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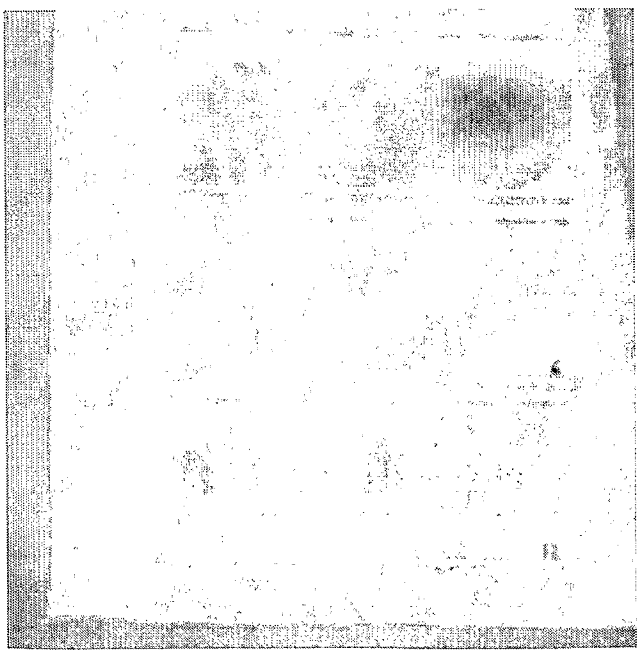
(54) Title: COATING ON A FIBER SUBSTRATE AND A COATED FIBER PRODUCT



(57) Abrégé/Abstract:
The invention relates in general level to a method for coating fiber products comprising large surface areas. The invention also relates to coated fiber products manufactured by the method. The coating is carried out by employing ultra short pulsed laser deposition wherein pulsed laser beam is scanned with a rotating optical scanner comprising at least one mirror for reflecting said laser beam. The invention has several both industrially and qualitatively advantageous effects such as high coating production rate, low-temperature coating conditions accomplishing coating of fiber-products excellent coating properties and overall low manufacturing costs.

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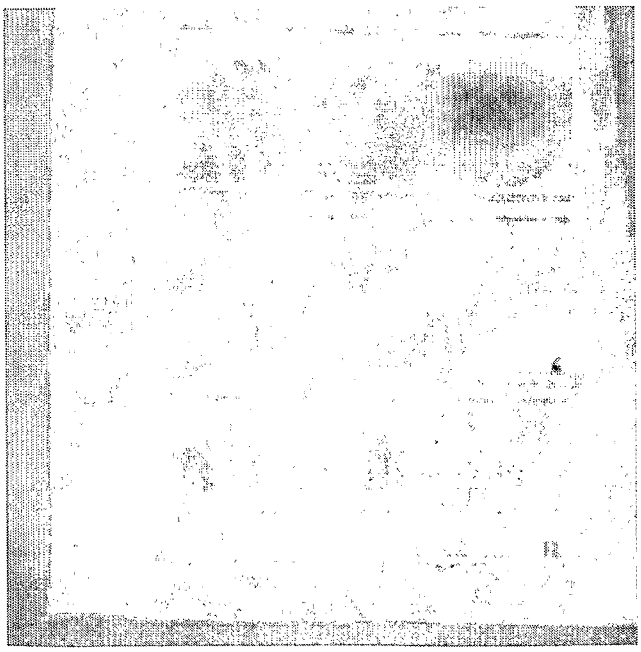
(54) **Title:** COATING ON A FIBER SUBSTRATE AND A COATED FIBER PRODUCT



(57) Abstract: The invention relates in general level to a method for coating fiber products comprising large surface areas. The invention also relates to coated fiber products manufactured by the method. The coating is carried out by employing ultra short pulsed laser deposition wherein pulsed laser beam is scanned with a rotating optical scanner comprising at least one mirror for reflecting said laser beam. The invention has several both industrially and qualitatively advantageous effects such as high coating production rate, low-temperature coating conditions accomplishing coating of fiber-products excellent coating properties and overall low manufacturing costs.

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Coating on a fiber substrate and a coated fiber product

Field of invention

The invention relates generally to a method for coating fiber products comprising large surface areas by ultra short pulsed laser ablation. The invention also relates to products manufactured by the method. The invention has many advantageous effects such as high coating production rate, low-temperature coating conditions accomplishing coating of fiber-products, excellent coating properties and low manufacturing costs.

Background

Fiber products

The fibers can be divided to natural fibers such as various cellulosic fibers from lignocelluloses, and to man-made fibers. Artificial fibers are commonly divided to main groups, namely mineral fibers and polymer fibers.

The most well-known mineral fibers are glass and metal fibers, such as fiberglass, optical fibers, metallurgic fibers and carbon fibers.

The polymer fibers are a subset of man-made fibers, which are based on synthetic chemicals (often from petrochemical sources) rather than arising from natural materials by a purely chemical process. Such fibers are typically made from polyamide (nylon), PET or PBT polyester, phenol-formaldehyde (PF), polyvinyl alcohol fiber (PVOH), polyvinyl chloride fiber (PVC), polyolefins (PP and PE), acrylic polymers such as pure polyacrylonitrile PAN and various aromatic polyamids such as Twaron, Kevlar and Nomex. Additionally, one can mention polyethylene (PE), HMPE; elastomers and polyurethane fibers.

Fibers are employed practically everywhere as in paper&board products and in various textiles for human, technical, exterior and interior use.

Regardless the nature of fibers, fiber materials are bendable. They are typically heat-sensitive and are applied in forms comprising large surfaces.

Laser-ablation

In the recent years, considerable development of the laser technology has provided means to produce very high-efficiency laser systems that are based on semi-conductor fibres, thus supporting advance in so called cold ablation methods.

At the priority date of the current application, solely fibrous diode-pumped semiconductor laser is competing with light-bulb pumped one, which both have the feature according to which the laser beam is lead first into a fibre, and then forwarded to the working target. These fibrous laser systems are the only ones to be applied in to the laser ablation applications in an industrial scale.

The recent fibres of the fibre lasers, as well as the consequent low radiation power seem to limit the materials to be used in the vaporization/ablation as the vaporization/ablation targets. Vaporizing/ablating aluminium can be facilitated by a small-pulsed power, whereas the more difficult substances to be vaporized/ablated as Copper, Tungsten, etc. need more pulsed power. The same applies into situation in which new compounds were in the interest to be brought up with the same conventional techniques. Examples to be mentioned are for instance manufacturing diamond directly from carbon (graphite) or alumina production straight from aluminium and oxygen via the appropriate reaction in the vapour-phase in post-laser-ablation conditions.

On one hand, one of the most significant obstacles to the forwarding progress of fibre-laser technology seems to be the fibre capabilitity of the fibre to tolerate the high power laser pulses without break-up of the fibre or without diminished quality of the laser beam.

When employing novel cold-ablation, both qualitative and production rate related problems associated with coating, thin film production as well as cutting/grooving/carving etc. has been approached by focusing on increasing laser power and reducing the spot size of the laser beam on the target. However, most of the power increase was consumed to noise. The qualitative and production rate related problems were still remaining although some laser manufacturers resolved the laser power related problem. Representative samples for both coating/thin film as well as cutting/grooving/carving etc. could be produced only with low repetition rates, narrow scanning widths and with long working time beyond industrial feasibility as such, highlighted especially for large bodies.

If the energy content of a pulse is kept constant, the power of the pulse increases in the decrease of the pulse duration, the problem with significance increases with the decreasing laser-pulse duration. The problems are significant even with the nano-second-pulse lasers, although they are not applied as such in cold ablation methods. The pulse duration decrease further to femto or even to atto-second scale makes the problem almost irresolvable. For example, in a pico-second laser system with a pulse duration of 10-15 ps the pulse energy should be 5 μJ for a 10-30 μm spot, when the total power of the laser is 100 W and the repetition rate 20 MHz. Such a fibre to tolerate such a pulse is not available at the priority date of the current application according to the knowledge of the writer at the very date.

The production rate is directly proportional to the repetition rate or repetition frequency. On one hand the known mirror-film scanners (galvano-scanners or back and worth wobbling type of scanners), which do their duty cycle in way characterized by their back and forth movement, the stopping of the mirror at the both ends of the duty cycle is somewhat problematic as well as the accelerating and decelerating related to the turning point and the related momentary stop, which all limit the utilizability of the mirror as scanner, but especially also to the scanning width. If the production rate were tried to be scaled up, by increasing the repetition rate, the acceleration and deceleration cause either a narrow scanning range, or uneven distribution of the radiation and thus the plasma at the target when radiation hit the target via accelerating and/or decelerating mirror.

If trying to increase the coating/thin film production rate by simply increasing the pulse repetition rate, the present above mentioned known scanners direct the pulses to overlapping spot of the target area already at the low pulse repetition rates in kHz-range, in an uncontrolled way. At worst, such an approach results in release of particles from the target material, instead of plasma but at least in particle formation into plasma. Once several successive laser pulses are directed into the same location of target surface, the cumulative effect seems to erode the target material unevenly and can lead to heating of the target material, the advantages of cold ablation being thus lost.

The same problems apply to nano-second range lasers, the problem being naturally even more severe because of the long lasting pulse with high energy. Here, the target material heating occurs always, the target material temperature being elevated to approximately 5000 K. Thus, even one single nano-second range pulse erodes the target material drastically, with aforesaid problems.

In the known techniques, the target may not only ware out unevenly but may also fragment easily and degrade the plasma quality. Thus, the surface to be coated with such plasma also suffers the detrimental effects of the plasma. The surface may comprise fragments, plasma may be not evenly distributed to form such a coating etc. which are problematic in accuracy demanding application, but may be not problematic, with paint or pigment for instance, provided that the defects keep below the detection limit of the very application.

The present methods ware out the target in a single use so that same target is not available for a further use from the same surface again. The problem has been tackled by utilising only a virgin surface of the target, by moving target material and/or the beam spot accordingly.

In machining or work-related applications the left-overs or the debris comprising some fragments also can make the cut-line un even and thus inappropriate, as the case could for instance in flow-control drillings. Also the surface could be formed to have a random bumpy appearance caused by the released fragments, which may be not appropriate in certain semiconductor manufacturing, for instance.

In addition, the mirror-film scanners moving back and forth generate inertial forces that load the structure itself, but also to the bearings to which the mirror is attached and/or which cause the mirror movement. Such inertia little by little may loosen the attachment of the mirror, especially if such mirror were working nearly at the extreme range of the possible operational settings, and may lead to roaming of the settings in long time scale, which may be seen from uneven repeatability of the product quality. Because of the stoppings, as well as the direction and the related velocity changes of the movement, such a mirror-film scanner has a very limited scanning width so to be used for ablation and plasma production. The effective duty cycle is relatively short to compared the whole cycle, although the operation is anyway quite slow. In the point of view of increasing the productivity of a system utilising mirror-film scanners, the plasma production rate is in prerequisite slow, scanning width narrow, operation unstable for long time period scales, but yield also a very high probability to get involved with unwanted particle emission in to the plasma, and consequently to the products that are involved with the plasma via the machinery and/or coating.

Summary of the invention

The fiber products such as paper, board and textiles provide would provide an excellent scaffold for introducing various thin-film solutions on bendable bodies.

The coating and especially uniform coating of heat-sensitive, large fiber surfaces with one or several of the following properties: excellent optical properties, chemical and/or wear resistance, thermal resistance, electrical resistivity, semi-conducting properties, enhanced coating adhesion, hydrofobicity, hydrophility, self-cleaning properties, chemical and/or biological activity and for example radiation shielding properties has remained an unsolved problem.

Thus, there is an unmet demand for achieving fiber based products comprising chemical or biological activities such as active filtering papers and medias, safety mask + air cleaning filters, bendable electronics, μ-metals, led-scaffolds, solar cell-structures, anti-bacterial properties, hydrophobic or hydrophilic properties, fire-retard properties, active packages for nutrition and daily food product packages, safety clothing, conducting textiles for determining human body functions, UV-protective properties for retaining the original appearance of the fiber body, anti-decay properties and biocide properties.

Neither recent high-technological coating methods, nor present coating techniques related to laser ablation either in nanosecond or cold ablation range (pico-, femto-second lasers) can provide any feasible method for industrial scale coating of fiber products comprising larger surfaces. The present CVD- and PVD-coating technologies require high-vacuum conditions making the coating process batch wise, thus non-feasible for industrial scale coating of most of the present fiber products. Moreover, the distance between the metal material to be coated and the coating material to be ablated is long, typically over 50 cm, making the coating chambers large and vacuum pumping periods time- and energy-consuming. Such high-volume vacuumed chambers are also easily contaminated with coating materials in the coating process itself, requiring continuous and time-consuming cleaning processes.

While trying to increase the coating production rate in present laser-assisted coating methods, various defects such as pinholes, increased surface roughness, decreased or disappearing optical properties, particulates on coating surface, particulates in surface structure affecting corrosion pathways, decreased surface uniformity, decreased adhesion, unsatisfactory surface thickness and tribological properties etc. take place.

A first object of this invention is to provide a new method how to solve a problem to coat a certain surface of a fiber product by pulsed laser deposition that so that the uniform surface area to be coated comprises at least 0.2 dm^2.

A second object of this invention is to provide new fiber products being coated by pulsed laser deposition so that the coated uniform surface area comprises at least 0.2 dm^2.

A third object of this invention is to provide at least a new method and/or related means to solve a problem how to provide available such fine plasma practically from any target to be used in coating of fiber products, so that the target material do not form into the plasma any particulate fragments either at all, i.e. the plasma is pure plasma, or the fragments, if exist, are rare and at least smaller in size than the ablation depth to which the plasma is generated by ablation from said target.

A fourth object of the invention is to provide at least a new method and/or related means to solve how to coat the uniform surface area of a fiber product with the fine plasma without particulate fragments larger in size than the ablation depth to which the plasma is generated by ablation from said target, i.e. to coat substrates with pure plasma originating to practically any material.

A fifth object of this invention is to is to provide a good adhesion of the coating to the uniform surface area of a fiber product by said pure plasma, so that wasting the kinetic energy to particulate fragments is suppressed by limiting the existence of the particulate fragments or their size smaller than said ablation depth. Simultaneously, the particulate fragments because of their lacking existence in significant manner, they do not form cool surfaces that could influence on the homogeneity of the plasma plume via nucleation and condensation related phenomena.

A sixth object of the invention is to provide at least a new method and/or related means to solve a problem how to provide a broad scanning width simultaneously with fine plasma quality and broad coating width even for large fiber bodies in industrial manner.

A seventh object of the invention is to provide at least a new method and/or related means to solve a problem how to provide a high repetition rate to be used to provide industrial scale applications in accordance with the objects of the invention mentioned above.
An eighth object of the invention is to provide at least a new method and/or related means to solve a problem how to provide fine plasma for coating of uniform fiber surfaces to manufacture products according to the first to seven objects, but still save target material to be used in the coating phases producing same quality coatings/thin films where needed.

A further object of the invention is to use such method and means according previous objects to solve a problem how to cold-work and/or coat surfaces for coated products. The present invention is based on the surprising discovery that fiber products comprising large surfaces can be coated with industrial production rates and excellent qualities regarding one or more of technical features such as optical transparency, chemical and/or wear resistance, scratch-free –properties, hydrofobicity, hydrophility, thermal resistance and/or conductivity, chemical activity, biological activity, irradiation shielding, coating adhesion, self-cleaning properties and possibly, particulate-free coatings, pinhole-free coatings and electronic conductivity or resistivity by employing ultra short pulsed laser deposition in a manner wherein pulsed laser beam is scanned with a rotating optical scanner comprising at least one mirror for reflecting said laser beam. Moreover, the present method accomplishes the economical use of target materials, because they are ablated in a manner accomplishing the reuse of already subjected material with retained high coating results. The present invention further accomplishes the coating of fiber products in low vacuum conditions with simultaneously high coating properties. Moreover, the required coating chamber volumes are dramatically smaller than in competing methods. Such features decrease dramatically the overall equipment cost and increase the coating production rate. In many preferable cases, the coating equipment can be fitted into production-line in online manner.

The coating deposition rates with 20W USPLD-apparatus are 2 mm^3/min. While increasing the laser power to 80 W, the USPLD coating deposition rate is increased to 8 mm^3/min, accordingly. According to the invention, the increase in deposition rate can now be fully employed to high quality coating production.

In this patent application the term "coating" means forming material of any thickness on a substrate. Coating can thus also mean producing thin films with thickness of e.g. < 1 μm.

Various embodiments of the inventions are combinable in suitable part.

When read and understood the invention, the skilled men in the art may know many ways to modify the shown embodiments of the invention, however, without leaving the scope of the invention, which is not limited only to the shown embodiments which are shown as examples of the embodiments of the invention.

Figures

The described and other advantages of the invention will become apparent from the following detailed description and by referring to the drawings where:

Fig 1. illustrates an exemplary galvano -scanner set-up comprising two galvano-scanners employed in state of the art cold ablation coating/thin-film production and in machining and other work-related applications. The number of galvano-scanners directing the laser beam varies but is typically limited to one single galvano-scanner,

Fig 2. illustrates ITO-coating on polycarbonate sheet (~100 mm x 30 mm) produced by employing a prior art vibrating mirror (galvo-scanner), in different ITO thin-film thicknesses (30 nm, 60 nm and 90 nm).

Fig 3. illustrates the situation wherein prior art galvanometric scanner is employed in scanning laser beam resulting in heavy overlapping of pulses with repetition rate of 2 Mhz.

Fig 4. illustrates one possible turbine scanner mirror employed in method according to the invention,

Fig 5. illustrates the movement of the ablating beam achieved by each mirror in the example of Fig 5,

Fig 6. illustrates beam guidance through one possible rotating scanner to be employed according to the invention,

Fig 7. illustrates beam guidance through one possible rotating scanner to be employed according to the invention,

Fig 8. illustrates beam guidance through one possible rotating scanner to be employed according to the invention,

Fig 9a. illustrates an embodiment according to the invention, wherein target material ablated by scanning the laser beam with rotating scanner (turbine scanner).

Fig 9b. illustrates an exemplary part of target material of Figure 9a.

Fig 9c. illustrates an exemplary ablated area of target material of Figure 9b.

Fig 10. illustrates an exemplary way according to the invention to scan and ablate target material with turbine scanner (rotating scanner).

Fig 11 a. illustrates plasma-related problems of known techniques.

Fig 11 b. illustrates plasma-related problems of known techniques.

Detailed Description of Embodiments of the Invention

According to the invention there is provided a method for coating a certain surface of a fibre product by laser ablation in which method the uniform surface area to be coated comprises at least 0.2 dm^2 and the coating is carried by employing ultra short pulsed laser deposition wherein pulsed laser beam is scanned with a rotating optical scanner comprising at least one mirror for reflecting said laser beam.

With fiber products is hereby meant but not limited to fiber products such as all paper and board products as well as textile products comprising chemical or biological activities such as active filtering papers and medias, safety mask + air cleaning filters, bendable electronics, μ-metals, led-scaffolds, solar cell-structures, anti-bacterial properties, hydrophobic or hydrophilic properties, fire-retard properties, active packages for nutrition and daily food product packages, safety clothing, conducting textiles for determining human body functions, UV-protective properties for retaining the original appearance of the fiber body, anti-decay properties and biocide properties. The fiber product according to the invention can comprise virtually whichever fiber, for example in form of paper, board or textile. With textile is hereby meant all fibrous products comprising woven structure, regardless the use. In other words, the textile is not limited to clothing.

According to one embodiment of the invention, textile materials are bent during the coating procedure in order to ensure the best possible coating quality for rough substrate.

The fiber product must not be necessarily of fiber as such. According to the invention, all the products comprising fiber surfaces regardless whether their fiber content is 100 % or 0.1% can be coated with now presented method.

Ultra Short Laser Pulsed Deposition is often shortened USPLD. Said deposition is also called cold ablation, in which one of the characteristic features is that opposite for example to competing nanosecond lasers practically no heat transfer takes place from the exposed target area to the surroundings of this area, the laser pulse energies being still enough to exceed ablation threshold of target material. The pulse lengths are typically under 50 ps, such as 5 – 30 ps. i.e. ultra short, the cold ablation being reached with pico-second, femto-second and atto-second pulsed lasers. The material evaporated from the target by laser ablation is deposited onto a substrate that is held near room temperature. Still, the plasma temperature reaches 1.000.000 K on exposed target area. The plasma speed is superior, gaining even 100.000 m/s and thus, better prospective for adequate adhesion of coating/thin-film produced.

In another preferred embodiment of the invention, said uniform surface area comprises at least 0.5 dm^2. In a still preferred embodiment of the invention, said uniform surface area comprises at least 1.0 dm^2. The invention accomplishes easily also the coating of products comprising uniform coated surface areas larger than 0.5 m^2, such as 1 m^2 and over. As the process is especially beneficial for coating large surfaces with high quality plasma, it meets an underserved or unserved market of several different metal products.

In industrial applications, it is important to achieve high efficiency of laser treatment. In cold ablation, the intensity of laser pulses must exceed a predetermined threshold value in order to facilitate the cold ablation phenomenon. This threshold value depends on the target material. In order to achieve high treatment efficiency and thus, industrial productivity, the repetition rate of the pulses should be high, such as 1 MHz, preferably over 2 MHz and more preferably over 5 MHz. As mentioned earlier, it is advantageous not to direct several pulses into same location of the target surface because this causes a cumulating effect in the target material, with particle deposition leading to bad quality plasma and thus, bad quality coatings and thin-films, undesirable eroding of the target material, possible target material heating etc. Therefore, to achieve a high efficiency of treatment, it is also necessary to have a high scanning speed of the laser beam. According to the invention, the velocity of the beam at the surface of the target should generally be more than 10 m/s to achieve efficient processing, and preferably more than 50 m/s and more preferably more than 100 m/s, even such speeds as 2000 m/s. However, in the optical scanners based on vibrating mirror the moment of inertia prevents achieving sufficiently high angular velocity of the mirror. The obtained laser beam at the target surface is therefore just a few m/s, figure 1 illustrating an example of such vibrating mirror, also called galvano-scanner.

As the present coating methods employing galvano-scanners can produce scanning widths at most 10 cm, preferably less, the present invention also accomplishes much broader scanning widths such as 30 cm and even over 1 meter with simultaneously excellent coating properties and production rates.

According to one embodiment of the invention, rotating optical scanner is here meant scanners comprising at least one mirror for reflecting laser beam. Such a scanner and its applications are described in patent application FI20065867. According to another embodiment of the invention, rotating optical scanner comprises at least three mirrors for reflecting laser beam. In one embodiment of the invention, in the coating method employs a polygonal prism illustrated in figure 4. Here, a polygonal prism has faces 21, 22, 23, 24, 25, 26, 27 and 28. Arrow 20 indicates that the prism can be rotated around its axis 19, which is the symmetry axis of the prism. When the faces of the prism of the Fig. 4 are mirror faces, advantageously oblique in order to achieve scanning line, arranged such that each face in its turn will change, by means of reflection, the direction of radiation incident on the mirror surface as the prism is rotated around its axis, the prism is applicable in the method according to an embodiment of the invention, in its radiation transmission line, as part of a rotating scanner, i.e. turbine scanner. Fig. 4 shows 8 faces, but there may be considerably more faces than that, even dozens or hundreds of them. Fig. 4 also shows that the mirrors are at the same oblique angle to the axis, but especially in an embodiment including several mirrors, the said angle may vary in steps so that, by means of stepping within a certain range, a certain stepped shift on the work spot is achieved on the target, illustrated in Fig. 5, among other things. The different embodiments of invention are not to be limited into various turbine scanner mirror arrangements regarding for example the size, shape and number of laser beam reflecting mirrors.

The structure of the turbine scanner, Fig. 4, includes at least 2 mirrors, preferably more than 6 mirrors, e.g. 8 mirrors (21 to 28) positioned symmetrically around the central axis 19. As the prism 21 in the turbine scanner rotates 20 around the central axis 19, the mirrors direct the radiation, a laser beam, for instance, reflected from spot 29, accurately onto the line-shaped area, always starting from one and the same direction (Fig. 5). The mirror structure of the turbine scanner may be non-tilted (Fig. 6) or tilted at a desired angle, e.g. Figs. 7 and 8. The size and proportions of the turbine scanner can be freely chosen. In one advantageous embodiment of the coating method it has a perimeter of 30 cm, diameter of 12 cm, and a height of 5 cm.

In an embodiment of the invention it is advantageous that the mirrors 21 to 28 of the turbine scanner are preferably positioned at oblique angles to the central axis 19, because then the laser beam is easily conducted into the scanner system.

In a turbine scanner according to be employed according to an embodiment of the invention (Fig. 4) the mirrors 21 to 28 can deviate from each other in such a manner that during one round of rotational movement there are scanned as many line-shaped areas (Fig. 5) 29 as there are mirrors 21 to 28.

According to the invention, the surface to be coated can comprise whole or a part of the fiber product surface. In one preferred embodiment of the invention laser ablation is carried out under vacuum of 10^{-1} to 10^{-12} atmospheres. High vacuum conditions require quite long pumping times, and thus prolonged production times of coatings. With certain high end-products this is not so big problem, but with for example commodity products especially comprising larger surfaces this definitely is. If taking into account to for example novel chemically/biologically active or inert coatings, μ-metal-coatings, anti-bacterial coatings, hydrophobic or hydrophilic properties comprising coatings, thermally resistant and/or thermally conductive coatings, anti-decay coatings, fire-retard properties, electrically conductive or resistive coatings and possibly simultaneously excellent transparencies, there simply aren't any coating methods available for said products, neither from technological point of view and/or from economical point of view.

Thus, in a specially preferred embodiment of invention, the laser ablation is carried out under vacuum of 10^{-1} to 10^{-4} atmospheres. According to the invention, excellent coating/thin-film properties can be achieved already in low atmospheres, leading to dramatically decreased processing times and enhanced industrial applicability.

According to the invention it is possible to conduct the coating in a manner wherein the distance between the target material and said uniform surface area to be coated is under 25 cm, preferably under 15 cm and most preferably under 10 cm. This accomplishes the development of coating chambers with drastically diminished volumes, making the overall price of coating production lines lower and decreasing further the time required for vacuum pumping.

In a preferred embodiment of the invention the ablated surface of said target material can be repeatedly ablated in order to produce defect-free coating. In case of most of the present coating technologies, the target material wears unevenly in a manner that the affected area cannot be reused for ablation and must thus be either discarded or sent for regeneration after certain use. The problem has been tackled by developing different techniques for feeding constantly new, non-ablated target surface for coating purposes by for example moving the target material in x/y-axis or by rotating a cylinder-formed target material. The present invention accomplishes simultaneously excellent coating properties and production rates as well as use of target material in a way wherein the good quality plasma retains its quality throughout the use of substantially whole piece of target material. Preferably, more than 50% of the single target material weight is consumed to production of good quality plasma according to the invention. With good quality plasma is hear meant plasma for producing defect-free coatings and thin-films, the high quality of plasma plume being maintained at high pulse frequencies and deposition rates. Some of such properties are described here below.

According to one embodiment of the invention, the average surface roughness of produced coating on said uniform surface area is less than 100 nm as scanned from an area of 1 μm^2 with Atomic Force Microscope (AFM). More preferably, the average surface roughness is less than 30 nm. With average surface roughness is here meant the average deviation from the centre line average curve fitted by a proper procedure, such as those available in AFM or profilemeter. The surface roughness affects amongst the other the wear- and scratch-free properties, tribological properties as well as the transparency of coating on metal products coated according to the invention.

In a still preferable embodiment of the invention, the optical transmission of produced coating on said uniform surface area is no less than 88%, preferably no less than 90% and most preferably no less than 92%. It can even be higher than 98%. The optical transparency of a coating in metal products is especially important in uses wherein the original metallic look is preferred in addition to other advantages gained by the coating according to invention.

In another embodiment of the invention, produced coating on said uniform surface area contains less than one pinhole per 1 mm^2, preferably less than one pinhole per 1 cm^2 and most preferably no pinholes at said uniform surface area. Pinhole is a hole going through or substantially through the coating. Pinholes provide a platform for erosion of the originally coated material for example by chemical or environmental factors.

Thus, in another preferred embodiment said uniform surface area is coated in a manner wherein the first 50% of said coating on said uniform surface area does not contain any particles having a diameter exceeding 1000 nm, preferably 100 nm and most preferably 30 nm. If the early stages of the coating manufacturing process produce micrometer size particles, such particles can cause open corrosion pathways in the next layers of produced coating. Moreover, due to irregular shape of particles, it is extremely difficult to seal the surface underneath such particles. Additionally, such particles increase surface roughness substantially. The present method allows even here increased lifetime and lowered maintenance cost of different fiber products.

The fiber product itself can comprise virtually whichever fiber such as natural fiber, semi-synthetic fiber or synthetic fiber. The fiber product can be for instance in paper or board form or in the form of textile.

According to the invention, said uniform surface area of fiber product is coated with metal, metal oxide, metal nitride, metal carbide or mixtures of these. Non-limiting examples of metals include aluminum, molybdenum, titan, zirconium, copper, yttrium, magnesium, zinc, chromium, silver, gold, cobalt, tin, nickel, tantalum, gallium, manganese, rhodium, ruthenium, lead, vanadium, platinum and virtually whichever metal.

When producing coatings according to invention which comprise both excellent optical, wear, and scratch-free properties, especially advantageous metal oxides are for example aluminum oxide and its different composites such as aluminum titan oxide (ATO). Due to its resistivity, high-optical transparencies possessing high-quality indium tin oxide (ITO) is especially preferred in applications wherein the coating can be employed to warm-up the coated surface. It can also be employed in solar-control. Ytrium stabilized zirconium oxide is another example of different oxides possessing both excellent optical, wear-resistant and scratch-free properties. Some metals can be applied in solar cell applications.

According to the invention, the solar cell structures can be grown on fibre bodies, and in especially preferable form on bendable fiber bodies. As with existing technologies on glass and plastics, the demand for reproducible, low-cost and high-quality coatings producing methods is a prerequisite.

The optical properties of metal-derived thin-films are somewhat different from those of bulk metals. In ultra thin films (< 100 Å thick) variations make the concept of optical constants problematic, the quality and surface roughness of the coating (thin film) being thus critical technical features. Such coatings can easily be produced with the method of present invention.

As most of the pure metals, all the metals usually employed as mirrors (Al, Ag, Au, Cu, Rh and Pt) regardless their use are easily subjected to oxidation (Al), sulfide tarnishing (Ag) and mechanical scratching. Mirrors must therefore be coated with hard transparent protective layers. Thus, films of SiO, SiO_2 and Al_2O_3 are commonly used to protect evaporated Al mirrors, but usually at the cost of increasing absorbance. The problem can be tackled with present invention by producing hard coatings comprising better optical transparencies and heat conductivities. At present, various substrate film thin films (e.g. Al_2O_3, SiO) are used to improve adhesion, but Ag film use in mirrors remains restricted. The adhesion of appropriate films can be enhanced by producing both now employed films and other enhanced carbon-based films such as diamond and carbon nitride with the method of present invention.

Dielectric materials employed in present optical coating applications include fluorides (e.g. MgF_2, CeF_3), oxides (e.g. Al_2O_3, TiO_2, SiO_2), sulfides (e.g. ZnS, CdS) and assorted compounds such as ZnSe and ZnTe. An essential common feature of dielectric optical materials is their very low absorption ($\alpha < 10^3$/cm) in some relevant portion of the spectrum; in this region they are essentially transparent (e.g. fluorides and oxides in the visible and infrared, chalcogenides in the infrared).

Dielectric coatings can now be advantageously produced on fiber bodies with the method of present invention.

Somewhere between dielectrics and metals is a class of materials called transparent conductors. According to electromagnetic theory, high conductivity and optical transparency are mutually exclusive properties since photons are strongly absorbed by the high density of charge carriers. Although there are materials that separately are far more conductive or transparent, the transparent conductors dealt with here exhibit a useful compromise of both desirable properties. Broadly speaking, transparent conducting films consist either of very thin metals or semi-conducting oxides and/ and most presently even nitrides such as indiumgalliumnitride in solar cell applications. The first widespread use of such films was to transparent electrical heaters in aircraft windshield de-icing during World War II. Today, they are somewhat used for automobile and airplane window defrosters, liquid crystal and gas-discharge displays, front electrodes for solar cells, antistatic coatings, heating stages for optical microscopes, IR-reflectors, photoconductors in television camera vidicons, and Pockel cells for laser Q-switches.

Metals that have conventionally been employed as transparent conductors include Au, Pt, Rh, Ag, Cu, Fe and Ni. Simultaneous optimization of conductivity and transparency presents a considerable challenge in film deposition. At one extreme are discontinuous islands of considerable transparency but high resistivity; at the other are films that coalesce early and are continuous, possessing high conductivity but low transparency. For these reasons, the semi-conducting oxides such as SnO_2, In_2O_3, CdO, and, more commonly, their alloys (e.g. ITO), doped In_2O_3 (with Sn, Sb) and doped SnO_2 (with F, Cl, etc.) are used.

The prior art deposition systems include both chemical and physical methods. Hydrolysis of chlorides and pyrolysis of metalorganic compounds are examples of the former, reactive evaporation and sputtering in oxygen environment being examples of the latter – none of the systems being beneficial for heat sensitive fiber bodies. Optimum film properties require maintenance of tight stoichiometry.

The prior art techniques employ commonly glass substrates and in such techniques the glass body is commonly heated up close to the softening temperature. In that system, care must be taken to prevent stresses and warpage of the final product. Such system can not be employed at all to heat sensitive plastic bodies. Thus, the present method of invention also solves the problems associated with softening temperature with glass products and yields said films in high quality and economically feasible manner.

For the most part, n in fluoride and oxide films has a value less than 2 at the reference wavelength of 0.55 µm. For many applications, however, it is important to have films with higher refractive index in the visible range. To meet these needs, materials like ZnS and XnSe are typically employed. High transmittance is an essential requirement in optical films, and as an arbitrary criterion only materials with an absorption constant less than α = 10^3/cm are entered in the following list: NaF (c), LiF (c), CaF_2 (c), Na_3AlF_6 (c), AlF_3 (a), MgF_2 (c), ThF_4 (a), LaF_3 (c), CeF_3 (c), SiO_2 (a), Al_2O_3 (a), MgO (c), Y_2O_3 (a), La_2O_3 (a), CeO_2 (c), ZrO_2 (a), SiO (a), ZnO (c), TiO_2, ZnS (c), CdS (c), ZnSe (c), PbTe, Si (a), Ge (a); (c) = crystalline; (a)= amorphous.

In practice, however, only films with significantly lower absorption can be tolerated. For example, in laser AR coatings losses must be kept to less than 0.01%, corresponding to $k \approx 4 \times 10$ -5 or $\alpha = 10$/cm at $\lambda = 5500$ Å.

The present method of invention solves the problems associated difficulties to yield films with higher refractive index in the visible range and accomplishes the production of said films in high quality and economically feasible manner. Moreover, it is now possible to produce above listed materials and compounds in crystalline form, enhancing further the film properties.

According to one embodiment of the invention certain metal oxides such as titan oxide and zinc oxide can be applied on surface thicknesses providing UV-protection of produced coating. Such properties are highly desired in order to accomplish the long-term use of several fiber products in both interior, exterior as well as in clothing use.

The metal oxide coatings can be produced by either ablating metal or metals in active oxygen atmosphere or by ablating oxide-materials. Even in latter possibility, it is possible to enhance the coating quality and/or production rate by conducting the ablation in oxygen atmosphere. The same applies for producing nitrides in various nitrogen atmospheres.

According another embodiment of the invention, said uniform surface area of fiber product is coated with carbon material comprising over 90 atomic-% of carbon, with more than 70% of sp^3-bonding. Such materials include for example amorphous diamond, nano-crystalline diamond or even pseudo-monocrystalline diamond. Various diamond coatings give the metal product excellent wear- and scratch-free properties but increase also the heat-conductivity and –resistance.

In a still another embodiment of the invention, said uniform surface area of fiber product is coated with material comprising carbon, nitrogen and/or boron in different ratios. Such materials include boron carbon nitride, carbon nitride (both C_2N_2 and C_3N_4), boron nitride, boron carbide or phases of different hybridizations of B-N, B-C and C-N phases. Said materials are diamond-like materials having low densities, are extremely wear-resistant, and are generally chemically inert.

According to one embodiment of the invention certain uniform surface area of fiber product is coated with organic polymer material. Such materials include but are not limited to organic colorants, conducting polymers, chitosan and its derivatives, polysiloxanes, and other different organic polymers.

By coating fiber product with chitosan there are promising perspectives to produce a new class of fiber products for both interior and exterior use. Here, polysiloxanes are especially advantageous for manufacturing products with relatively high wear-resistance and scratch-free properties with simultaneously excellent optical transparencies.

According to still another embodiment of invention said uniform surface area is coated with inorganic material. Such materials include but are not limited to for instance stone and ceramic derived materials.

According to one embodiment of the invention, both present and new coating materials such as colorants can applied in paper and board production in order to achieve products comprising nano-scale features in or on said fiber product. Due to nature of nanotechnology, such features can be achieved with minimal material volumes and thus, in economical and environmentally manner.

According to another embodiment of the invention, both present and new colorants and active species in terms of biological, chemical, radiative, electrically and/or thermally conducting, electrically resisting activities can applied in textile production in order to achieve products comprising nano-scale features in or on said fiber product. Due to nature of nanotechnology, such features can be achieved with minimal material volumes and thus, in economical and environmentally manner.

According to still another embodiment of the invention the previous mentioned active species are applied in paper or board product.

In one preferred embodiment of the invention, different fiber bodies are coated by ablating a target material comprising pink agate resulting in colored product retaining the original agate color.

According to one embodiment of invention, said uniform surface of the fiber product is coated with only one single coating. According to another embodiment of the invention, said uniform surface of the fiber product is coated with multilayered coating. Several coatings can be produced in for different reasons. One reason might be to enhance the adhesion of certain coatings to fiber product surfaced by manufacturing a first set of coating having better adhesion to fiber surface and possessing such properties that the following coating layer has better adhesion to said layer than to fiber surface itself. Additionally, the multilayered coating can possess several functions not achievable without said structure. The present invention accomplishes the production of several coatings in one single coating chamber or in the adjacent chambers.

The present invention further accomplishes the production of composite coatings to fiber product surface by ablating simultaneously one composite material target or two or more target materials comprising one or more substances.

According to invention the thickness of said coating on uniform surface of fiber product is between 20 nm and 20 µm, preferably between 100 nm and 5 µm. The coating thicknesses must not be limited to those, because the present invention accomplishes the preparation of molecular scale coatings on the other hand, very thick coatings such as 100 µm and over, on the other hand.

The present invention further accomplishes the preparation of 3D-structures employing the fiber component as a scaffold for growing said 3D-structure. Due to their organic nature, said scaffold can be easily decomposed by for example heating or chemical means.

According to the invention there is also provided a fiber product comprising a certain surface being coated by laser ablation wherein the coated uniform surface area comprises at least 0.2 dm^2 and that the coating has been carried by employing ultra short pulsed laser deposition wherein pulsed laser beam is scanned with a rotating optical scanner comprising at least one mirror for reflecting said laser beam. The benefits received with these products are described in more detail in the previous description of the method.

In one embodiment of the invention said uniform surface area comprises at least 0.5 dm^2. In a more preferable embodiment of the invention said uniform surface area comprises at least 1.0 dm^2. The invention accomplishes easily also the products comprising uniform coated surface areas larger than 0.5 m^2, such as 1 m^2 and over.

According to one embodiment of the invention the average surface roughness of produced coating on said uniform surface area is less than 100 nm as scanned from an area of 1 μm^2 with Atomic Force Microscope (AFM). More preferably, the average surface roughness is less than 30 nm. With average surface roughness is here meant the average deviation from the centre line average curve fitted by a proper procedure, such as those available in AFM or profilemeter. The surface roughness affects amongst the other the wear- and scratch-free properties, tribological properties as well as the transparency of coating on metal products coated according to the invention.

According to another embodiment of the invention the optical transmission of produced coating on said uniform surface area is no less than 88%, preferably no less than 90% and most preferably no less than 92%. In some cases the optical transmission can exceed 98%. The optical transparency of a coating in fiber products is important in uses wherein the original fibrous look is preferred in addition to other gained advantages by the coating according to the invention.

Additionally, such feature is important in for example embodiments of the invention wherein various layers of coatings for various electronic devices built on fiber body are deposited.

According to still another embodiment of the invention said produced coating on said uniform surface area contains less than one pinhole per 1 mm^2, preferably less than one pinhole per 1 cm^2 and most preferably no pinholes at said uniform surface area.

According to still another embodiment of the invention said uniform surface area is coated in a manner wherein the first 50% of said coating on said uniform surface area does not contain any particles having a diameter exceeding 1000 nm, preferably 100 nm and most preferably 30 nm.

The fiber product according to the invention can comprise virtually whichever fiber, for example in form of paper, board or textile. With textile is hereby meant all fibrous products comprising woven structure, regardless the use. In other words, the textile is not limited to clothing.

As mentioned earlier, the definition of fiber product in this connection must be understand in a manner, wherein the product comprises a certain fiber surface, which has been coated according to now invented method. The fiber content of the product scaffold (uncoated product) can thus vary everywhere between 0.1 to 100%.

According to one embodiment of the invention said uniform surface area of fiber product is coated with metal, metal oxide, metal nitride, metal carbide or mixtures of these. The possible metals were described earlier in description of now invented coating method.

According to another embodiment of the invention said uniform surface area of fiber product is coated with carbon material comprising over 90 atomic-% of carbon, with more than 70% of sp^3-bonding. The possible carbon materials were described earlier in description of now invented coating method.

According to still another embodiment of the invention said uniform surface area of fiber product is coated with material comprising carbon, nitrogen and/or boron in different ratios. Such materials were described earlier in description of now invented coating method.

According to still another embodiment of the invention said uniform surface area of fiber product is coated with organic polymer material. Such materials were described earlier in more detail in description of now invented coating method.

In certain applications it is important to be able to control the heat and moisture transfer of the fiber body. Such products include but are not restricted to medical products. According to one embodiment of the invention, said heat and/moisture transfer of the fiber based product can be controlled by introducing certain diamond coatings on the fiber body surface. The coating and thus, controlling properties can be enhanced by diamond (DLC) composite coatings, which comprise in addition to DLC also silicon and/or Teflon material. Preferably, silicon and/or Teflon materials are incorporated in coating structure as fragments of polymer chains.

According one embodiment of the invention said uniform surface area is coated with inorganic material. Such materials were described earlier in more detail in description of now invented coating method.

According to another preferred embodiment of the invention said uniform surface of fiber product is coated with multilayered coating. According to another preferred embodiment of the invention said uniform surface of fiber product is coated with single coating layer.

According to one preferred embodiment of the invention the thickness of said coating on uniform surface of fiber product is between 20 nm and 20 µm, preferably between 100 nm and 5 µm. The invention accomplishes also coated fiber products comprising one or several atomic layer coatings and thick coatings such as exceeding 100 µm, for example 1 mm. The present invention further accomplishes the 3D-structures prepared by employing the fiber component as a scaffold for growing said 3D-structure.

Examples

Example to demonstrate known art problems – laser technology

Figure 2 represents the ITO-coating on polycarbonate sheet (~100 mm x 30 mm) produced by employing a prior art optical scanner, namely vibrating mirror (galvo-scanner), in different ITO thin-film thicknesses (30 nm, 60 nm and 90 nm). Although the ITO-coating is not deposited on metal substrate, the picture clearly demonstrates some of the problems associated with employing vibrating mirror as an optical scanner especially in ultra short pulsed laser deposition (USPLD) but also in laser assisted coatings in general. As a vibrating mirror changes its direction of angular movement at its end positions, and due to moment inertia, the angular velocity of the mirror is not constant near to its end positions. Due to vibrating movement, the mirror continuously brakes up and stops before speeding up again, causing thus irregular treatment of the target material at the edges of the scanned area. As it can be seen from figure 2, this in turn results in low quality plasma comprising particles especially in the edges of the scanned area and finally, in low quality and seemingly uneven coating result.

The coating parameters have been selected in order to demonstrate the uneven distribution of ablated material due to the nature of employed scanner. If selecting the parameters appropriately, the film quality can be enhanced, problems becoming invisible but not excluded.

Example to demonstrate known art problems –laser technology

Conventionally galvanometric scanners are used to scan a laser beam with a typical maximum speed of about 2-3 m/s, in practice about 1 m/s. This means that even 40-60 pulses are overlapping with a repetition rate of 2 MHz (Fig. 3).

Example to demonstate known art problems – laser technology

Plasma related quality problems are demonstrated in Figure 11a and 11b, which indicate plasma generation according to known techniques. A laser pulse □ 1114 hits a target surface 1111. As the pulse is a long pulse, the depth h and the beam diameter d are of the same magnitude, as the heat of the pulse 1114 also heat the surface at the hit spot area, but also beneath the surface 1111 in deeper than the depth h. The structure experiences thermal shock and tensions are building, which while breaking, produce fragments illustrated F. As the plasma may be in the example quite poor in quality, there appears to be also molecules and clusters of them indicate by the small dots 1115, as in the relation to the reference by the numeral 1115 for the nuclei or clusters of similar structures, as formed from the gases 1116 demonstrated in the Figure 11b. The letter "o"s demonstrate particles that can form and grow from the gases and/or via agglomeration. The released fragments may also grow by condensation and/or agglomeration, which is indicated by the curved arrows from the dots to Fs and from the os to the Fs. Curved arrows indicate also phase transitions from plasma 1113 to gas 1116 and further to particles 1115 and increased particles 1117 in size. As the ablation plume in Figure 11b can comprise fragments F as well as particles built of the vapours and gases, because of the bad plasma production, the plasma is not continuous as plasma region, and thus variation of the quality may be met within a single pulse plume. Because of defects in composition and/or structure beneath the deepness h as well as the resulting variations of the deepness (Figure 11a), the target surface 1111 in Figure 11b is not any more available for a further ablations, and the target is wasted, although there were some material available.

Such problems are common with nanosecond-lasers in general, and present pico-second lasers, if they were employing the state of the art scanners.

Example of invention - 1

Figure 9a demonstrates a target material ablated with pico-second –range pulsed laser employing rotating scanner with speed accomplishing the ablation of target material with slight overlapping of adjacent pulses, avoiding the problems associated with prior art galvano-scanners. Figure 9b shows enlarged picture of one part of the ablated material, clearly demonstrating the smooth and controlled ablation of material on both x- and y-axis and thus, generation of high quality, particle-free plasma and further, high quality thin-films and coatings. Figure 9c demonstrates one example of possible x- and y-dimensions of one single ablation spot achieved by one or few pulses. Here, it can be clearly seen, that the invention accomplishes the ablation of material in a manner wherein the width of the ablated spot is always much bigger than the depth of the ablated spot area. Theoretically, the possible particles (if they would be generated) could now have a maximum size of the spot depth. The rotating scanner now accomplishes the production of good quality, particle free plasma with great production rate, with simultaneously large scanning width, especially beneficial for substrates comprising large surface areas to be coated. Furthermore, the figures 9a, 9b and 9c clearly demonstrate that opposite to present techniques, the already ablated target material area can be ablated for new generation of high class plasma – reducing thus radically the overall coating/thin-film producing cost.

Example of invention- 2

Figure 10 demonstrates an example wherein coating is carried out by employing a pico-second USPLD-laser and scanning the laser pulses with turbine scanner. Here, the scanning speed is 30 m/s, the laser spot-width being 30 μm. In this example, there is an 1/3 overlapping between the adjacent pulses.

Examples of invention – coated products

The following samples were grown on various fiber substrates by employing ultra short pulsed laser deposition (USPLD) with a picosecond-range laser (X-lase, 20-80 W) at 1064 nm. Substrate temperature varied from room temperature to 200 °C and target temperature in the range of room temperature to 700 °C. Both oxides, sintered graphite and various metal targets were employed. When employing oxygen atmosphere, the oxygen pressure varied n the range of 10^{-4} to 10^{-1} mbar. The employed scanner was a rotating mirror scanner accomplishing tunable velocity of the beam at the surface of the target between 1 m/s to 350 m/s. The employed repetition rates varied between 1 to 30 MHz, clearly demonstrating the importance of both the scanner and high repetition rates when producing high quality coatings in industrial manner. Deposited films were characterized by confocal microscope, FTIR and Raman spectroscopy, AFM, optical transmission measurements, ESEM and in some cases, electrical measurements (University of Kuopio, Finland; ORC, Tampere, Finland and Corelase Oy, Tampere Finland). The employed spot sizes varied between 20 to 80 μm.

Example 1

An ark of copy paper (80 g/m^2, white, uncoated) comprising 100 mm x 100 mm was coated by ablating sintered carbon with pulse repetition rate of 4 MHz, pulse energy 5 μJ, pulse length 20 ps and the distance between the target material and surface to be coated was 60 mm. The vacuum level was 10^{-5} atmospheres during the coating process. The process resulted in a uniform pale-brown coloured, transparent coating. The coating thickness was approximately 210 nm.

Example 2

An ark of copy paper (80 g/m^2, white, uncoated) comprising 100 mm x 100 mm was coated by ablating titanium dioxide with pulse repetition rate of 4 MHz, pulse energy 5 µJ, pulse length 20 ps and the distance between the target material and surface to be coated was 60 mm. The vacuum level was 10^{-5} atmospheres during the coating process. The process resulted in a uniform and transparent coating. The coating thickness was approximately 110 nm.

Example 3

An ark of copy paper (80 g/m^2, white, uncoated) comprising 100 mm x 100 mm was coated by ablating ITO in oxide form (90 wt.% In_2O_3; 10 wt.% SnO_2) with pulse repetition rate of 3 MHz, pulse energy 5 µJ, pulse length 20 ps and the distance between the target material and surface to be coated was 40 mm. The vacuum level was 10^{-6} atmospheres during the coating process. The process resulted in a uniform, transparent coating. The coating thickness was measured to 570 nm.

Example 4

An ark of copy paper (110 g/m^2, white, uncoated) comprising 100 mm x 100 mm was coated by ablating silver metal with pulse repetition rate of 4 MHz, pulse energy 5 µJ, pulse length 20 ps and the distance between the target material and surface to be coated was 60 mm. The vacuum level was 10^{-5} atmospheres during the coating process. The process resulted in a uniform coating. The coating thickness was approximately 110 nm.

Example 5

An ark of white board (300 g/m^2, white) comprising 100 mm x 100 mm was coated by ablating cold-pressed chitosan with pulse repetition rate of 4 MHz, pulse energy 5 µJ, pulse length 20 ps and the distance between the target material and surface to be coated was 40 mm. The vacuum level was 10^{-5} atmospheres during the coating process. The process resulted in partially opaque coating possessing coating thickness of 220 nm.

Example 7

An ark of white board (300 g/m^2, white) comprising 100 mm x 100 mm was coated by ablating pink agate (crushed and sintered) with pulse repetition rate of 1 MHz and the distance between the target material to be coated was 4 cm. The vacuum level was 10^{-4} atmospheres during the coating process. The processes resulted in pink agate colored, opaque coating comprising thickness of 270 nm.

Example 8

According to example 7, a piece of textile material made of polyamide (natural white) cut to 100 mm x 100 mm was coated by ablating pink agate (crushed and sintered) with pulse repetition rate of 1 MHz and the distance between the target material to be coated was 4 cm. The vacuum level was 10^{-4} atmospheres during the coating process. The processes resulted in pink agate coloured, opaque coating comprising thickness of 280 nm.

Example 9

A piece of textile material made of polyamide (natural white) cut to 100 mm x 100 mm was coated by ablating silver metal with pulse repetition rate of 4 MHz, pulse energy 5 µJ, pulse length 20 ps and the distance between the target material and surface to be coated was 60 mm. The vacuum level was 10^{-5} atmospheres during the coating process. The process resulted in a uniform and transparent coating. The coating thickness was approximately 110 nm. The silver coating seemed to oxidize easily.

Example 10

A piece of cotton material was cut to 100 mm x 100 and coated by ablating ITO in oxide form (90 wt.% In_2O_3; 10 wt.% SnO_2) with pulse repetition rate of 2 MHz, pulse energy 5 µJ, pulse length 20 ps and the distance between the target material and surface to be coated was 4 mm. The vacuum level was 10^{-3} atmospheres during the coating process. The process resulted in a uniform, transparent coating. The coating thickness was measured approximately 100 nm and the average surface roughness was typically determined to be below 10 nm.

Claims

1. A method for coating a certain surface of a fiber product by laser ablation, **characterized** in that the uniform surface area to be coated comprises at least 0.2 dm^2 and the coating is carried by employing ultra short pulsed laser deposition wherein pulsed laser beam is scanned with a rotating optical scanner comprising at least one mirror for reflecting said laser beam.

2. A method according to claim 1, **characterized** in that said uniform surface area comprises at least 0.5 dm^2.

3. A method according to claim 1-2, **characterized** in that said uniform surface area comprises at least 1.0 dm^2.

4. A method according to claim 1-3, **characterized** in that the employed pulse frequency of said laser deposition is at least 1 MHz.

5. A method according to any of the preceding claims, **characterized** in that said laser ablation is carried out under vacuum of 10^{-1} to 10^{-12} atmospheres.

6. A method according to claim 5, **characterized** in that said laser ablation is carried out under vacuum on 10^{-1} to 10^{-4} atmospheres.

7. A method according to any of the preceding claims, **characterized** in that the distance between the target material and said uniform surface area to be coated is under 25 cm, preferably under 15 cm and most preferably under 10 cm.

8. A method according to any of the preceding claims, **characterized** in that the ablated surface of said target material can be repeatedly ablated in order to produce defect-free coating.

9. A method according to claim 1, **characterized** in that the average surface roughness of produced coating on said uniform surface area is less than 100 nm as scanned from an area of 1 μm^2 with Atomic Force Microscope (AFM).

10. A method according to claim 1, **characterized** in that the optical transmission of produced coating on said uniform surface area is no less than 88%, preferably no less than 90% and most preferably no less than 92%.

11. A method according to claim 1, **characterized** in that the said produced coating on said uniform surface area contains less than one pinhole per 1 mm^2,

preferably less than one pinhole per 1 cm^2 and most preferably no pinholes at said uniform surface area.

12. A method according to claim 1, **characterized** in that said uniform surface area is coated in a manner wherein the first 50% of said coating on said uniform surface area does not contain any particles having a diameter exceeding 1000 nm, preferably 100 nm and most preferably 30 nm.

13. A method according to claim 1, **characterized** in that said uniform surface area of fiber product is coated with metal, metal oxide, metal nitride, metal carbide or mixtures of these.

14. A method according to claim 1, **characterized** in that said uniform surface area of fiber product is coated with carbon material comprising over 90 atomic-% of carbon, with more than 70% of sp^3-bonding.

15. A method according to claim 1, **characterized** in that said uniform surface area of fiber product is coated with material comprising carbon, nitrogen and/or boron in different ratios.

16. A method according to claim 1, **characterized** in that said uniform surface area of fiber product is coated with organic polymer material.

17. A method according to claim 1, **characterized** in that said uniform surface area is coated with inorganic material.

18. A method according to any of the preceding claims, **characterized** in that said uniform surface of fiber product is coated with multilayered coating.

19. A method according to any of the preceding claims, **characterized** in that the thickness of said coating on uniform surface of metal product is between 20 nm and 20 μm, preferably between 100 nm and 5 μm.

20. A fiber product comprising a certain surface being coated by laser ablation, **characterized** in that the coated uniform surface area comprises at least 0.2 dm^2 and that the coating has been carried by employing ultra short pulsed laser deposition wherein pulsed laser beam is scanned with a rotating optical scanner comprising at least one mirror for reflecting said laser beam.

21. A fiber product according to claim 20, **characterized** in that said uniform surface area comprises at least 0.5 dm^2.

22. A fiber product according to claim 20-21, **characterized** in that said uniform surface area comprises at least 1.0 dm^2.

23. A fiber product produced coating on said uniform surface area is less than 100 nm as scanned from an area of 1 μm^2 with Atomic Force Microscope (AFM).

24. A fiber product according to claim 20, **characterized** in that the optical transmission of produced coating on said uniform surface area is no less than 88%, preferably no less than 90% and most preferably no less than 92%.

25. A fiber product according to claim 20, **characterized** in that the said produced coating on said uniform surface area contains less than one pinhole per 1 mm^2, preferably less than one pinhole per 1 cm^2 and most preferably no pinholes at said uniform surface area.

26. A fiber product according to claim 20, **characterized** in that said uniform surface area is coated in a manner wherein the first 50% of said coating on said uniform surface area does not contain any particles having a diameter exceeding 1000 nm, preferably 100 nm and most preferably 30 nm.

27. A fiber product according to claim 20, **characterized** in that said uniform surface area of fiber product is coated with metal, metal oxide, metal nitride, metal carbide or mixtures of these.

28. A fiber product according to claim 20, **characterized** in that said uniform surface area of fiber product is coated with carbon material comprising over 90 atomic-% of carbon, with more than 70% of sp^3-bonding.

29. A fiber product according to claim 20, **characterized** in that said uniform surface area of fiber product is coated with material comprising carbon, nitrogen and/or boron in different ratios.

30. A fiber product according to claim 20, **characterized** in that said uniform surface area of fiber product is coated with organic polymer material.

31. A fiber product according to claim 20, **characterized** in that said uniform surface area is coated with inorganic material.

32. A fiber product according to any of the preceding claims 20-31, **characterized** in that said uniform surface of fiber product is coated with multilayered coating.

33. A fiber product according to any of the preceding claims 20-32, **characterized** in that the thickness of said coating on uniform surface of fiber product is between 20 nm and 20 μm, preferably between 100 nm and 5 μm.

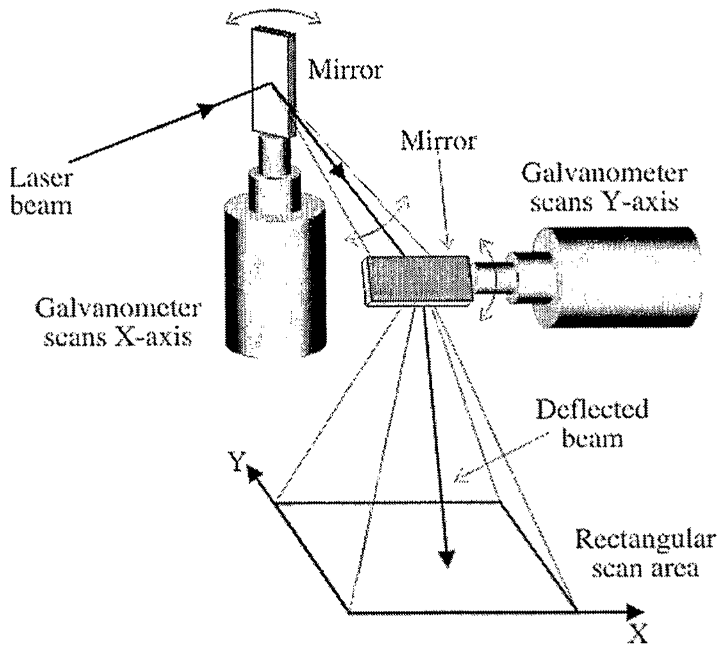


Figure 1

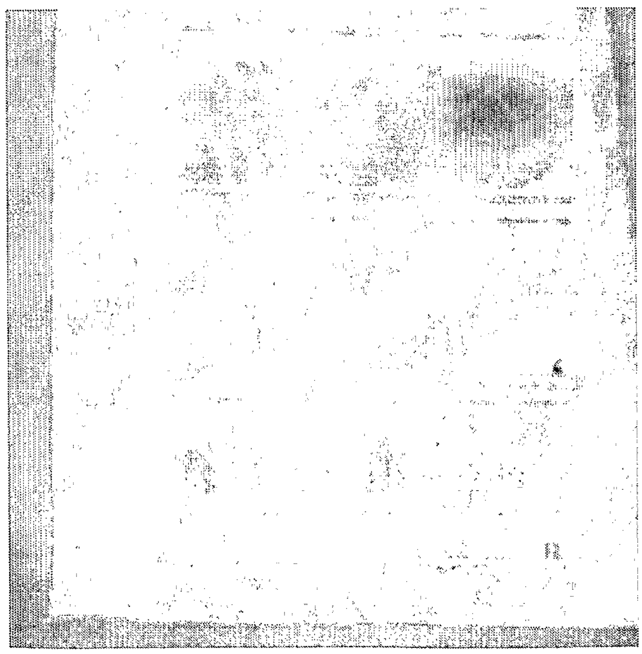


Figure 2

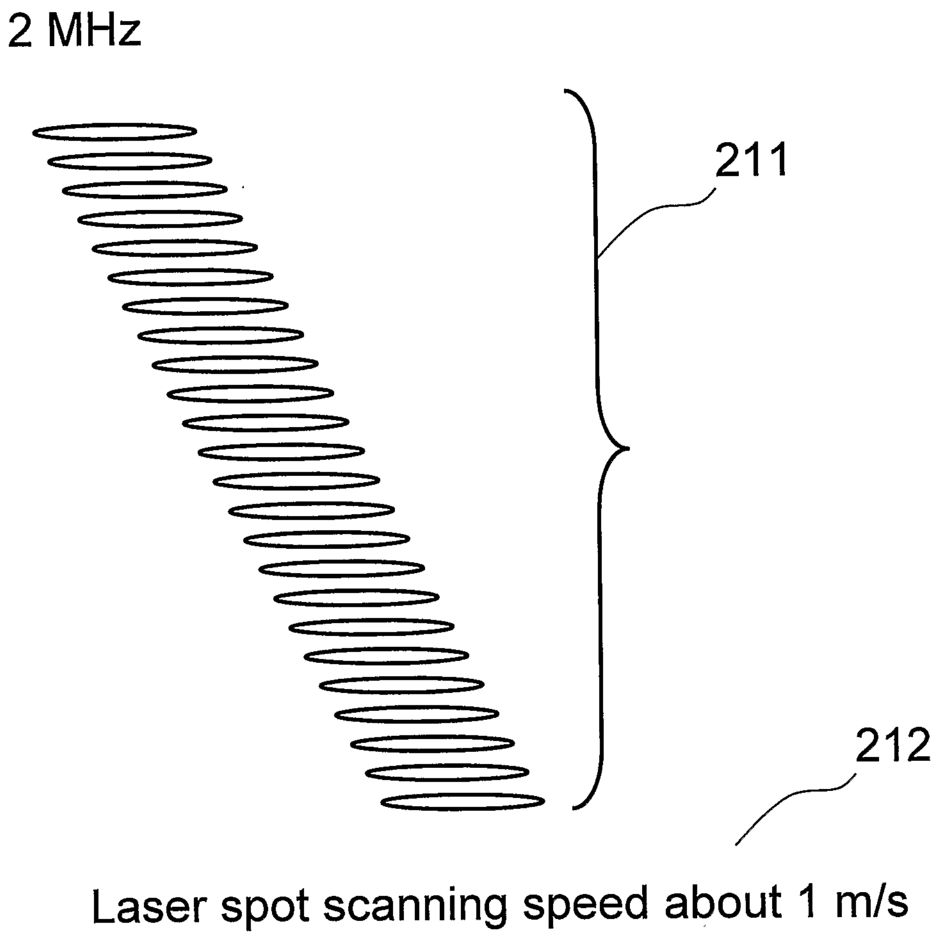


Figure 3

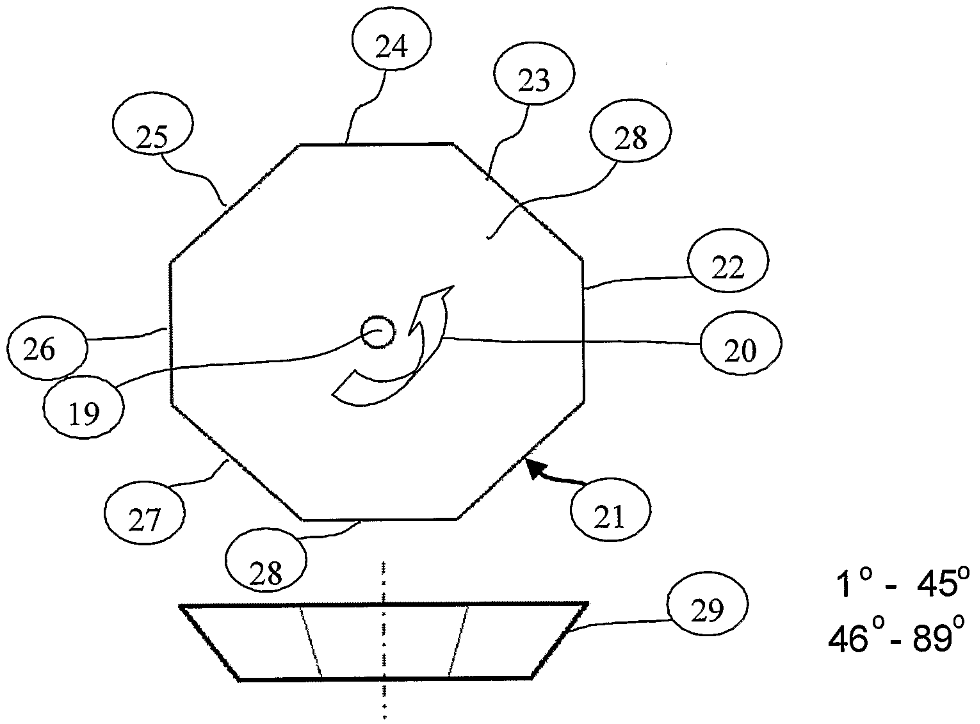


Figure 4

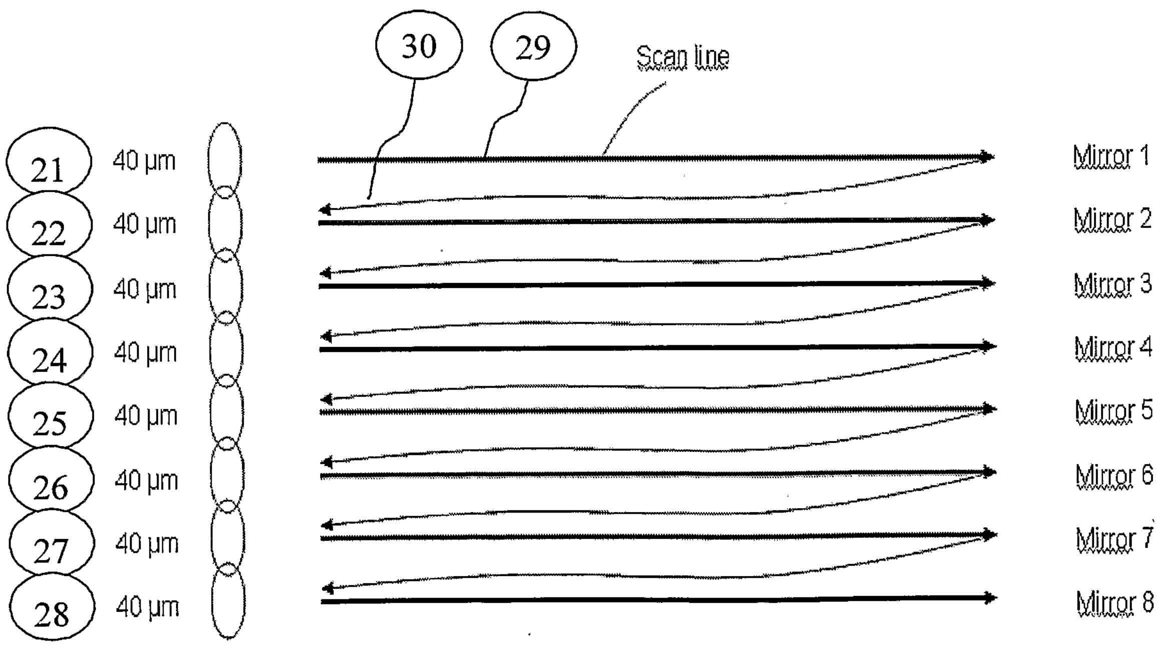


Figure 5

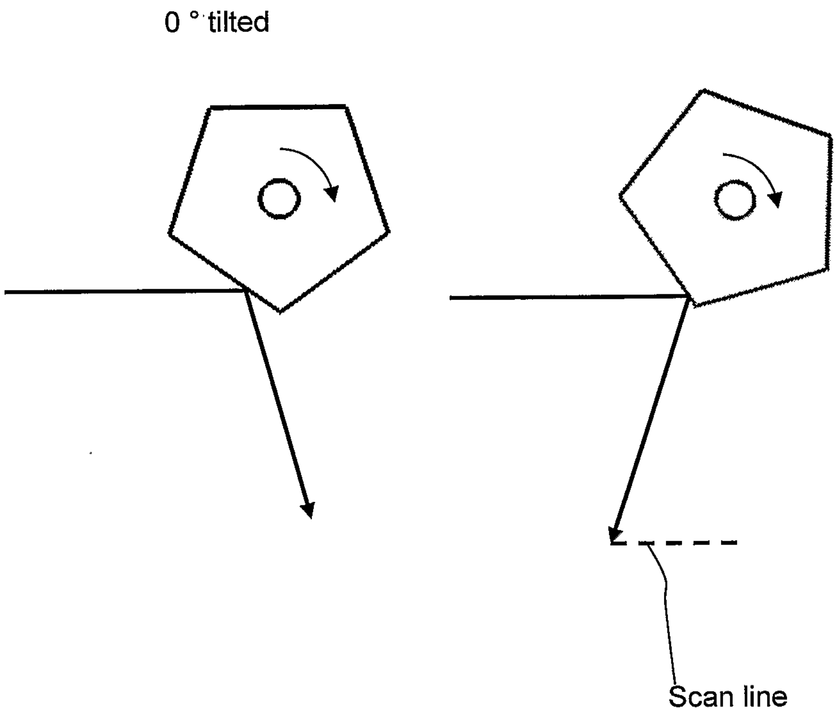


Figure 6

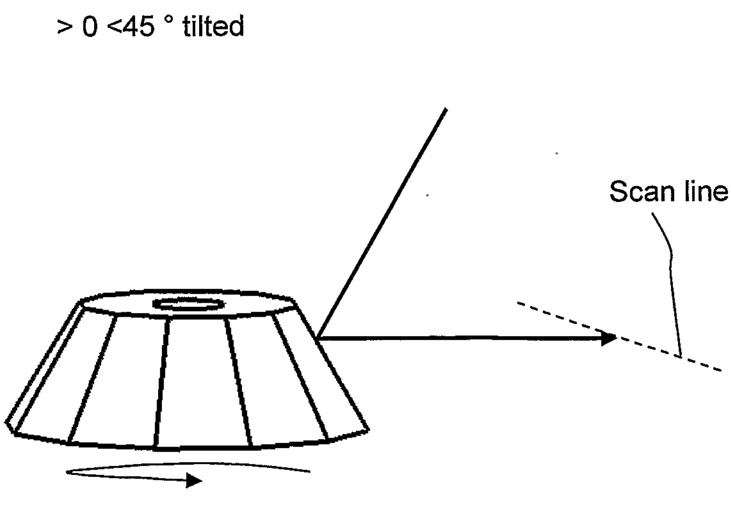


Figure 7

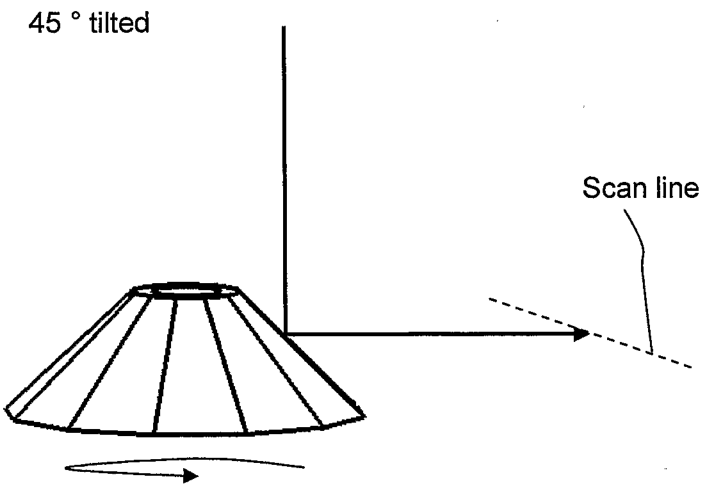


Figure 8

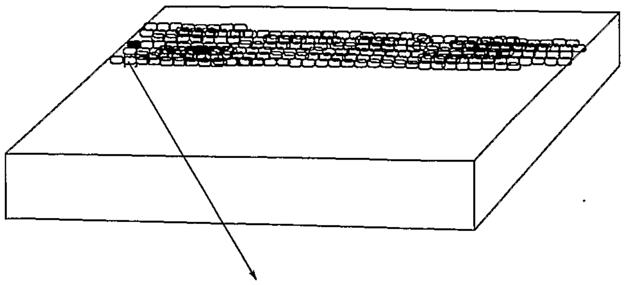


Figure 9a

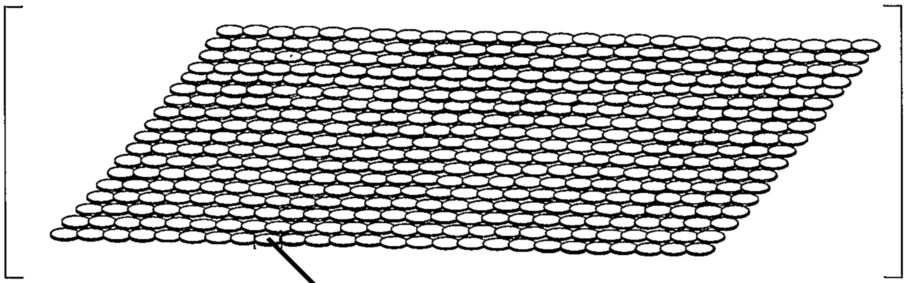


Figure 9b

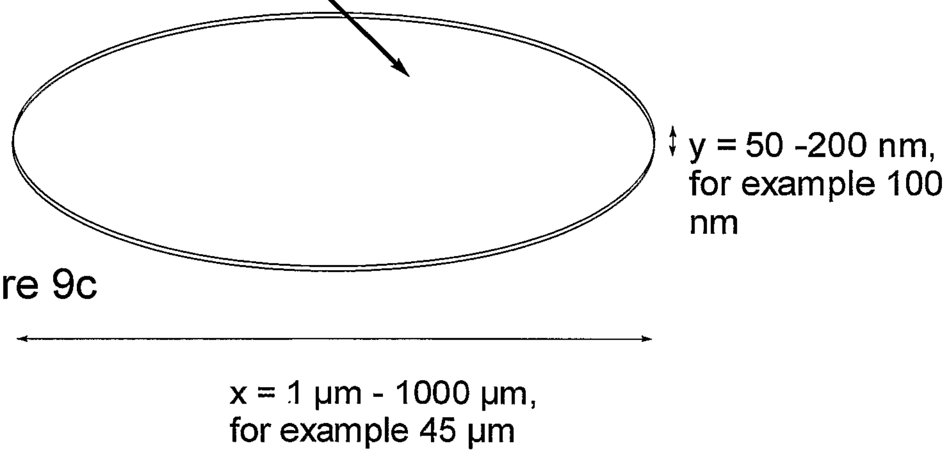


Figure 9c

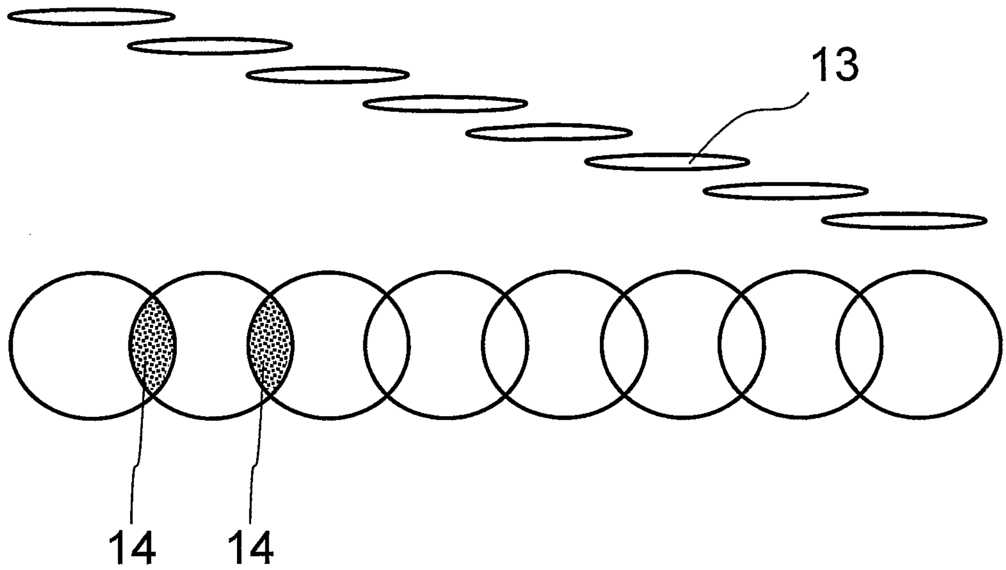


Figure 10

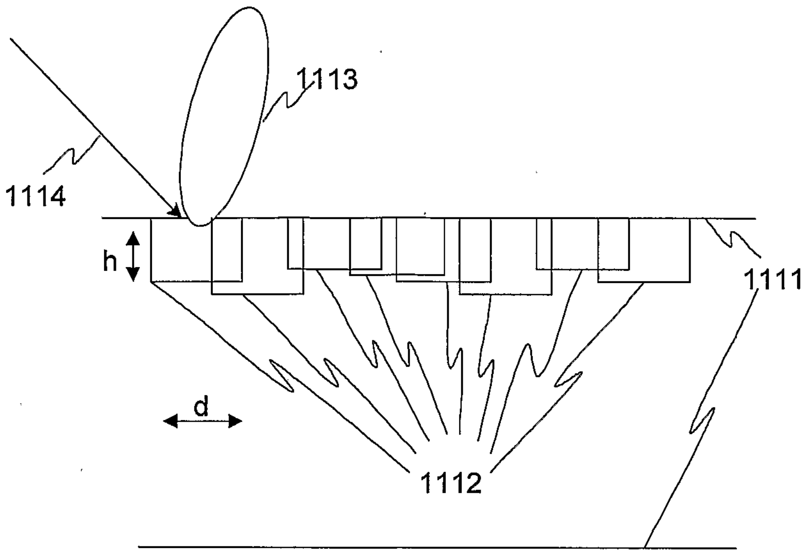


Figure 11a

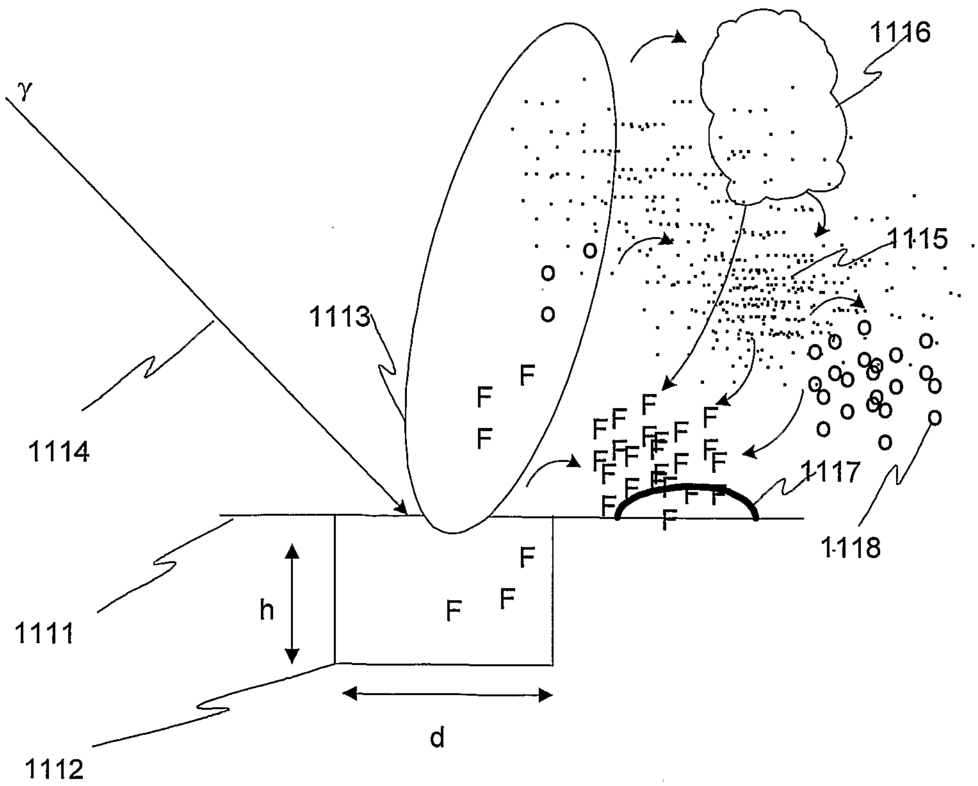
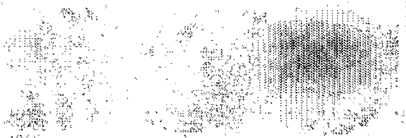


Figure 11b



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