Cleaning Apparatus Using a Laser Beam

BACKGROUND OF THE INVENTION

Field of the invention

This invention relates generally to cleaning apparatuses. More particularly, the invention relates to a cleaning apparatus for optically cleaning a surface of a substrate requiring cleaning in the process of manufacturing a magnetic recording medium, a semiconductor, a liquid crystal display or the like.

Description of the prior art

In the process of manufacturing magnetic recording disks for hard disk apparatuses, the hard disk substrates are formed using a base material of aluminum, glass or the like. For the aluminum substrates, the surfaces are coated by NiP. The coated surfaces are then polished in texture. After contaminants such as polish dusts are removed away, a magnetic material is sputtered over the coated surface of the substrate.

There are generally known wet and dry methods to clean the coated surface and remove of contaminants therefrom. In the wet scheme, the hard disk substrate is immersed in water, isopropyl alcohol and other types of liquids and although ultrasonic cleaning or scrub cleaning is applied, since harmful cleansers and solvents are used, there has been a secondary problem with stains on the substrate and an environmental pollution problem originating from their use. Meanwhile, the dry scheme includes such methods as of UV/O_3 cleaning, ultrasonic wave vibration air cleaning, dry-ice blast cleaning, and so on. These methods, however, have problems that removal rate is low and the contaminants adhered firmly are difficult to remove.

In recent, there has been a proposal on a method using a pulse laser beam as a

method to solve these problems. This prior art includes a laser light source, such as an excimer laser, to directly irradiate a pulse laser beam to contaminants existing on a substrate, thereby removing the contaminants through such a mechanism as ablation.

U.S. Pat. 5,024,968 discloses an Engelsberg technique that irradiates 6000 pulses of a pulse excimer laser having an energy density of 75 mJ/cm^2 to a silicon wafer while blowing an inert gas (argon gas) thereto, thereby removing carbon contaminant from the wafer. However, in the technique of Engelsberg, damage to the silicon wafer occurs at an energy density of as low as 300 mJ/cm^2. In order to conduct cleaning while avoiding damage, it is required to irradiate a laser beam with reduced energy density, resulting in a problem of low capability of cleaning.

Also, a recent study on laser cleaning (G. Vereecke "Laser assisted removal of particles on silicon wafers", J. Appl. Phys. 85,3837(1999)) points out that, in the Engelsberg technique, the efficiency of removing 0.3-μm SiO_2 particles from a silicon wafer is as low as 20% or less. Meanwhile, G. Vereecke discloses to improve the removal efficiency by performing laser cleaning in a high humidity state. In this method, however, the efficiency of removing 1-μm SiO_2 particles is nearly 80%. Thus, removal capability practically applicable has not yet been feasible.

Magee proposes, in U.S. Pat. 5, 151,135, a similar technique to that of Engelsberg. Using the technique of Magee, the present inventors have tried to remove slurry particles from a hard-disk aluminum substrate coated with NiP. However, with an energy density of 100 mJ/cm^2 almost the slurry particles could not have been removed. When the energy density was increased to 150 J/cm^2, a removal effect was recognized but damage occurred on the substrate before contaminants removal is not completed. Furthermore, there was deterioration in magnetic characteristic after film forming.

That is, in both prior arts, a laser beam is entered normal to the substrate surface,

wherein as shown in Fig. 10 a laser beam irradiation region on the substrate has a width H1 equal to a laser beam width. Due to this, there is a fear that a surface of a substrate 1 be damaged if the laser beam irradiated to the substrate is increased in laser density up to such an energy that can remove particular contaminants 2.

Meanwhile, when a laser beam is irradiated to the contaminants 2 as shown in Fig. 10, only an energy portion is effective that is irradiated to a circular area having a diameter H2 while the other energy portion is ineffective that is irradiated to the substrate surface the contaminants do not exist. Such a method requires a multiplicity of pulses of irradiation with reduced energy density so as no to cause damage to the substrate. Thus, it is difficult to realize a practical cleaning apparatus, in consideration of cleaning capability, throughput and economy.

There is a disclosure of a laser cleaning apparatus characterized in incident angle, for example, in Japanese Patent Publication No. S57-13634. This prior art is intended to remove a lubrication film from a steel plate surface. In this prior art, a laser beam is irradiated to a steel plate at an inclination angle in optical axis of 70 degrees or greater with respect to a normal line thereto so that the removed contaminants can be sucked away while blowing an inert gas of nitrogen, argon or the like. This prior art discusses on the effects of broadening an irradiation area by controlling the incident angle and of increasing energy absorption by the lubrication film. This prior art however fails to consider on a polarization condition. For a steel plate high in damage energy density and in reflectivity, it is generally effective to provide a beam incidence with p-polarization that is ready to be absorbed by the lubrication film. However, there is a high possibility that, if this prior art is applied to such a substrate that is low in damage energy density or in reflectivity, the substrate be damaged despite contaminants are to be removed.

SUMMARY OF THE INVENTION

It is therefore a primary object of the present invention to provide a cleaning apparatus which is applicable to a substrate susceptible to damage or low in reflectivity and provides a satisfactory cleaning effect without causing damage to a surface of the substrate.

A cleaning apparatus according to the present invention is a cleaning apparatus for irradiating a laser beam to a substrate surface and cleaning said substrate surface, comprising: a laser beam source for emitting a laser beam; and polarizing means for s-polarizing the laser beam emitted from said laser beam source with respect to said substrate surface, wherein the laser beam has an incident angle set smaller than 90 degrees with respect to said substrate surface.

A laser beam emitted from the laser beam source is s-polarized and incident on a substrate surface at an incident angle of smaller than 90 degrees. This accordingly increases irradiation area to the substrate surface and decreases irradiation density as compared to a case of vertical incidence onto the substrate surface. Also, the s-polarized laser beam has an increasing energy reflectivity on the substrate surface with decrease in the incident angle. The laser beam reflected is indirectly irradiated to contaminants thereby increasing an amount of laser beam irradiation to the contaminants. The increased energy reflectivity, in turn, decreases energy absorption by the substrate. Furthermore, the s-polarized laser beam has an electric vector vibrating in a parallel direction with the substrate surface. The energy of vibration effectively acts as a force to remove the contaminants.

Meanwhile, the reflection light, if re-irradiated by a re-irradiation means, makes it possible to effectively utilize a small amount of energy. This is effective particularly where s-polarized light incidence is made that is great in energy reflectivity upon the

substrate surface. In this case, if different points on the substrate surface are irradiated, the occurrence of interference fringes can be avoided and variation in laser density be prevented even where using a laser beam source that is long in coherent length.

According to the invention, it is possible to efficiently remove contaminants without causing a surface damage problem. That is, contaminants removal is possible in a brief time with using a reduced number of pulses. The invention, accordingly, suited particularly for cleaning of a substrate of a basic material that is low in threshold of damage, e.g. aluminum, glass, etc.

The above described objects and other objects, features, aspects and advantages of the present invention will become more apparent from the following detailed description of the present invention when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is an illustrative view showing one embodiment of the present invention;

Figure 2 is an illustrative view showing an optical system used in the Figure 1 embodiment;

Figure 3 is an illustrative view showing a state that a laser beam is irradiated to contaminants existing in an abrasive groove;

Figure 4 is an illustrative view showing an incident angle θ and irradiation area of a laser beam;

Figure 5 is a graph showing a relationship between an incident angle θ and energy reflection rate of a laser beam;

Figure 6 is a graph showing a relationship between an incident angle θ and energy density of a laser beam;

Figure 7 is a graph showing a relationship between an irradiation energy density

and a signal output reduction rate;

Figure 8 is an illustrative view showing another optical system;

Figure 9 is an illustrative view showing still another optical system; and

Figure 10 is an illustrative view showing an irradiation area of a laser beam in a prior art.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

A cleaning apparatus 10 of this embodiment shown in Figure 1 is to clean surface of a substrate during the process of manufacturing a magnetic recording medium, semiconductor, liquid crystal display or the like. The apparatus is suited particularly for cleaning a substrate formed using a basic material that is low in a threshold of damage, such as aluminum, glass or the like. Explanations are made hereunder on the assumption that the cleaning apparatus 10 is used to clean a hard disk substrate 12.

Here, the hard disk substrate 12 is the one before a process of being sputtered with a magnetic material. The hard disk substrate 12 has a surface coated with an NiP film and polished in texture. Accordingly, the hard disk substrate has on its surface a plurality of polish grooves 12a extending in a circumferential direction thereof as shown in Figure 3.

The cleaning apparatus 10 (Figure 1) includes a personal computer (hereinafter referred to as "PC") 14, an excimer laser 16, a variable attenuator 18, optical systems 20 and 22, moving stages 24 and 26, a light source 28, contaminants detection section 30, a suction port 32, an energy meter 34, a spindle motor 36 and so on.

The spindle motor 36 includes an output shaft 36a. A hard disk substrate 12 is mounted nearly horizontal on a tip of the output shaft 36a. The spindle motor 36 also incorporates therein a not-shown rotary encoder so that the rotary encoder can detect rotation position information to be delivered to the PC 14.

The spindle motor 36 is controlled in rotation velocity in a range of approximately 50 to 20,000 rpm by the PC 14. The scheme of rotation control uses CAV (Constant Angular Velocity) control or CLV (Constant Linear Velocity) control. The CAV control is easy to control wherein correspondence is given between a pulse repetition frequency of the excimer laser 16 and a rotational frequency of the spindle motor 36. Accordingly, the CAV control is suited for irradiating a laser beam to aim at particular contaminants. On the other hand, the CLV control is facilitated to irradiate a laser beam at constant pulse repetition frequency, and suited for irradiating a laser beam evenly over a surface of a hard disk substrate 12. From a view piont of throughput, the faster is set the maximum rotation velocity of the spindle motor 36, the greater advantage will be available. However, in the light of controlling a laser-beam irradiation point, it is preferred that the same maximum rotation velocity is set below a pulse repetition frequency of the excimer laser 16.

The excimer laser 16 includes a KrF excimer laser oscillator (with a wavelength: of approximately 248 nm and a pulse width of nearly 25 ns) to emit a random-polarizing laser beam. The exciner laser 16 in oscillation is on/off-controlled and switched in pulse repetition frequency by the PC 14. The excimer laser 16 also includes control unit to control a laser density. The application voltage, if controlled by the control unit, provides adjustment in laser pulse energy in a range, for example, of 300 to 700 mJ. In an event that a laser pulse energy decreases due to deterioration in excitation gas, optical components or the like, the application voltage is increased to maintain the laser pulse energy at constant. The pulse repetition frequency of the excimer laser 16 is desirably higher in a view point of removing contaminants, specifically set at approximately 400 Hz.

The use of the KrF excimer laser oscillator is due to the reasons of high photon

energy suited for cleaning, high oscillation efficiency, no necessity of purging a nitrogen gas along an optical path due to low ozone occurrence, high transmittance of optical elements, etc. However, other excimer laser oscillators may be used, e.g. an XeCl excimer laser oscillator (a wavelength of 308 nm), ArF excimer laser oscillator (a wavelength of 193 nm), or other laser oscillator, such as a solid-state laser oscillator, or a semiconductor laser oscillator.

The variable attenuator 18 adjusts constant the intensity per unit area of a laser beam, or laser density, irradiated from the excimer laser 16. The variable attenuator 18 is adjusted in transmittance within a range of 0 to 100 % under control of the PC14. It should be noted that the variable attenuator 18 is desirably used at a transmittance of from 70 to 100 % in the viewpoint of energy efficiency of the excimer laser 16.

The optical system 20 shapes and polarizes a laser beam from the variable attenuator 18 into a rectangular-formed beam. The optical system 20 is structured by combining optical components, such as a mirror, beam shaper and the like. The optical system 20 desirably changes a laser beam into collimated light with evenness in profile.

The moving stage 24 includes a not-shown stage portion to be moved radially of the hard disk substrate 12. The stage portion is controlled in movement by the PC14, so that information of a moving position thereof is supplied as a position signal to the PC14. The stage portion is fixed with an optical system 22. Accordingly, the optical system 22 is moved by movement of the stage portion so that the optical system 22 can be grasped in position based on the moving position information of the stage portion.

The optical system 22 s-polarizes a random-polarizing laser beam given from the optical system 20 with respect to the top surface of the hard disk substrate 12, and irradiate it tangentially onto the top surface of the hard disk substrate 12 at an angle of 90 degrees or smaller. The optical system 22 is formed by combining various optical

components.

That is, the optical system 22 includes, as shown in Figure 2(A), a polarizing beam splitter 38, a mirror 40, and a half wavelength plate 42. The random polarized laser beam, to be given to the optical system 22, has an electric vector oscillating radiatively in a plane orthogonal to a travelling direction of the laser beam, as shown in Figure 2(B). In Figure 2(A), this state is illustrated by horizontal arrow and double circle. When the laser beam is incident on the polarizing beam splitter 38, one part thereof transmits through it and has an electric vector changed in oscillation direction into only a horizontal component (Figure 2(C)), thus irradiated onto the top surface of the hard disk substrate 12. The other part is reflected by a birefringent crystal, such as a Wollaston prism, whereby its electric vector is changed in oscillation direction into only a vertical component (Figure 2(D)). The laser beam is then totally reflected upon the mirror 40 and sent to the half wavelength plate 42 where it is rotated in polarizing plane by 90 degrees into a s-polarized beam to be irradiated onto the top surface of the hard disk substrate 12. The two laser beams thus split are irradiated two opposite positions sandwiching a center of the hard disk substrate 12, as shown in Figure 2(A). Thus cleaning is conducted in the respective positions.

Note that laser beam was irradiated in the tangential direction because, even where contaminants 44 are adhered in the polish groove 12a circumferentially formed as shown in Figure 3(A), a laser beam can be fully irradiated to the contaminants. That is, laser beam irradiation if in a radial direction is insufficient to the contaminants 44, as shown in Figure 3(B), which should be avoided.

The energy meter 34 directly detects a density of a laser beam (a dotted line in Figure 1) irradiated from the optical system 22 when the hard disk substrate 12 is being removed. The energy meter 34 is arranged below the optical system 22. The laser density

signal detected by the energy meter 34 is supplied to the PC14 so that the laser density can be precisely adjusted according to the laser density signal. That is, the density of laser irradiation to the hard disk substrate 12 is roughly adjusted by controlling a voltage applied to the excimer laser 16 according to a previously-set target laser density, and precisely adjusted by controlling the variable attenuator 18 using a laser density signal (measured value) as a feedback signal from the energy meter 34. Consequently, the density of laser irradiated to the hard disk substrate 12 is maintained constant even where the laser density of the excimer laser 16 is decreased due to deterioration in the excitation gas, optical components and the like. Meanwhile, it is possible to detect a deterioration in the variable attenuator 18, optical system 20 or optical system 22 by comparing between the control inputs of rough and precise adjustments. Note that laser density fine adjustment may be satisfactorily conducted at such an interval that the hard disk substrate 12 is exchanged. This is because deterioration in the excitation gas, optical components or the like proceeds comparatively moderately.

The suction port 32 sucks/discharges the contaminants (abrasive dusts, etc) removed from the hard disk substrate 12 surface. In the case that the entire cleaning apparatus 10 or the peripheral part for the hard disk substrate 12 is arranged within a clean room, an HEPA (High Efficiency Particulate Air) filter if provided on a clean room air supply source would provide a high degree of clean environment. The HEPA filter is a gas filter formed of glass wool, and collects particles through use of three principles of inertia, diffusion and collision.

The moving stage 26 includes a stage portion to be moved radially of the hard disk substrate 12. The stage portion is controlled in movement by the PC14, and moving position information thereof is sent as a position signal to the PC14. The stage portion is fixed with a light source 28 and contaminants detection section 30. Consequently, the

light source 28 and contaminants detection section 30 are moved by moving the stage portion so that the positions of the light source 28 and contaminants detection section 30 can be grasped in position according to the moving position information of the stage portion.

The light source 28 is a linear or surface light source to tangentially radiate homogeneous light with an angle smaller than 90 degrees onto the top surface of the hard disk substrate 12 in order to detect contaminants. The light source 28 includes a semiconductor laser for emission of light of red, (blue) purple or the like, and is controlled by the PC14. Because the light source 28 radiates light to the top surface of the hard disk substrate 12 tangentially thereof, diffusion light due to the polish groove 12a is suppressed from occurring (Figure 3). Note that the light source 28 preferably uses a short wavelength.

The contaminants detection section 30 receives a light emitted from the light source 28 and reflected upon the top surface of the hard disk substrate 12, and photo-electrically converts it for outputting. The contaminants detection section includes a multiplier phototube, an A/D converter, and so on. The analog signal photoelectrically converted by the contaminants detection section 30 is converted into a digital signal by the A/D converter and supplied to the PC 14. Accordingly, in the case there exist contaminants on the top surface of the hard disk substrate 12, a light amount signal outputted from the contaminants detection section 30 is changed in value. Based upon this, that contaminants can be detected. Incidentally, the contaminants detection section 30 may be configured to receive scattering light caused by a roughened portion (including the contaminants 44) of the top surface of the hard disk substrate 12.

In a cleaning process using the present cleaning apparatus 10, polish dusts, etc. adhered on the surface of the hard disk substrate 12 are first roughly removed away. That

is, the hard disk substrate 12 is rotated by the spindle motor 36, in which state the moving stage 24 is actuated and the excimer laser 16 is turned on. Thereupon, a laser beam in 1 to 2 pulses per point is irradiated throughout the entire top surface of the hard disk substrate 12. This removes comparatively large polish dusts or the like put on the surface of the hard disk substrate 12. Incidentally, prior to the rough removal process may be used a removal process using ultrasonic vibration air cleaning, water cleaning or the like.

Subsequently, detected is a position where contaminants are put on. That is, the moving stage 26 is actuated and the light source 28 is turned on, to determine a presence or absence and size of contaminants present on the top surface of the hard disk substrate 12 according to a signal detected by the contaminants detection section 30. The position of contaminants are present is specified according to a signal given from the contaminants detection section 30, moving position information from the moving stage 26, etc.

Then, removed are contaminants that could not have been removed in the rough removal process. That is, the excimer laser 16 is turned on, to irradiate again a laser beam in one pulse a time onto the contaminants. This process is repeated until the contaminants are removed away. At this time, the laser beam is irradiated only to the contaminants 44 according to the position information obtained in the former process, without giving radiation to other areas. This is for reducing a cleaning time and preventing the surface of the hard disk substrate 12 from being damaged.

According to the present embodiment, because the incident angle θ of a laser beam to the surface of the hard disk substrate 12 is set smaller than 90 degrees ($\theta < 90$ degrees), the irradiation area on the hard disk substrate 12 has a width H1 that is greater than the width H1 of the prior art shown in Figure 10. This in turn increases an irradiation area per unit time and decreases a time required for cleaning. Also, the density of a laser beam irradiated to the hard disk substrate 12 surface decreases, thereby suppressing

occurrence of surface damage.

Meanwhile, the light reflected upon the top surface of the hard disk substrate 12 provides indirectly illumination a lower to side portion of the contaminants 44. Thus, the irradiation area to the contaminants 44 has a width H2 that is given by a sum in size of a width H21 of a direct irradiation area and a width H22 of an indirect irradiation area. This is greater than the width H2 of the prior art shown in Figure 10. That is, there is obtained an increase in the amount of laser beam irradiation to the contaminants 44. Also, the laser beam indirect radiation provides a force acting toward stripping off the contaminants 44 (an upward force). Accordingly, the removality of contaminants 44 is drastically improved. In obtaining a same degree of removality, the density of irradiation laser beam can be reduced, thus suppressing occurrence of surface damage.

Also, the laser beam is s-polarized. Accordingly, as shown in a graph of Figure 5, as the laser beam incident angle θ decreases the energy reflectivity on the hard disk substrate 12 surface increases, thereby increasing the density of a laser beam directly irradiated to the contaminants 44. Meanwhile, in s-polarization, the electric vector vibrates in a parallel direction with the surface of the hard disk substrate 12 (Figure 2). It is therefore possible to efficiently remove the contaminants 44 by decreasing the laser beam incident angle θ in conjunction with increase in irradiation amount (Figure 4) stated above. In particular, in the case that the contaminants 44 have electric charges or deposited on the hard disk substrate 12 surface due to an electrostatic force, intense vibration energy occurs due to an interaction between the electric charge and the electric field, enhancing the effect of removal.

Furthermore, the s-polarized light incidence with high energy reflectivity decreases an energy absorbed in the hard disk substrate 12. This, together with decrease of laser density, suppresses occurrence of surface damage.

Incidentally, when using a p-polarized laser beam, the energy reflectivity is low regardless of the incident angle θ as shown in the graph of Figure 5, decreasing the density of a laser beam indirectly irradiated to the contaminants 44. Also, with p-polarized light, the electric vector vibrates in directions of urging on and stripping off the contaminants 52 for the hard disk substrate. Thus, the removal effect is only in the stripping-off direction. Accordingly, the removal effect to be expected is not greater than that with the s-polarized light. Furthermore, because low energy reflectivity means high energy absorbtivity. With p-polarizing light, it is difficult to expect an effect to suppress occurrence of surface damage to the hard disk substrate 12.

The irradiation of an s-polarized laser beam with a smaller incident angle θ than 90 degrees in this manner serves to enhance the cleaning effect as compared to the case with p-polarized light of the prior art. However, the cleaning effect in an objective sense needs to meet the following three requirements, i.e. ① no occurrence of surface damage, ② removal of contaminants and ③ obtaining record/reproduce characteristics. In order to achieve this, the present inventors has conducted experiments to determine an incident angle θ and irradiation energy density satisfying these requirements, results of which are illustrated in the graphs of Figure 6 and Figure 7.

Figure 6(A) is a graph showing a relationship between an incident angle θ and an energy density at which surface damage occurs (hereinafter referred to as "damage energy density"). As seen in this graph, as the incident angle θ decreases both s-polarized light and p-polarized light increase in damage energy density. It will be understood that from around the point that the incident angle θ becomes smaller than 45 degrees, the damage energy density of s-polarized light becomes greater than that of p-polarized light.

Figure 6(B) is a graph wherein an energy density at which contaminants removing

effect appears (hereinafter referred to as "cleaning energy density") and an energy density at which magnetic characteristic deterioration occurs (hereinafter referred to as "magnetic deterioration energy density) are added to the graph of (A). Incidentally, in this graph a region having an energy density of up to 500 mJ/cm^2 is shown by magnification. In order to obtain contaminants removing effect without causing surface damage and magnetic characteristic deterioration, there is a necessity that irradiation energy density is rendered smaller than damage energy density and magnetic deterioration energy density but greater than cleaning energy density (damage energy density · magnetic deterioration energy density > irradiation energy density > cleaning energy density). Consequently, for p-polarized light, an irradiation energy density and incident angle θ must be set in a P region of the graph. For s-polarized light, an irradiation energy density and incident angle θ have to be set in an S region of the graph.

Accordingly, for p-polarized light the incident angle θ must be given smaller than 10 degrees while for s-polarized light the incident angle θ be smaller than 35 degrees. In other words, the incident angle θ must be set such that a predetermined irradiation energy density is smaller than a damage energy density and magnetic deterioration energy density but greater than cleaning energy density based on damage energy density, magnetic energy density and cleaning energy density varying according to a magnitude of incident angle θ. Within a range satisfying this condition, cleaning capacity can be increased with increase in the irradiation energy density. The irradiation area on the hard disk substrate 12 can be broadened as the incident angle is smaller, thus shortening cleaning time.

Incidentally, in the graph of Figure 6 the magnetic deterioration energy density is taken as a criterion to fix a P region or S region in consideration of cleaning the hard disk substrate 12. However, for cleaning a semiconductor substrate, liquid crystal display

substrate, or the like, an energy density that its performance deterioration occurs will be taken, in place of the magnetic deterioration energy density, as a criterion to fix a P region or S region.

Figure 7 is a graph showing a relationship, when the incident angle θ is fixed, between an irradiation energy density and a signal output lowering rate. The signal output lowering rate is a value having been determined based on a certifier test, and has an allowable range of higher than 3 % (above dotted line). As seen in this graph, the signal output lowering rate increases with increase in irradiation energy density, the tendency of which becomes conspicuous as the incident angle θ increases. It will be understood from this graph that a magnetic record/reproduce signal becomes hardly lower as the incident angle θ is smaller wherein it is possible, at an incident angle of approximately 15 degrees, to use at an irradiation energy density (nearly 400 to 500 mJ/cm^2) that the magnetic record/reproduce signal will not lower.

Incidentally, in the above embodiment the two-split laser beams were respectively irradiated to different positions on the top surface of the hard disk substrate 12. However, as shown in Figure 8 two-split laser beams may be respectively irradiated to the opposite surfaces of the hard disk substrate 12. An optical system 46 shown in Figure 8 splits a laser beam into two, respective of which are s-polarized and irradiated to the top and back surfaces of the hard disk substrate 12. The optical system 46 includes a polarizing beam splitter 48, a mirror 50 and a half wavelength plate 52. When a laser beam is incident on the polarizing beam splitter 48, part of which is reflected upon to have an electric vector having only a horizontal component of vibration. This component is then totally reflected upon the mirror 50 and irradiated as an s-polarized light beam to the top surface of the hard disk substrate 12. The other part of the beam transmits through the beam splitter 48 to have an electric vector having only a vertical component of vibration. This laser beam

is given to the half wavelength rate 52 where it is rotated in polarizing plane by 90 degrees and irradiated as an s-polarized light beam to an underside of the hard disk substrate 12. Accordingly, cleaning is simultaneously made on the opposite surfaces of the hard disk substrate 12.

Meanwhile, in the above embodiment the laser beam was once irradiated to the hard disk substrate 12. However, as shown in Figure 9 the laser beam may be reflected by an optical component to provide a plurality of number of irradiations.

The structure of Figure 9 has a concave mirror 54, a convex mirror 56 and a terminal member 58, in addition to the above-mentioned optical system (Figure 2) or 46 (Figure 8). The laser beam s-polarized by the optical system 22 or 46 is reflected by the hard disk substrate 12, the concave mirror 54 and the convex mirror 56 and then absorbed to the terminal member 58. The concave mirror 54 and the convex mirror 56 are radially arranged to provide respective laser beam irradiation positions on the hard disk substrate 12. Also, the irradiation laser beam is in a rectangular form having a lengthwise direction in a radial direction of the hard disk substrate 12. The concave mirror 54 and concave mirror 56 each have a radius of curvature set such that the density of a laser beam to be irradiated to the hard disk substrate 12 is constant at all times. That is, setting is made such that the concave mirror 54 and convex mirror 56 have a contraction magnification coincident with a square root of an energy reflectivity on the top surface of the hard disk substrate 12. Due to this, a broad irradiation area is available with one laser beam source, over which area a laser beam can be irradiated with a constant density. Note that it is possible to properly modify the number of mirrors, concave and convex surfaces in combination or the like.

In the Figure 9 structure, although laser beams are re-irradiated to different positions on the hard disk substrate 12, they may be re-irradiated to a same position. In

such a case, cleaning is preferably made with low energy because an irradiation amount to contaminants 44 can be increased even with an low output of the excimer laser 16. In this case, however, there is a need to use a laser beam source with a short coherent length in order to prevent deviation of laser density due to interference fringes.

In the above embodiment the polarizing beam splitter 38 (Figure 2) or 48 (Figure 8) was used to split a laser beam. Instead, a plate polarizer may be used. The plate polarizer is an element having a multifilm polarizer coating on surface of an optical substrate, such as synthetic quartz, MgF_2, CaF_2 or the like. The plate polarizer serves to split a laser beam into two orthogonal polarized beams. Meanwhile, the polarizing beam splitter, the half wavelength plate and the like are provided in plurality of number in order to split laser beam into three or more, so that the individual laser beams can be irradiated onto the surface of the hard disk substrate 12.

In the above embodiment, determination was made on a presence or absence and size of contaminants 44 according to a light amount signal given from the light source 28 (Figure 1) reflected upon the hard disk substrate 12 surface. Alternatively, the reflectivity in the excimer laser 16 may be utilized to perform spectrum analysis on reflection light thereby determine a presence or absence, size, kind and material, etc. of contaminants 44.

Furthermore, although in the above embodiment a random-polarization laser beam was used which has been split and polarized by the polarizing beam splitter 38, 48. Alternatively, it is possible to use a laser beam having a linear polarizing characteristic to be split by a non-polarizing beam splitter.

Although the present invention has been described and illustrated in detail, it is clearly understood that the same is by way of illustration and example only and is not to be taken by way of limitation, the spirit and scope of the present invention being limited

only by the terms of the appended claims.

WHAT IS CLAIMED IS:

1. A cleaning apparatus for irradiating a laser beam to a substrate surface and cleaning said substrate surface, comprising:

a laser beam source for emitting a laser beam; and

polarizing means for s-polarizing the laser beam emitted from said laser beam source with respect to said substrate surface, wherein

the laser beam has an incident angle set smaller than 90 degrees with respect to said substrate surface.

2. A cleaning apparatus according to claim 1, wherein said incident angel is set, based upon a damage energy density, a performance deterioration energy density and a cleaning energy density that vary according to said incident angle, such that an irradiation energy density is smaller than said damage energy density and said performance deterioration energy density but greater than said cleaning energy density.

3. A cleaning apparatus according to claim 1 or 2, wherein said laser beam source emits a laser beam with random polarization, and said polarizing means having a polarizing beam splitter and a half wavelength plate.

4. A cleaning apparatus according to any of claims 1 to 3, further comprising re-irradiation means for reflecting a laser beam reflected upon said substrate surface and re-irradiating the laser beam to said substrate surface.

5. A cleaning apparatus according to claim 4, wherein provided at different positions a first irradiation area of the laser beam irradiated from said laser beam source to said substrate surface and a second irradiation area of the laser beam irradiated from said re-irradiation means to said substrate surface.

