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# Precision manufacture of optical disc master stampers

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This paper details a new manufacturing process for compact disc master stamper production. Stamper is an optical disc industry term for the mold used to replicate polymer compact discs (CDs) in an injection molding device. The stamper surface contains a negative image of the CDs more than 1 billion, submicrometer features embossed in a spiral pattern on a 138-mm diameter substrate. In conventional mastering, nickel submaster stampers are generated by electroforming from a glass master. In the proposed process, submaster stampers are not required, and a ceramic master is used directly as a stamper for injection molding. In the new process, ceramic substrates are ion machined through a photoresist mask, resulting in improved productivity, reduced hazardous waste, and lower production costs. All critical process steps have proved feasible in the research reported here. The new stamper production technique replaces the conventional glass master substrate with a tough ceramic and replaces several difficult electrochemical and manual operations with a single precision ion machining step. Processes that precede and follow stamper fabrication remain largely unchanged. In the new process, precision stamper manufacturing (PSM), more than 200 minutes of chemical processing, electroforming, back-polishing, punching, and handling are replaced by fewer than 20 minutes of automatically controlled ion machining. At the same time, PSM eliminates nearly all process steps that produce toxic and hazardous wastes. The process is suitable for production of CD-audio, CD-ROM, and high-density DVD formats. A process flow diagram and a series of proof-of-concept experiments are described. © Elsevier Science Inc., 1997

## Introduction

Optical data storage is currently a $10-billion dollar business per year.[1] Worldwide sales of optical data products as a whole are growing at rate of more than 10% per year, and sales of such products as optical disc drives and CD-ROM discs are growing at more than 30% per year. In North America, more than one billion compact discs (CDs) were sold in 1996. In 1997, the number of CD-audio and CD-ROM discs produced for the North American market will grow to 1.6 billion. This paper outlines a process that could significantly improve stamper manufacturing productivity.

Compact discs are made by injection molding of polycarbonate in a cavity formed between a mirror block and a submaster stamper. A stamper has a spiral pattern of ~1 billion bumps measuring 0.6-μm wide, 0.8 to 3.1-μm long, and 150-nm tall encoded on its surface. Typically, stampers are 138-mm in diameter and 0.3-mm thick, with a 20–40-mm central hole. To manufacture a stamper, a layer of photoresist on a glass substrate is first patterned using a laser beam recorder (LBR) system. After development, the photoresist

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layer contains a unique spiral pattern of elongated holes corresponding to the digitally encoded data that is to be reproduced. A thick electroformed layer of nickel is grown on top of the photoresist to form a stamper. After peeling it from the glass and photoresist, this nickel stamper can be used in an injection molding system to replicate polymer discs. The number of discs molded with each stamper is usually determined by the customer's order for replicas and not by the maximum possible stamper life. The average order is 3000 replicas/stamper. In 1997, the North American market will require more than 500,000 stampers, with an average sales price of $400–$800 per stamper. Presently, a stand-alone mastering process line costs more than $2.5 million, and has a peak yield of approximately 15 stampers per day.

Although the CD market is flourishing, CD manufacturing processes have seen little improvement since the product was first introduced more than a decade ago. Today, the industry faces intense demand for increased production speed, reduced toxic waste generation, and increased yield.

The new process described in this paper replaces several difficult and failure prone process steps with a radically improved, simpler alternative. Specifically, the process of electroforming to generate a submaster stamper and the subsequent manual processes of peeling, varnishing, back-polishing, and punching are replaced by a single, automated process: neutral ion machining of CD features directly onto a ceramic master stamper. Ion machining, an emerging precision manufacturing technology, is inherently suited to nanometer-scale material removal. In the process described here, ion machining of the ceramic master is performed through a patterned photoresist mask. By eliminating the processes responsible for most of the toxic waste byproducts (e.g., heavy metals, acids, and solvents) generated during stamper manufacturing, the new process is cleaner. Also, the processing time for fabricating a master stamper is cut in half. As a final benefit, the process eliminates the manual handling required in conventional stamper manufacturing. Substantial increases in the process yield are expected. By industry standards these new steps represent a revolutionary change in optical disc mastering technology.

## Conventional stamper manufacturing

Major steps in the conventional process for fabricating optical disc stampers are illustrated in *Figure 1*.[2] A flat, polished glass substrate disk is cleaned and then coated with a thin layer of positive-tone

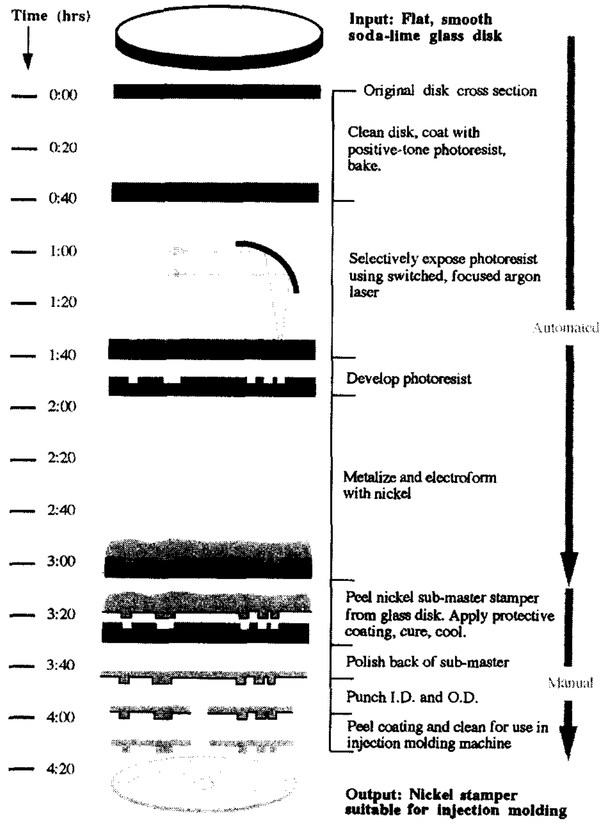



**Figure 1** Conventional stamper manufacturing process steps

photoresist. Next begins the recording process. A focused laser beam traces a spiral path on the disk surface. A control computer containing the digital information to be recorded on the disk switches the beam on and off according to a streaming binary signal. After recording, the photoresist is developed, leaving elongated pits where it was exposed to laser irradiation. The patterned photoresist is coated with a thin layer of nickel or silver by sputtering or chemical immersion to make the surface conductive for subsequent electroforming. In electroforming, a thick film of nickel is grown on the substrate. This nickel *submaster stamper* is then peeled away from the substrate and cleaned. A protective varnish coating is temporarily deposited onto the stamper surface and cured. The stamper back side is polished, and the inner and outer diameters are punched on a press. The varnish is then removed from the stamper, which is now ready to be used in an injection molding machine to generate thousands of polycarbonate CD replicas. The total manufacturing time for a single CD submaster stamper is a little more than 4 hours. The overall process yield for master stamper production is typically about 80%.

Toxic waste byproducts of metalization and electroforming include, for each stamper generated, more than 3 liters of *treatable* chemical waste containing about 250 ml each of silane, palladium chloride, tannine, and stannous chloride in aqueous solutions. Chemical wastes that must be contained and treated as *hazardous* include another 3 liters of aqueous solutions containing about 250 ml each of nickel and silver nitrate. Exhaust gases from metalization and electroforming also contain hazardous vapors that require treatment, including methyl-ether-ketone (MEK), toluol, ammonia, nickel, and boric acid. In processes following electroforming, further solvent wastes are generated.

In addition to waste generation and yield problems, the electroforming process fundamentally limits the speed at which CD stampers can be fabricated. Growth of the nickel, for example, is already performed at the maximum rate that will allow acceptable metallurgical properties in the stamper. In the first few minutes of electroforming, all of the detail and fine structure encoded on the glass and photoresist master disc are replicated in the nickel. Subsequent growth increases stamper thickness to allow sufficient structural rigidity for stamper use in a mold. Slow procedures and sensitive processing chemistry make electroforming a troublesome, though universally used, step in CD stamper manufacturing. Batch electroforming of multiple stampers has been used in the past to increase overall manufacturing speed. However, recent industry demand for turnaround of individual stamper orders in 24 hours or less makes in-line processing a more competitive strategy. Most new CD stamper fabrication systems use in-line manufacturing, for which recording and electroforming are the principal bottlenecks. In recent years, double and triple speed recording systems have been developed, but no parallel productivity increases have been made in electroforming.

A revision of the CD manufacturing process that replaces the latter half of the processing steps with direct ion machining of the master disc could dramatically improve the process economy, speed, and yield while reducing its environmental impact.

## An alternative technical approach to stamper fabrication

A new manufacturing process for stamper fabrication that uses ion machining to etch CD features directly onto a stamper surface is described below. The new process, precision stamper (PSM), calls for two major changes in the manufacturing process for stampers:

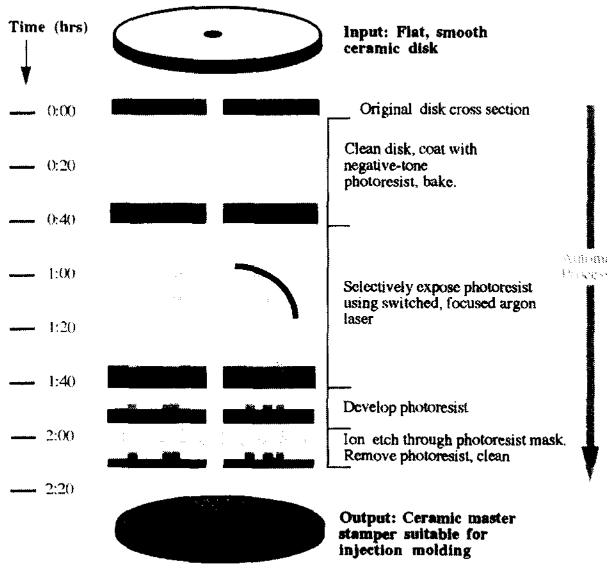



**Figure 2** Schematic of the new process for precision stamper manufacturing (PSM)

1. replacing the glass master disk substrate with a tough ceramic, which is used as the injection molding stamper; and
2. replacing metalization, electroforming, peeling, protecting, polishing, and punching operations with a single ion machining step on the ceramic substrate through a photoresist mask.

All other processes, including cleaning the master disc, spinning on a photoresist layer, laser recording, and photoresist development remain largely unchanged. In PSM, production of a submaster nickel stamper is no longer necessary. The ion-machined ceramic master stamper is used *directly* for polymer injection molding. The proposed manufacturing cycle is illustrated schematically in *Figure 2*. Note that the processing time is reduced by a factor of 2 from the conventional manufacturing process detailed in *Figure 1*. More than 200 minutes of the present manufacturing processes are replaced by 10–20 minutes of ion-machining processes (inclusive of time for part handling, transfer through a vacuum interlock, and cleaning). Capital equipment costs and direct manufacturing costs for PSM are similar to those required for the present process. An additional benefit of the proposed process in comparison with the conventional process is that it eliminates many of the process steps that produce toxic and hazardous wastes.

Ion machining as a precision material removal process has been refined for use in subaperture shaping of glass and ceramic substrates, and for such high-technology applications as fabrica-

**Table 1** Prospective stamper substrate materials and relevant properties

| Substrate | Knoop hardness, ($kg/mm^2$) | Fracture toughness, (MPa $m^{1/2}$) | Thermal shock resistance, (W/m) | Thermal conductivity, (W/m K) | Ion machinability (surface quality) |
|---|---|---|---|---|---|
| Nickel | 100 | ~100 | 7138 | 80 | Poor |
| $Al_2O_3$ | 2100 | 4 | 3225 | 30 | Very good |
| SiC | 2500 | 3 | 19149 | 90 | Excellent |
| Glassy carbon® | 500 | 2 | 135517 | 120 | Excellent |
| Corning 9647® | 450 | 1.3 | 546 | 2.5 | Excellent |

tion of individual three-dimensional (3-D) microstructures, sharpening of scanning probe tips, and imprinting patterns on carbides.[3–6] The process, which is distinct from the more well-known process of *reactive ion etching*, employs a plasma-generating source that ionizes argon gas in an evacuated chamber. While still in the source, ionized atoms (usually argon, but helium and other inert gasses have also been used) are accelerated by a DC electric field through a grid-shaped aperture. As they leave the source at high velocity, the collimated beam of chemically inert ions is electrically neutralized by an oblique beam of electrons emerging from an adjacent source. This neutral plasma is directed toward a target surface, from which it sputters molecules in a finely controlled erosion process. Typical beam current densities used in the PSM process are 1–2 $mA/cm^2$, accelerated by a 1000-volt potential. For many ceramic and glass materials, this results in a sputtering rate of several tens of nanometers per minute. Sources range in diameter from 3 cm to more than 60 cm, and a number of unusual geometries of aperture (and consequently beam shape) have been reported.

Adaptation of ion machining to optical surface contouring was first demonstrated by McNeil et al.[7] The most visible success of this process came with the Keck mirror telescope project.[8] Although it was not part of the original manufacturing proposal for that project, ion machining succeeded where fine polishing had failed as a final contouring process for the Keck's 36 hexagonal optical segments (each measuring more than 1 m across.) More recently, ion machining has been used to fabricate ceramic optical elements for space-based applications.[9–11] The process has not been used previously in an advanced manufacturing application requiring micrometer-sized lateral features on a large surface area. Producing billions of such features with uniform good quality on a single substrate by broad-beam ion machining through a mask is a principal focus of the research reported in this paper.

## Process feasibility experiments for precision stamper manufacturing

Objectives of the experimental research reported here were to verify feasibility of a newly proposed manufacturing method for CD stampers, and to manufacture prototype CD stampers using the new method. The feasibility of all process steps in the new method has been demonstrated. At the same time, several important limitations for each process step have been uncovered and quantified. Each of the processing steps has been combined into a manufacturing cycle through which a full-scale working stamper prototype can be made. These experiments made use of available facilities at two disc-mastering equipment suppliers, an ion-machining equipment supplier, and a national laboratory facility, in addition to facilities at Boston University and Prism Corporation.

## Substrates for ceramic stamper prototypes

Various subprocesses required in PSM have been modeled, the results of which revealed several critical property requirements for stamper substrates. The principal attributes required of a stamper substrate are toughness, thermal shock resistance, ion machinability, thermal conductivity, and hardness. Thermal shock resistance is the product of a material's modulus of rupture or tensile strength and its thermal conductivity, divided by the product of its coefficient of thermal expansion and its modulus of elasticity. Larger numbers imply greater ability to absorb rapid heating or cooling without fracture or yielding. These properties are important for raw substrate fabrication, ion machining, and injection molding. For injection molding in particular, toughness, thermal shock resistance, and thermal conductivity of the stamper are critical. *Table 1*, tabulated from various reference sources,[12,13] shows some of these properties of substrate materials considered in the feasibility research. Also included in the table are properties for the currently used stamper material: electroformed nickel. For PSM, the stamper substrate must exhibit high values of hardness, toughness, and thermal shock resistance. In addition, to maintain compatibility with the thermal cooling systems used on conventional injection molding machines, it would be advantageous to use a material with thermal conductivity similar to that of nickel. Finally, it is important that the stamper substrate is ion machinable: it must erode at a uniform, controllable rate without sustaining an increase in surface roughness. Chemical vapor-deposited silicon carbide (CVD SiC) is the clear choice based on its physical properties. It is exceptionally hard, reasonably tough, and very resistant to thermal shock. Also, it has been demonstrated to be an ideal material for ion machining, and its thermal conductivity is a near match to that of nickel. Chemical vapor-deposited silicon carbide is, however quite expensive, because of both raw material and finishing costs. For that reason, although most of the feasibility research reported here has been conducted on CVD SiC, substrate samples in all of the other materials listed in *Table 1* have been fabricated, and several have been tested as stamper prototypes.

Compact disc stampers are nominally 138-mm in diameter with a 35.4-mm diameter central hole, and 0.3-mm thick. Required finish quality is specular, with roughness lower than 10 nm. Silicon carbide ceramic stamper substrates were designed to meet these specifications, and were further constrained in flatness (± 5 μm), roughness (1.0 nm Ra), and surface damage (none visible with 1000 X optical microscopy). For ceramic stampers, the 0.3-mm thickness is probably insufficient to avoid fracture in injection molding. For these feasibility tests, 0.9 mm was chosen as a thickness specification for stamper substrates. Two CVD SiC substrate samples and one Corning 9647 glass substrate sample were made to these specifications by double-sided lapping and polishing.

## Ion-machining experiments

An ion-machining system was assembled and used in a series of PSM feasibility experiments. A schematic of the system is shown in *Figure 3*. In this system, which uses a 100-mm diameter source with a slightly divergent beam, it is possible to ion machine samples uniformly as large as 140-mm in diameter.

Material classes that can be ion machined without compromising surface quality include amorphous glass and single-phase polycrystalline ceramics. Small test samples of CVD SiC and Corning 9647 glass were machined. Samples were first lapped and polished to remove all subsurface damage and to obtain a specular finish. They were then ion machined using the conditions summarized in *Table 2*, which are typical of those used previously in optical contouring research.[11]

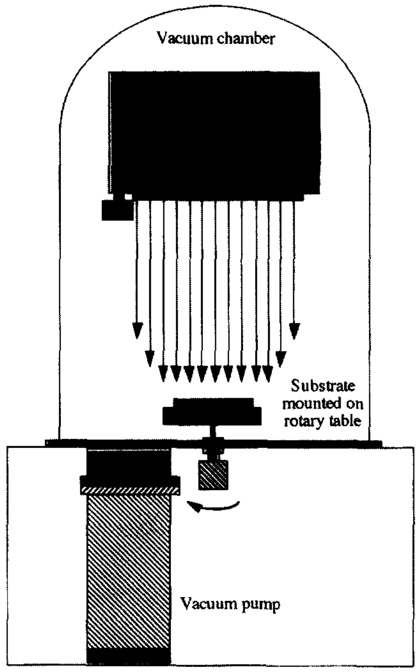



**Figure 3** Schematic of the ion-machining system used in these experiments

A portion of each sample was masked from ion beam exposure to provide an unmachined reference surface. After machining, surface roughness and machining depth were measured for each sample using a stylus profilometer, and all surfaces were examined using optical and scanning electron microscopy (SEM). For both samples tested, no roughening or damage occurred as a result of ion machining.

Surface normal material removal rates, determined by the ion machined step height measured on each sample, are listed in *Table 3*. Also in *Table 3* is the machining time to remove 150 nm from

**Table 2** Process conditions for ion-machining experiments

| Source | 110-mm Diameter |
|---|---|
| Beam voltage | 1000 V |
| Beam current | 300 mA |
| Argon flow rate | 6.5 sccm |
| Base pressure | $<1.2 \times 10^{-5}$ Torr |
| Process pressure | $2.2 \times 10^{-4}$ Torr |

**Table 3** Ion-maching rates for two materials tested and projected machining times for machining to a depth of 150 nm*

| Substrate | Ion-machining rate, nm/min | Required machining time, min |
|---|---|---|
| Corning 9647 | 17.9 | 8.4 |
| CVD SiC | 12.3 | 12.2 |

* Machining conditions listed in *Table 2*

the surface, as would be required in a stamper manufacturing process.

### Laser beam recording on ceramic stamper prototypes

A typical LBR for compact disc encoding uses a focused argon–ion beam, modulated by an opto-acoustic coupler, to selectively expose photoresist on a substrate surface. The beam exiting from the argon laser measures 1.87-mm in diameter, and it passes through optics with a total combined numerical aperture of 0.52. The resulting beam used to write the information onto the master is focused to a spot size of 0.6 μm. The laser focus tracks a spiral on the substrate surface.

A number of experiments were performed on prototype stamper substrates using a commercially available LBR. In the first series of experiments, stamper substrates were coated with thin layers of negative-tone photoresist (JSR-NFR-012R), and then recorded with the LBR. Three different thicknesses of photoresist were tested (200 nm, 680 nm, and 1010 nm), corresponding to three dilutions of the base photoresist compound used. Photoresist coating was achieved using nominally identical conditions on a commercially available photoresist spinner. During 60 minute recording cycles using the LBR on these substrates, digitally encoded signals were used to switch the laser beam as it tracked along a spiral on the spinning and translating substrate. The argon–ion laser power used to record on the substrate was varied by adjusting a neutral density filter in the optical path. Because the optimal beam power for exposure was unknown, beam power was varied from 1.0 mW to 30.0 mW in 0.5 mW steps during the recording cycle. After recording, the photoresist was developed, rinsed, and dried.

With the 200-nm thick photoresist, it was found that the ideal feature geometry (i.e., a feature width of ~0.6 μm) was obtained at an incident power of 15 mW. At a writing speed of 1.2 m/s and a laser spot size of 0.6 μm, this input power corresponds to an exposure dosage of ~2.0 J/cm$^2$. The absorption coefficient of this photoresist was measured and found to be 1.5 cm$^{-1}$ at the argon–ion laser wavelength (458 nm). (Commercially available negative-tone photoresists all exhibit low absorption at 458 nm. Most are optimized for maximum absorption at UV wavelengths from 200–365 nm.) The 200-nm photoresist used in this test, then, transmits 99.993% of the incident beam. As a result, only a small fraction of the incident energy is available for the photochemical reaction needed to transform the photoresist. In addition, the coherent radiation from the argon–ion laser was found to create standing waves (i.e., destructively interfering internal reflections) in the photoresist film, further reducing the absorbed power. The standing wave phenomenon is well known in coherent photolithography and is most detrimental when the film thickness is an odd multiple of a quarter of the incident beam wavelength as it passes through the photoresist. As a result, optimal exposure dosage is a strong, periodic function of photoresist thickness. In a subsequent series of LBR experiments using this combination of laser and photoresist, it was found that found that optimal exposure dosage varied by up an to order of magnitude for this photoresist in response to film thickness changes as little as 70 nm. Therefore, the degree to which photoresist films can be deposited uniformly and to precise thickness tolerances on PSM substrates is critical. Photoresist films were repeatedly deposited on PSM substrates and measured using a standard ellipsometer. It was found that submicrometer-thick films of this photoresist could be repeatably and uniformly deposited to tolerances of ~5 nm using commercial photoresist spinning equipment, in a clean room environment.

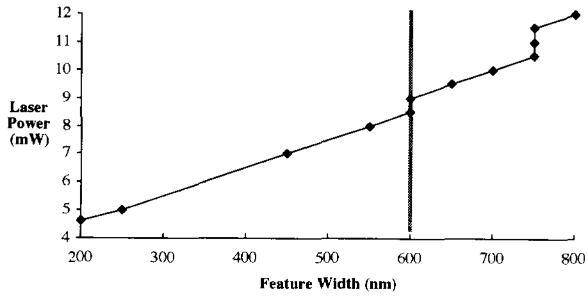
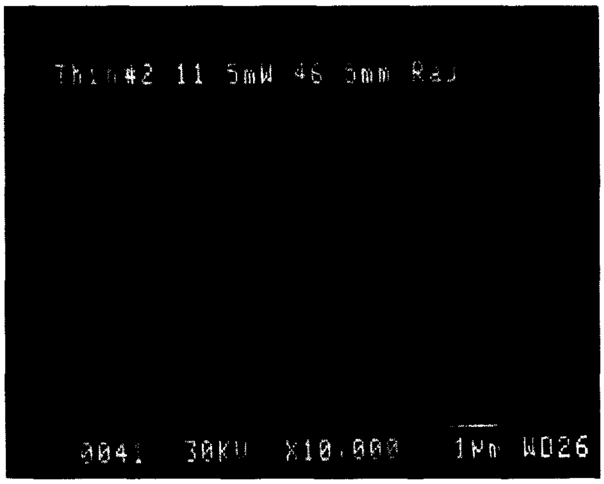



**Figure 4** Feature width in developed photoresist as a function of incident laser power from the laser beam recorder system; results shown are for 680-nm thick JSR NFR-012R negative tone photoresist on CVD SiC; Desired feature width is 600 nm

*Figure 4* shows the relationship between feature width on the exposed and developed photoresist and incident laser power for 680-nm thick


a




b


c

**Figure 5** Scanning electron micrographs of exposure power tests; these display the relationship between LBR exposure power and photoresist "feature" size; LBR exposure powers are 8.0 mW, 11.5 mW, and 4.6 mW (a, b, c, respectively); higher power overexposes the photoresist, and lower power underexposes it; 8.0 mW power correctly exposes the photoresist, producing correct feature geometry on the PSM substrate

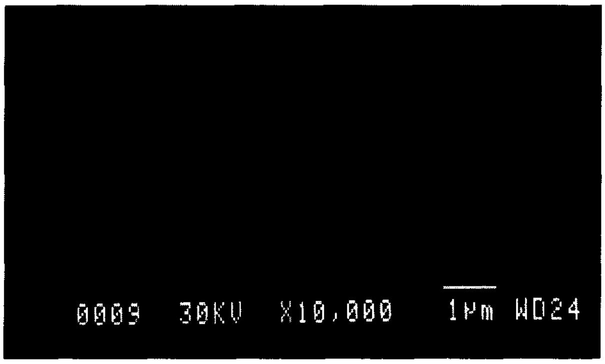
photoresist exposed using the LBR. The thicker photoresist was used here, because it was found to be considerably more absorptive to the argon–ion laser than the thinner photoresist (probably because of strong standing waves in the thinner photoresist).

*Figure 5* is a collection of three SEM photographs from this set of experiments. These correspond to regions on the substrate exposed to laser powers of 8.0 mW (a), 11.5 mW (b), and 4.6 mW (c). Because it is desired that the stamper's feature width be 600 nm for optimum replication and playback of the CD, 8.0-mW incident is best suited for this photoresist thickness. (Note, however, that the features produced using 5-mW laser power are of approximately the correct width for high-density storage.)

The low absorption of this photoresist to argon–ion laser exposure suggests the use of a shorter wavelength recording laser. Some preliminary experiments were performed with a krypton laser, (wavelength 411 nm), and the features obtained were sharp and well defined. The power needed for correct exposure was more than two orders of magnitude lower for the krypton laser than for the argon ion laser, because of greater sensitivity of the photoresist to lower wavelength irradiation. Results of these tests indicate that it is feasible to record CD-like features on PSM substrates using commercially available LBR equipment.

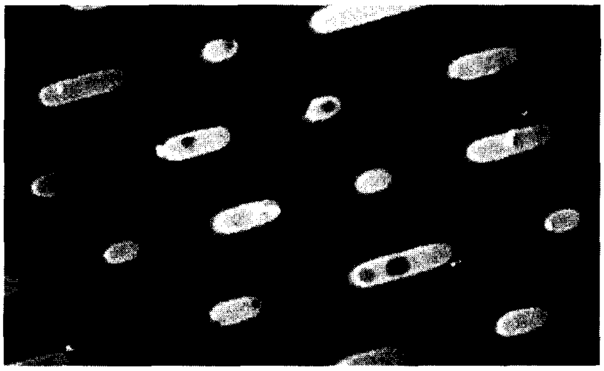
## Ion machining of ceramic stamper prototypes

Two ion machining tests were carried out on full-scale stamper prototypes. In the first, a stamper substrate was ion machined after first spinning on a 200-nm thick layer of photoresist and then recording with an argon–ion LBR at 15-mW incident laser power, and finally developing the photoresist to create a mask on the PSM substrate. Ion machining was performed at Oak Ridge National Laboratory (ORNL), and involved rastering a 3-cm source over the surface of the substrate. The ion beam current, acceleration voltage, and translational rastering speed were chosen to result in 150 nm material removal depth on the unmasked areas of the SiC substrate, based on previous ion-




a


b



c

**Figure 6** Scanning electron micrographs of: (a) laser recorded photoresist mask on PSM substrate; (b) ion-machined substrate surface; and (c) conventional electroformed nickel stamper (for comparison)

machining experiments. This rastering process required about 1 h of continuous machining with the 3-cm ion source.

In this experiment, the photoresist mask itself was machined by the ion beam at a higher rate than expected. As a result, by the time that 50-nm deep features had been ion machined into the SiC substrate, the 200-nm thick protective photoresist mask had been completely machined away. Further machining removed material at both the top and the bottom of the stamper features at an equal rate, resulting in no net change in feature height. Because stampers need to have feature heights of ~150 nm, the prototype stamper produced in this experiment was not useful for replication. However, SEMs of the photoresist mask before ion machining and of the silicon carbide surface after ion machining showed excellent feature transfer through ion machining.

The second set of full-scale ion-machining experiments employed a thicker photoresist layer (1000 nm) to avoid machining away the entire mask during stamper fabrication. These were recorded using a krypton laser (45 μW power) on a commercially available LBR. Also, instead of rastering, in these experiments, a stationary 110-mm diameter broad-beam ion source was used. By using a fixed broad source instead of a rastered small source, the ion-machining time was reduced to 7 min from more than 180 min, while maintaining the same beam power *density* (~1 mW/cm$^2$ accelerated at 1000 V). Good feature quality was obtained, as shown in the SEMs in *Figure 6*. Also, a feature height of 150 nm (+/− 5 nm) was obtained, as measured by scanning profilometry.

For singly ionized argon beams, incident beam power density varies proportionally to machining rate for a given material and a given accelerating voltage. However, total power incident on the workpiece is the product of power density and beam area. For the broad-beam experiments, then, power input to the substrate was roughly 20 times as large as in the rastering experiments with a narrow ion beam. This additional power input has the potential to cause rapid thermal breakdown of the photoresist mask material. *Figure 7* is


**Figure 7** Photoresist mask material damaged by excessive heating during ion machining

**Table 4** Conditions for injection-molding experiments

| | |
|---|---|
| Mold temperature | 85°C |
| Polycarbonate temperature | 330°C |
| Clamping force | 60 tons |
| Injection time | 1 s |
| Cooling time | 2 s |

an SEM of an ion-machined PSM substrate for which the incident ion power was approximately twice as large as that used to produce the PSM substrate shown in *Figure 6.* Care must be taken, then, to limit overheating of the photomask material. This could be accomplished by limiting the incident power of the beam, by actively cooling the substrate, or by choosing a masking material with more resistance to thermal breakdown.

Removal of photoresist after machining is difficult, because the film becomes considerably harder and less soluble after exposure to the ion beam. Two techniques of photoresist removal were implemented successfully: oxygen plasma etching (also known as "dry ashing"), and wet etching with a solution of heated sulfuric acid and hydrogen peroxide (also known as "piranha etching"). Oxygen plasma etching worked well, but slowly, requiring several hours to completely remove the hardened photoresist. In wet etching, residual resist is removed in a few minutes, but the addition of an acid etchant process introduces an undesirable chemical-etching step in an otherwise waste-free process. A third alternative, designing the photoresist film to be completely eroded in the ion-machining process itself, has not been tested to date. For such a process to be successful, the photoresist mask thickness would have to be precisely controlled. Further testing of this approach is currently underway.

## Injection molding with a ceramic stamper prototype

Injection-molding tests using PSM substrates were performed on a commercial CD-molding machine. As mentioned earlier, the stamper substrates used for PSM were made 0.9-mm thick, as compared to conventional nickel stampers, which are 0.3-mm thick. Modified stamper venting rings were then used on the injection-molding machine so that these thicker stamper substrates could be used to mold conventional 1.2-mm thick CDs. Several hundred replicas were made with CVD SiC,

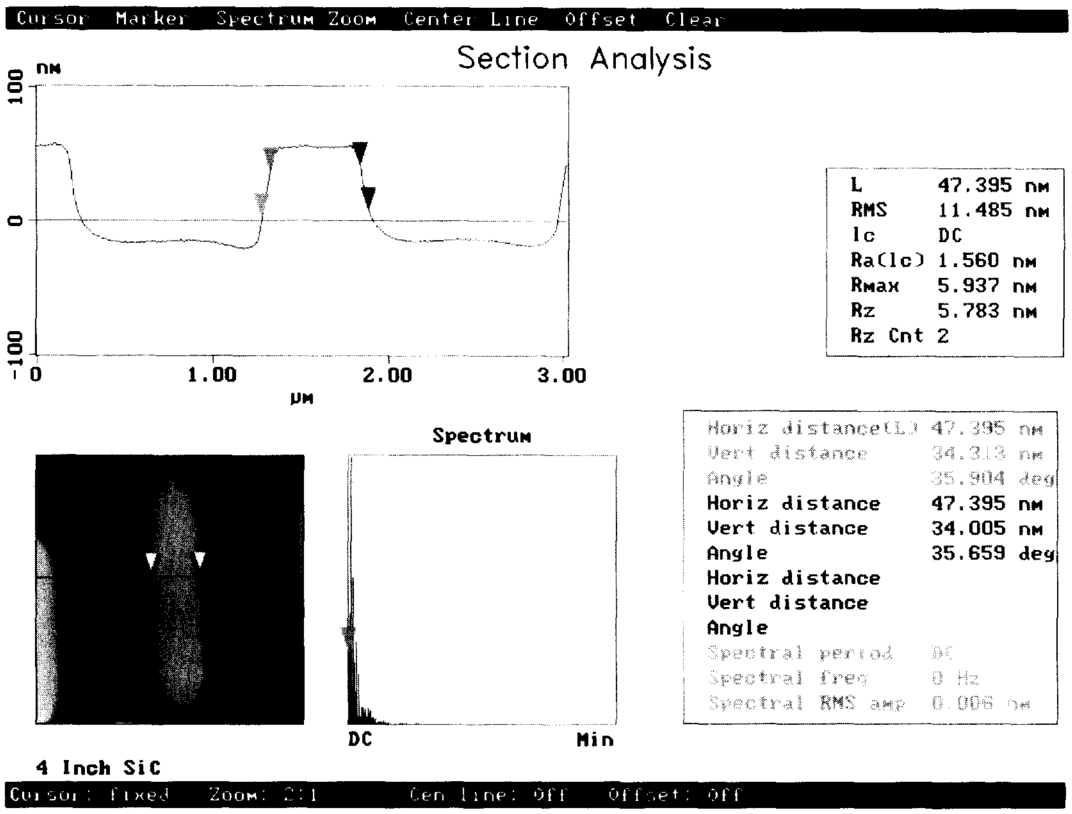



**Figure 8** Atomic force microscope scan of an ion-machined CVD SiC stamper, showing excellent feature definition and smooth side walls sloping at ~35°

Alumina, and Corning 9647 glass. Molding took place using the conditions outlined in *Table 4*. None of these stamper substrates showed visible signs of fracture or wear as a result of molding. Work is continuing on this, to quantify the stamper performance in terms of CD quality and stamper lifetime as a function of molding parameters.

## Analysis of stamper quality and feature geometry

An atomic force microscope (AFM) profile of a typical feature on an ion-machined stamper prototype is shown in *Figure 8*. The AFM profile was recorded in tapping mode with an etched silicon probe on a Nanoscope Dimension 3000. The parameters of this silicon tip include a cantilever length of 125 μm and the tip half cone angle of 18° side, 25° front, and 10° back. Several important observations can be made from this data. First, it is clear that both the masked areas (on top of the bump) and the unmasked areas have similar roughness. That is, the roughness of the sample was not increased by ion machining. Second, the wall slope of the feature is seen to be ~35°. The observed wall slope is well suited to the task of replicating CDs through injection molding. Substantially steeper slopes would adversely affect polymer release from the mold; whereas, shallower slopes would reduce the signal level produced by the CD in a player. Finally, it can be seen from this SEM that the feature shape is sharply defined, with edge straightness of better than 30 nm over the length of the feature. No feature analysis on polymer replicas has been performed to date.

## Conclusions

A novel process for precision manufacture of optical disc stampers has been introduced in this paper. The process uses ceramic instead of nickel substrates, and uses neutral ion machining instead of electroforming as a fabrication method. It promises to be faster, cleaner, more reliable, and more precise than the conventional process. Results from full-scale prototype fabrication experiments conducted on commercial equipment have verified that all production steps in the new process are feasible, and that the process is compatible with the conventional production systems that precede and follow stamper fabrication (i.e., laser beam recording and injection molding, respectively). Technical challenges related to integration and optimization of process steps have been identified, as have alternate substrate and mask materials.

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