$ Another mechanism is laser ablation of particles as particulate materials have small ablation threshold than that of the solid surfaces.$^{9)}$ The laser cleaning of organic film contaminants is considered due to laser photo-ablation and thermal-ablation of the contaminants.$^{7)}$ For steam laser cleaning, the proposed mechanism is assumed to be the momentum transfer from the laser-heated and suddenly evaporating liquid film to the particles on the solid surfaces.$^{3-5)}$ Compared with wet cleaning, it has several advantages such as dry process without using organic solvents, area-selective cleaning and cleaning samples on line.

Since the new process is chemical free and noise free, it is therefore environmentally friendly. It is also cost effective since there is no consumables and no need to treat the used chemicals in conventional cleaning processes. As shown in Fig. 1, laser cleaning can also remove a wide spectrum of contaminants, including those unable to be cleaned in conventional cleaning systems (such as embedded particles and thick organic films). This technology is also area selective, flexible to various kinds of substrates and applicable to on-line processing. This technology has been studies thoroughly and systematically, usually with an experimental setup as shown in Fig. 2. A complete set of theoretical model including laser steam cleaning has been developed based on experimental results, as shown in Figs. 3 and 4. The model fits the



Cleaning methods	Lower limit of diameter of particles removed (μm)
Wiping	5
Brush scrubbing	0.5
Ultrasonic cleaning	0.5
Etching	0.5
High-pressure jet	0.2
Megasonic cleaning	0.2
Laser cleaning	0.1

Fig. 1. Laser cleaning: Removal of microparticles.

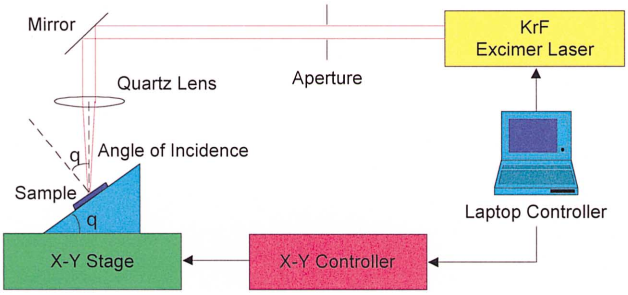


Fig. 2. Laser cleaning: Experimental setup.

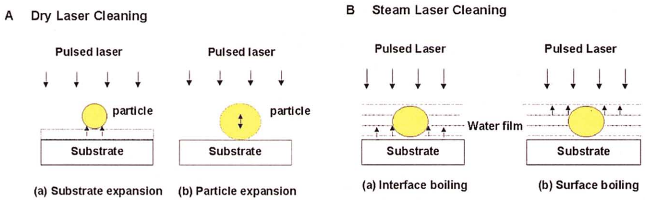


Fig. 3. Mechanisms of laser cleaning to remove particles.

experimental results well and has been successfully used to predict some new cleaning results in complex chemical and physical environments. Laser cleaning technology has been applied to clean magnetic media (Figs. 5 and 6), magnetic sliders (Fig. 7) and suspension of HGA (head gimble assembly) (Fig. 8).

Recently, A new cleaning technology combining laser and plasma sources is being developed. Through combining plasma activation of substrate surface and laser cleaning technologies, ultrahigh cleaning efficiency can be obtained. This will initiate a new advanced laser cleaning technology. The results are essentially beneficial to the hard disk industries. The development of the magnetic storage density and semiconductor miniaturization requires ultra-clean media and semiconductor surfaces. Any small contaminant residing on the surface will possibly cause failure to the device. The research results of this project fit the needs of data storage industries. The improvement of the research level of surface cleaning can strengthen the support to the cleanliness requirements in data storage industry.

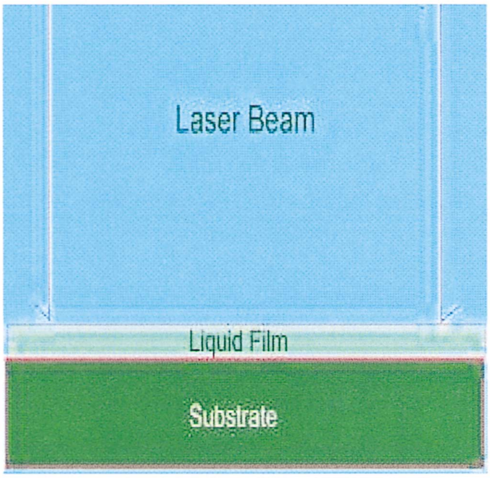


Fig. 4. Steam laser cleaning.

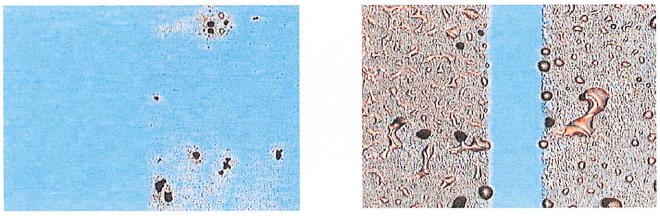


Fig. 5. Laser cleaning of dry and wet surfaces after mechanical texturing.

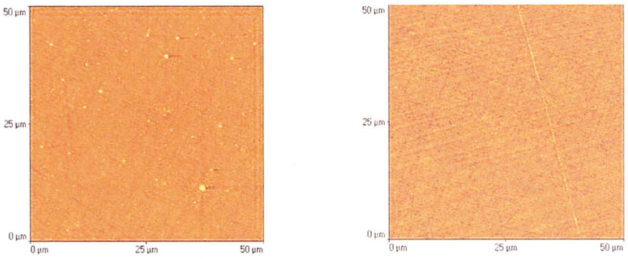
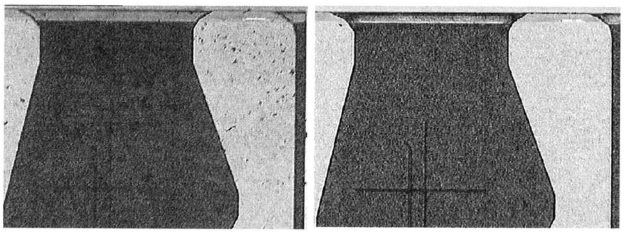


Fig. 6. Laser cleaning: Submicron particles.

Laser texturing, laser bumping and related technologies

Laser texture$^{21)}$ is another typical application of laser microprocessing technology in data storage industry. Laser texturing can provide controlled roughening of the media sur-



Before laser cleaning After laser cleaning

Fig. 7. Laser cleaning: Slider cleaning.

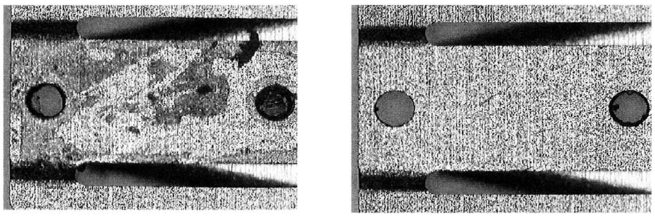


Fig. 8. Laser cleaning: HGA suspension.

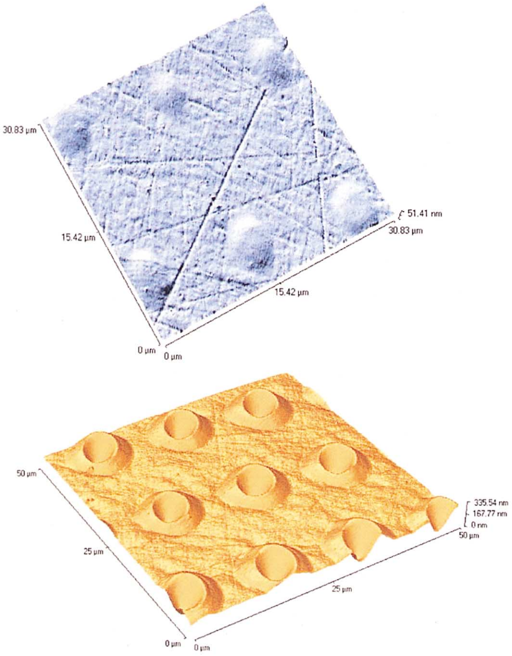


Fig. 9. Laser texturing.

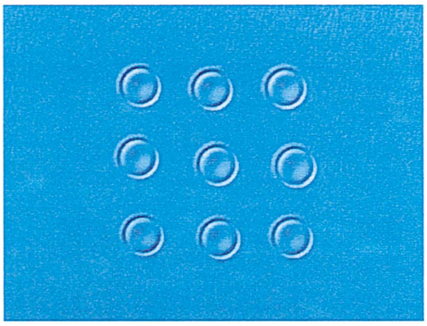


Fig. 10. Laser bumping.

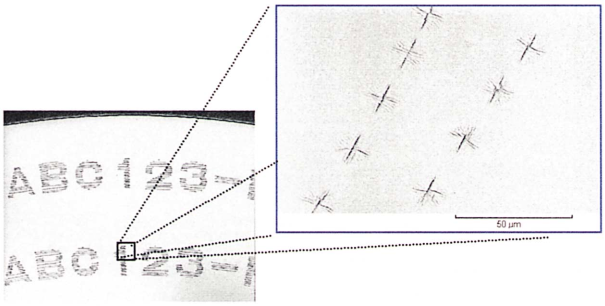


Fig. 11. Laser disk tagging: Marking formation.

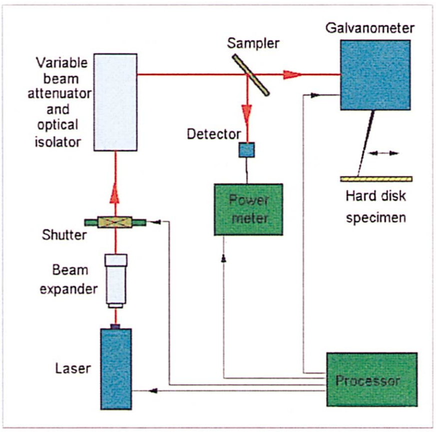


Fig. 12. Laser disk tagging: System configuration.

faces in landing zone and data zone of the disk surfaces to achieve better tribology performance. High frequency lasers are used to create micro-bumps on the media surfaces with a bump height from a few nanometers to a few ten nanometers (Fig. 9). The well-controlled surface roughness can significantly reduce the microfriction, microstiction and wearing. Similar to laser texturing, laser bumping can create bumps with high-accuracy bump heights. These bumps can be used as reference height in glider test (Fig. 10). In the case of disk tagging, as shown in Figs. 11 and 12, a new technology is developed for the first time with advantages over conventional laser tagging. Since current magnetic disk manufacturing does not have disk-identification, little traceability is available when failures happen at media or drive levels. Laser marking is usually used for the traceability of product and is necessary in modern mass production. However, conventional laser marking technique employs laser to ablate the product surface to form visual contrast. Due to the stringent cleanness requirement and multilayered structure of finished disk, conventional laser marking is no longer feasible for magnetic media. In this study, Laser beams are precisely controlled with TEM_{00} mode to induce deformation of NiP layer on multilayered disk surface. The research results showed that the coupling of excellent beam symmetry and multilayered structure resulted in only surface deformation to form visual contrast. The process is ablation-free and cleanness is ensured. The developed disk tagging machine in Fig. 13 is fully automatic and meets the requirement of mass production.

Real-time monitoring of laser surface processing

In situ monitoring and controlling of laser surface modification is focusing directly on industrial application. Up to now, all the laser surface modification including surface cleaning and texture can be *in situ* monitored and controlled through acoustic signal, electrical signal and optical spectrum detectors and feedback to the laser sources, as shown in Fig. 14. Hardware and software of this technology have been fully developed. This technology is very important to the commercialization of laser microprocessing technologies. It can remarkably improve the accuracy and efficiency of laser sur-

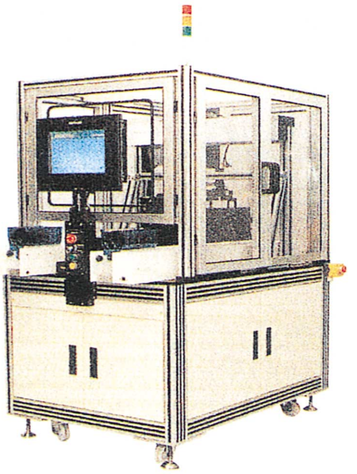


Fig. 13. Laser tagging machine.

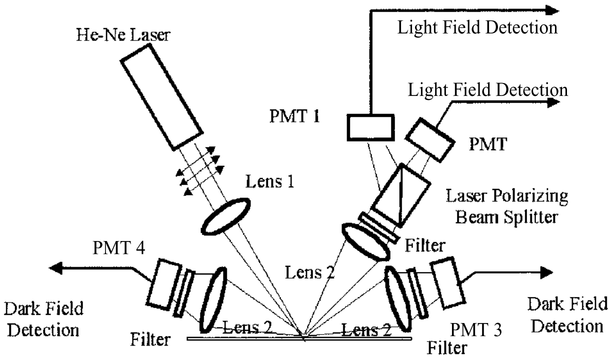


Fig. 14. Real-time monitoring of laser surface processing.

face processing and hence can cut cost in manufacture and save time. Based on the fully developed *in situ* monitoring and controlling technology, the research results of this new project can be expected to put into application easily and fast.

Laser-induced controllable periodic structures

Recently, a new texturing method, laser rippling,$^{22)}$ through formation of ripple structures on processed surface by laser irradiation has been developed, as shown in Fig. 15. The most obvious example is its prospective application in laser microtexturing, which requires microtextures with micro-order lateral periodicity and nanometer-order vertical roughness.

Laser nanopatterning and nanolithography by tip-enhanced laser irradiation

In the aspect of laser patterning, researchers have approached nano-scale by combining laser processing and scanning probe microscope (SPM) technology,$^{23,24)}$ as shown in Fig. 16. The width of the etching lines can reach as small as 30 nm. The SPM tips under the irradiation of a laser beam can induce a very strong electromagnetic field around the top in the scale of ten nanometer. The strong near field effect can produce etching patterns on various kinds of substrates with resolution much smaller than 100 nm. This method may provide potential solution for high-density recording such as making patterned media.

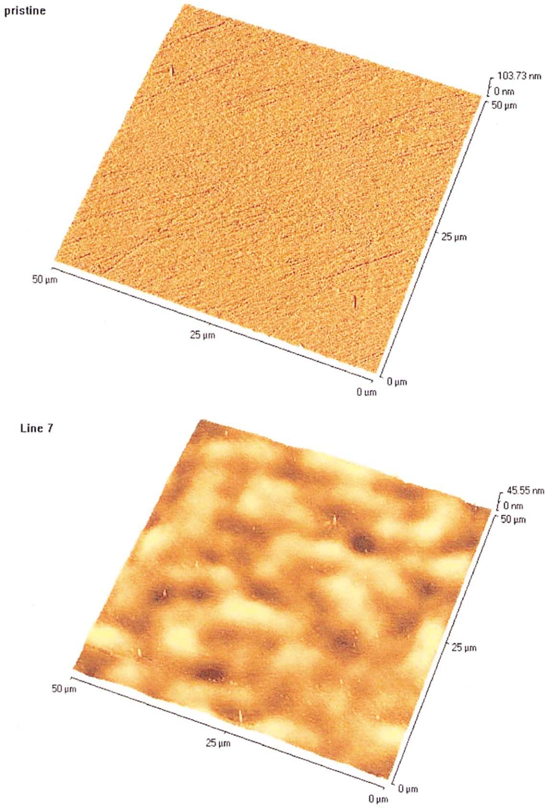


Fig. 15. Laser rippling.

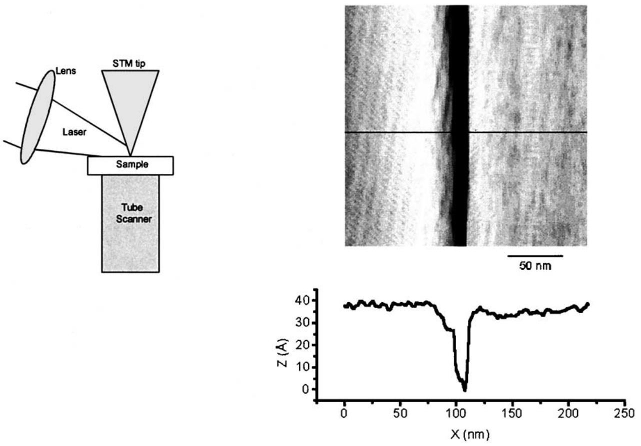


Fig. 16. Laser-SPM nanoprocessing.

Conclusions

In summary, laser microprocessing technology has been successfully applied in data storage industry in the field of laser cleaning, laser texturing, laser bumping, laser tagging, and laser rippling. Real-time monitoring of laser surface processing has been investigated to improve the performance of laser microprocessing technology. Laser nano-etching and nanolithography have been realized by AFM tip-enhanced laser irradiation through combination of laser microprocessing and SPM techniques. Therefore, laser microprocessing is an attractive processing options for future data storage applications.

The authors would like express their thanks to all staff and students of the ECE/DSI Microprocessing lab., who have participated the research effort in these areas, for their great effort and significant contribution.

References

1) K. L. Mittal: in *Particles on Surfaces*, Vol. 1 (Plenum Press, New York, 1988), p. 3.
2) K. L. Mittal: in *Particles on Surfaces* (Marcel Dekker, New York, 1995), p. 1, 405.
3) W. Zapka, W. Ziemlich, and A. C. Tam: Appl. Phys. Lett. **58**, 2217 (1991).
4) K. Imen, S. J. Lee, and S. D. Allen: Appl. Phys. Lett. **58**, 203 (1991).
5) A. C. Tam, W. P. Leung, W. Zapka, and W. Ziemlich: J. Appl. Phys. **71**, 3515 (1992).
6) J. D. Kelley and F. E. Hovis: Microelectron. Eng. **20**, 159 (1993).
7) Y. F. Lu, M. Takai, S. Komuro, T. Shiokawa, and Y. Aoyagi: Appl. Phys. A **59**, 281 (1994).
8) H. K. Park, C. P. Grigoropoulos, W. P. Leung, and A. C. Tam: IEEE Trans. Comp. Packaging, Manuf. Technol. A **17**, 631 (1994).
9) Y. F. Lu, W. D. Song, M. H. Hong, B. S. Teo, T. C. Chong, and T. S. Low: J. Appl. Phys. **80**, 499 (1996).
10) K. Mann, B. Wolff-Rottke, and F. Muller: Appl. Surf. Sci. **98**, 463 (1996).
11) R. Oltra, O. Yavas, F. Cruz, J. P. Boquillon, and C. Sartori: Appl. Surf. Sci. **98**, 484 (1996).
12) D. A. Wesner, M. Mertin, F. Lupp, and E. W. Kreutz: Appl. Surf. Sci. **98**, 479 (1996).
13) M. Afif, J. P. Girardeau-Montaut, C. Tomas, M. Romamd, M. Charbonnier, N. S. Prakash, A. Perez, G. Marest, and J. M. Frigerio: Appl. Surf. Sci. **98**, 469 (1996).
14) I. Gobernado-Mitre, J. Medina, B. Calvo, A. C. Prieto, L. A. Leal, B. Perez, F. Marcos, and A. M. de Frutos: Appl. Surf. Sci. **98**, 474 (1996).
15) J. B. Heroux, S. Boughaba, I. Ressejac, E. Sacher, and M. Meunier: J. Appl. Phys. **79**, 2857 (1996).
16) W. D. Song, Y. F. Lu, K. D. Ye, C. K. Tee, M. H. Hong, D. M. Liu, and T. S. Low: Proc. SPIE **3184**, 158 (1997).
17) Y. F. Lu, W. D. Song, B. W. Ang, M. H. Hong, D. S. H. Chan, and T. S. Low: Appl. Phys. A**65**, 9 (1997).
18) Y. F. Lu, W. D. Song, K. D. Ye, Y. P. Lee, D. S. H. Chan, and T. S. Low: Jpn. J. Appl. Phys. **36**, L1304 (1997).
19) Y. F. Lu, W. D. Song, K. D. Ye, M. H. Hong, D. M. Liu, D. S. H. Chan, and T. S. Low: Appl. Surf. Sci. **120**, 317 (1997).
20) Y. F. Lu, W. D. Song, C. K. Tee, D. S. H. Chan, and T. S. Low: Jpn. J. Appl. Phys. 840 (1998).
21) D. M. Liu, Y. F. Lu, Y. Yuan, W. J. Wang, T. S. Low, T. S. Wee, K. T. Chang, and R. J. K. Goh: Appl. Surf. Sci. **139**, 482 (1999).
22) Y. F. Lu, J. J. Yu, and W. K. Choi: Appl. Phys. Lett. **71**, 3439 (1997).
23) Y. F. Lu, Z. H. Mai, G. Qiu, and W. K. Chim: Appl. Phys. Lett. **75**, 2359 (1999).
24) Y. F. Lu, Z. H. Mai, Y. W. Zheng, W. D. Song, and W. K. Chim: Appl. Phys. Lett. **76**, 1200 (2000).