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(54) Coating a substance using a pulsed laser

(57) In a method of coating a substrate 58 by eroding a coating material from a target 36 by means of a pulsed laser beam 70 which is incident on the target and which exhibits an inhomogeneous power density profile having power density gradients and wherein each laser pulse continuously alters the surface of the target within an interaction area in such a way that a homogeneous, highly adherent layer of the coating material is deposited on the substrate, relative movement is produced between the target and the incident laser beam which is such that mutually overlapping interaction areas 72 of different laser pulses overlap in such a manner that the power density gradients of the different laser pulses co-operate in the overlapping region of the interaction areas in such a way that the overlapping region of the interaction areas is on average substantially uniformly eroded so that a coating that is low in droplets is formed on the substrate.

FIG. 1

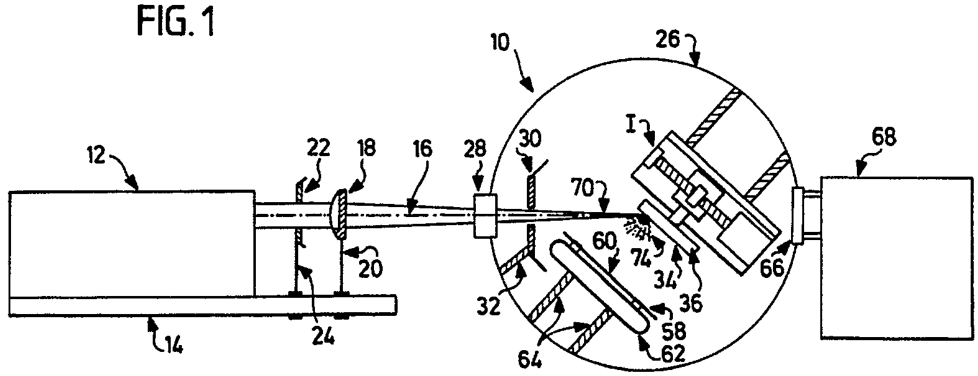

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FIG. 1

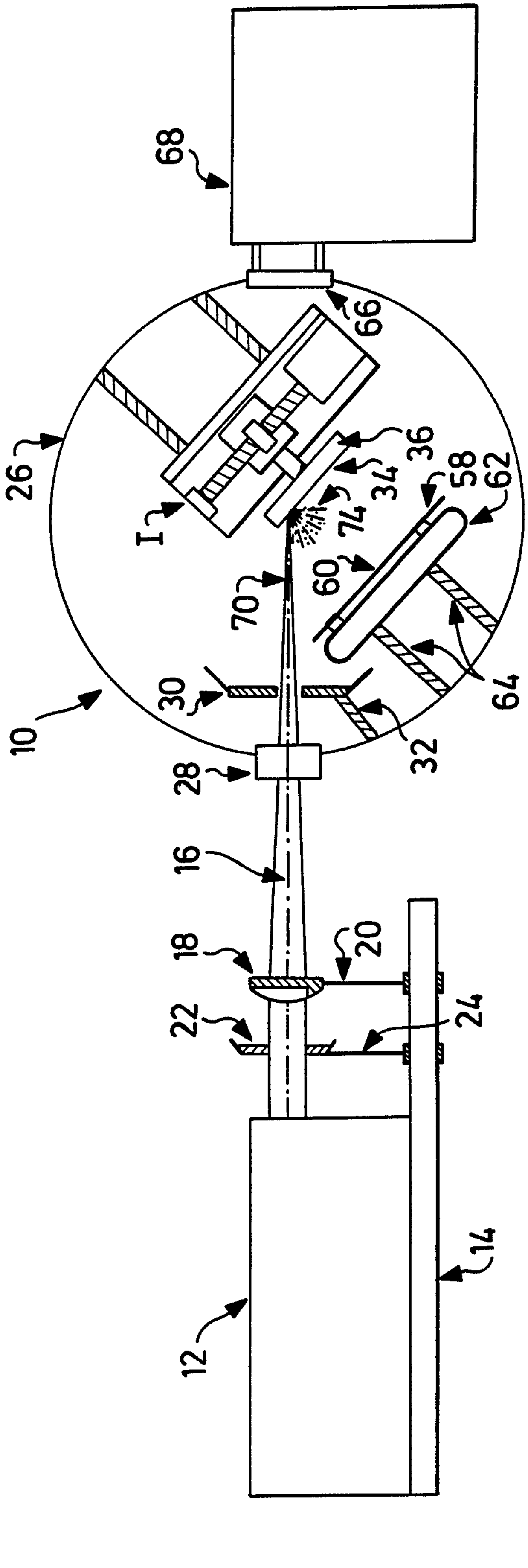


FIG.2

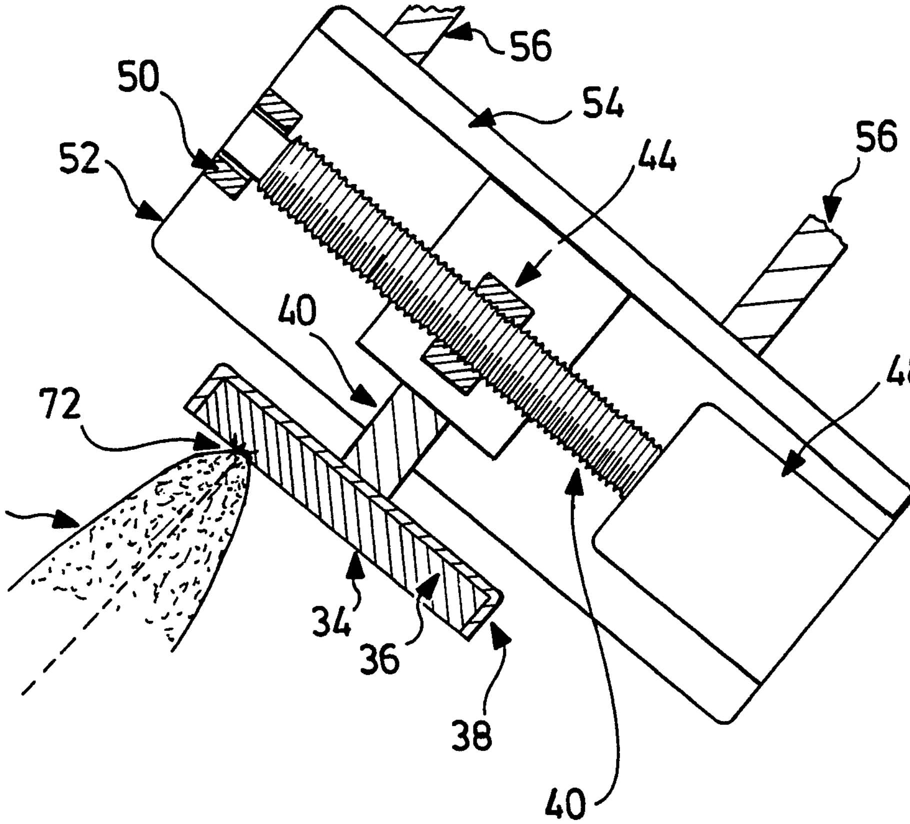


FIG.4

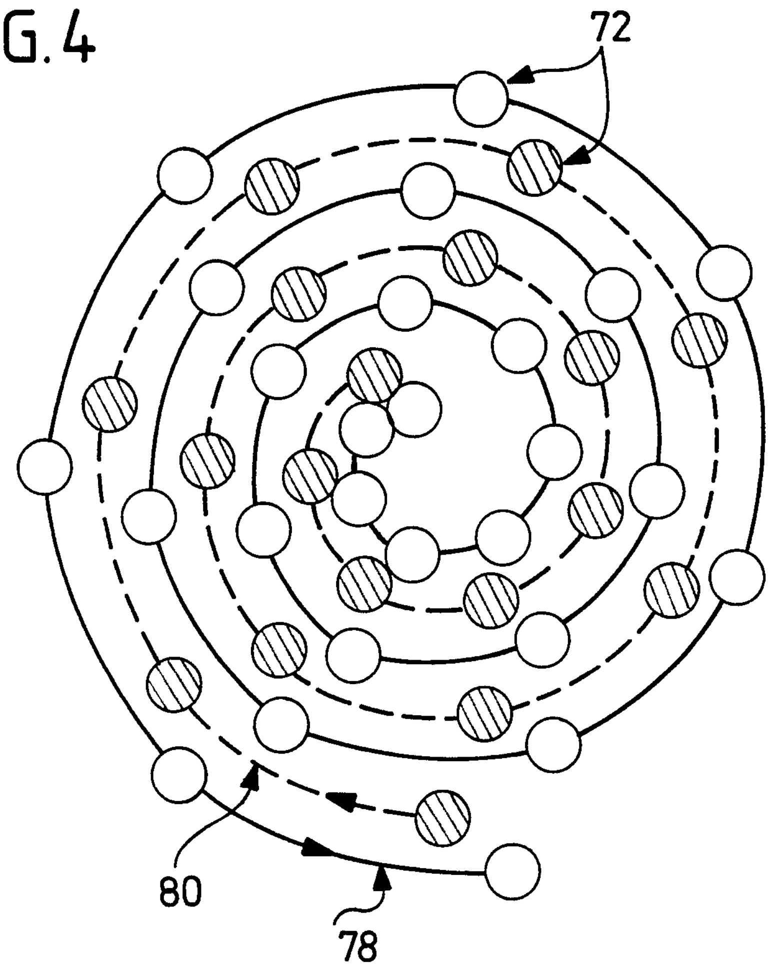
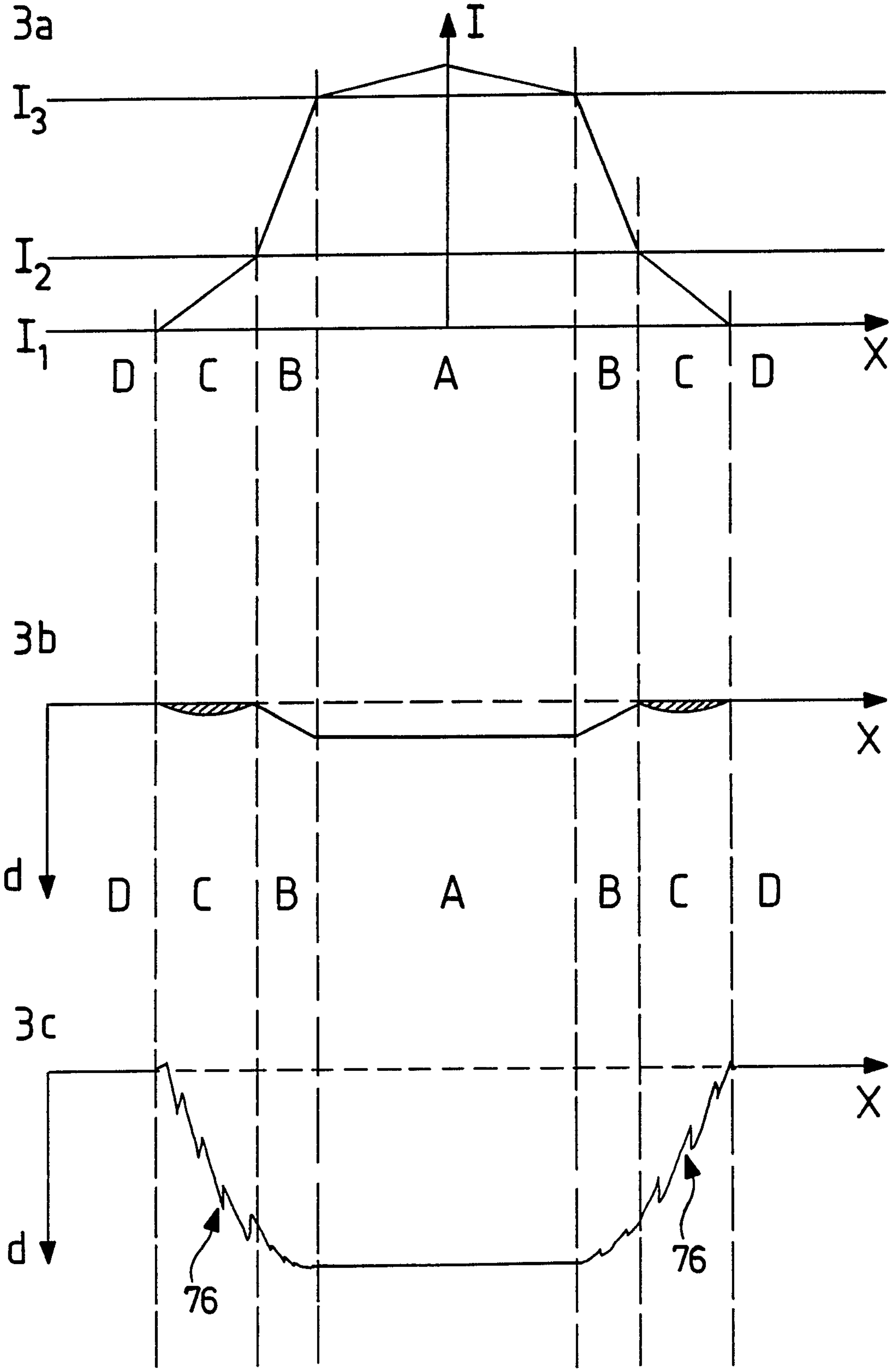


FIG. 3



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Method of coating a substrate and a coating device

The invention relates to a method of coating a substrate with the help of a pulsed laser beam which is incident on a target.

Furthermore, the invention relates to a coating device for carrying out such a method.

Methods of coating a substrate with the help of a pulsed laser beam which is incident on a target are known by the name "laser pulse vapour deposition" (LPVD) or "pulse laser deposition" (PLD).

In such LPVD processes, the surface of the target is subjected to spatially varying power densities during the effective period of a laser pulse which is focussed on the surface of the target because the power density varies over the cross-section of the laser beam and, in addition, because the surface of the target may be inclined by greatly differing amounts relative to the laser beam. If the power density incident on the target exceeds a certain value at one position, which one may refer to as the interaction threshold, then the surface of the target at this position is continuously altered and material is eroded from the surface of the target which then flows in a direction towards the substrate.

The material which was eroded from the target, condenses on a substrate located opposite to the surface of the target and forms a layer thereon.

However, the coatings produced by the previously known LPVD processes are in practice too inhomogeneous for many applications. Moreover, the coatings adhere only poorly to the substrate.

The invention seeks to improve a coating process of the type in accordance with the prior art, in such a way that a homogeneous, highly adherent layer of the coating material is deposited onto the substrate.

According to a first aspect of the present invention, there is provided a method of coating a substrate by eroding a coating material of a target by means of a pulsed laser beam which is incident on the target and exhibits an inhomogeneous power density profile having power density gradients, wherein each laser pulse continuously alters the surface of the target within an interaction area, wherein there is caused a relative movement between the target and the incident laser beam which is such that mutually overlapping interaction areas of different laser pulses overlap in such a manner that the power density gradients of the different laser pulses in the overlapping region of the interaction areas co-operate in such a way that on average the overlapping region of the interaction areas is substantially uniformly eroded so that a coating that is low in droplets is formed on the substrate.

It has proved to be still more beneficial if the coating formed on the substrate exhibits a droplet quota of less than 20 % especially, of less than 10 %. That is to say, that a portion of the material eroded from the target is deposited on the substrate in the form of virtually spherical fused particles. Such fused particles, which have a diameter of more than 1 μm, are referred to as droplets. The phrase droplet quota is to be understood as meaning the fraction of droplets relative to the total number of all the fused particles having a diameter of at least 0.2 μm. A coating that is low in droplets, is a coating such as one having no droplets, or one, wherein its droplet quota is less than 50 %. In addition, the numerical surface density of the droplets on the substrate reduces with a diminishing droplet quota.

The concept in accordance with the invention is based on the recognition of a causal relationship between the quality of the coating and the droplet quota on the one hand and between the inhomogeneous power density profile of the laser beam and the formation of droplets on the other hand.

By analysing scanning electron microscope photographs of the surface of a coated substrate with regard to the size distribution of the fused particles occurring in the coating, a correlation between the numerical surface density of the droplets and the droplet quota on the one hand, and the quality of the coating on the other, could be demonstrated. The homogeneity and the adherence of the coating improve with a diminishing droplet quota.

By analysing scanning electron microscope photographs of the surface of a partly eroded target, a correlation between the fraction of the droplets in the fused particles eroded from the target and the occurrence of irregularities in the surface, which are referred to hereinafter as fusion structures, was determined. The droplets are created mainly in the region of the target which exhibits such fusion structures.

In order to understand the process by which the fusion structures are created, it is essential to bear in mind the ever present inhomogeneity of the power density profile of the laser beam and the power density gradients resulting therefrom.

The regions of the laser beam cross-section in which the power density lies below the interaction threshold do not cause any lasting alteration to the surface of the target.

The regions of the laser beam cross-section in which the power density lies between the interaction threshold and a so-called sublimation threshold cause a fusion process on the surface of the target when incident thereon. The fusion structures referred to are formed during the resolidification process following the effect of a laser pulse.

The regions of the laser beam cross-section in which the power density lies between the sublimation threshold and a so-called saturation threshold lead to a droplet-free erosion of the target due to sublimation when there is incidence on the surface of the target. However, the erosion rate increases with the power density in these regions so that, following the effect of a laser pulse, an inclined target surface, whose erosion depth gradients are aligned in accordance with the power density gradients of the incident laser beam, is left behind.

The regions of the laser beam cross-section in which the power density exceeds the saturation threshold cause a droplet-free, uniform erosion due to sublimation when there is incidence upon the surface of the target. The erosion rate does not increase any further for power densities above the saturation threshold so that the power density gradients in these regions do not lead to any erosion depth gradients on the target.

If now, the interaction areas of different laser pulses overlap in such a manner that the power density gradients of the different laser pulses co-operate in the overlapping region of the interaction areas in such a way that spatial inhomogeneities of the erosion depth are increased, then steep slopes are formed on the surface of the target, upon which, the laser beam is incident at an increasingly flatter angle whereby the region of the target comprising the fusion structures is enlarged. As a result of this, coatings, which exhibit a rising droplet quota and thereby a diminishing quality with a growing duration of the coating process, are obtained on the substrate.

By contrast, the solution in accordance with the invention prevents this irregular erosion of the target and makes it possible to produce coatings having the desired degrees of homogeneity and adherence.

It is particularly beneficial if the relative movement between the target and the incident laser beam is effected such that the mutually overlapping interaction areas of each two laser pulses overlap in such a manner that the effects of the power density gradients of the two laser pulses are substantially compensated in the overlapping region. One thereby prevents parts of the surface of the target from becoming more inclined relative to the untouched surface of the target due to the combined effect of a plurality of laser pulses than is the case for a single laser pulse, which, as a consequence, would produce a reduction of the power density received by the surface of the target due to a banded incidence.

It is advantageous if the relative movement between the target and the incident laser beam is effected such that for each laser pulse, the region of the target, in which the power density of the incident laser beam lies between the interaction threshold and the sublimation threshold, overlaps as little as possible with the region of the target in which fusion structures have been created by earlier pulses. Due to this measure, one prevents the target being eroded in the form of droplets in the regions which exhibit the fusion structures.

It is especially advantageous if the relative movement between the target and the incident laser beam is effected such that for each laser pulse, the region of the target, in which the power density of the incident laser beam lies between the sublimation threshold and the saturation threshold, overlaps as little as possible with the region of the target in which fusion structures have been created by earlier pulses. The quantity of material eroded in the form of droplets can thereby be reduced still further.

It is beneficial if the relative movement between the target and the incident laser beam is effected such that for each laser pulse, the region of the target, in which the power density of the incident laser beam lies between the interaction threshold and the sublimation threshold, overlaps as little as possible with the region of the target in which the surface of the target has become inclined with respect to the untouched surface of the target due to the effect of the earlier laser pulses. The surface portion of the region, in which the target is fused instead of undergoing sublimation, can be made smaller in this manner.

It is particularly easy to control and is equally applicable for any sort of power density profile when the relative movement between the target and the incident laser beam is such that, on average, each possible relative position of each two overlapping interaction areas of different laser pulses occurs substantially equally often.

The danger of a deleterious combination of the power density gradients of different laser pulses is further minimised if the relative movement between the target and the incident laser beam is effected such that substantially the whole surface of the target is covered by the interaction areas of the laser pulses during every coating process.

Advantageously, the relative movement between the target and the incident laser beam is effected such that substantially the whole surface of the target is uniformly eroded during every coating process. Due to this manner of procedure, the full mass of the target can be utilised whereby a change of target will be required less frequently.

Basically, the relative movement between the target and the incident laser beam can be produced by a movement of the laser beam alone, a movement of the target alone or a movement of the target and the laser beam together.

A movement of the laser beam alone has the advantage that relatively high speeds and accelerations can be achieved. Here, the laser beam is deflected e.g. with the help of one or more pivotal mirrors. Where necessary, the optical projection means has to be servo-controlled in order to focus the laser on the surface of the target even when the path of the beam has been altered.

The movement of the target alone can be implemented at low cost and permits the laser beam to be optimally focussed on a fixed point.

It is particularly beneficial if the relative movement between the target and the incident laser beam exhibits more than one degree of freedom. One can thereby fully utilise such targets as extend to a greater extent in each direction than any one individual interaction area.

It is especially advantageous, particularly when using targets having a surface in the form of a circular disc, to produce the relative movement between the target and the incident laser beam by the superimposition of a rotational and a linear to-and-fro movement. The rotational and the linear to-and-fro movement can each be implemented at low cost and permit the full utilisation of a target having a surface in the form of a circular disc.

If the relative movement between the target and the incident laser beam is produced by a superimposition of a rotational and a linear to-and-fro movement then it is advisable to periodically interrupt the rotational movement while continuing the linear to-and-fro movement, or, the linear to-and-fro movement while continuing the rotational movement, in such a way that there results a relative movement between the target and the incident laser beam which is such that the interaction areas of the laser pulses on an associated section of the surface of the target, which extend to a greater extent in each direction than any one individual interaction area, are statistically uniformly distributed. The formation of steep slopes by the fusion structures is thereby avoided. Furthermore, it is of advantage to mask out those regions of the laser beam cross-section which exhibit a power density that lies below the saturation threshold with the help of a field diaphragm. Due to this measure, the power density gradients in the incident laser beam are increased and, as a result thereof, so do the erosion rate gradients on the surface of the target. The section of the surface of the target, at which an irregular erosion occurs and consequently where steep slopes can be created by the fusion structures, is thereby reduced.

In order to make the region of the surface of the target on which fusion structures can be created still smaller, it is of advantage to collate the shape and the dimensions of the diaphragms located in the path of the laser such that the secondary maxima of the power density occurring on the surface of the target due to diffraction do not exceed the interaction threshold.

According to a second aspect of the present invention, there is provided a coating device which comprises a substrate, a target consisting of coating material and a laser for producing a pulsed laser beam which is incident on the target and exhibits an inhomogeneous power density profile having power density gradients and the individual pulses of which continuously alter the surface of the target within a respective interaction area, wherein the coating device comprises a moving means for producing a relative movement between the target and the incident laser beam by virtue of which mutually overlapping interaction areas of different laser pulses overlap in such a manner that the power density gradients of the different laser pulses co-operate in the overlapping region of the interaction areas in such a way that the overlapping region of the interaction areas is on average substantially uniformly eroded so that a coating that is low in droplets is formed on the substrate.

Preferably there is formed a coating having a droplet quota which is less than 20 %, especially, one that is less than 10 %.

A preferred embodiment of the present invention will now be described, by way of example only, with reference to the accompanying drawings, of which:

Fig. 1 shows a diagrammatic illustration of a coating device in accordance with the invention;

Fig. 2 an enlarged illustration of the region I in Fig. 1;

Fig. 3 a diagrammatic illustration of the power density profile of a laser (Fig. 3a), a diagrammatic cross-section of a target after being subjected to an individual laser pulse (Fig. 3b) and a diagrammatic cross-section of a target after being subjected to a plurality of laser pulses at the same position of the target (Fig. 3c); and

Fig. 4 shows a top view of the surface of the target including a diagrammatic illustration of the distribution of the interaction areas.

The embodiment illustrated in the drawing of a coating device in accordance with the invention, which is referenced as a whole by 10, comprises a pulsed laser 12 which is arranged on an optical bench 14 that is aligned in parallel with the optical axis 16 of the laser 12.

The pulsed laser 12 may, for example, be a Q-switched Nd:YAG laser having a wavelength of 1,064 nm, a maximum pulse energy of 250 mJ, a pulse duration of 8 ns, a maximum repetition rate of 14 Hz and an annular power density profile, or, a Q-switched Nd:YAG laser having a wavelength of 532 nm, a maximum pulse energy of 200 mJ, a pulse duration of 6 ns, a maximum repetition rate of 10 Hz and a gaussian-shaped power density profile.

Furthermore, a collecting lens 18 is mounted on the optical bench 14 with the aid of a laser mount 20 in such a way that the axis of symmetry of the collecting lens 18 coincides with the optical axis 16. Moreover, a field diaphragm 22 may be mounted on the optical bench 14 between the laser 12 and the collecting lens 18 with the aid of a diaphragm mount 24 in such a way that the axis of symmetry of the aperture of the field diaphragm 22 coincides with the optical axis 16.

On the side of the collecting lens 18 which is remote from the laser 12, the optical axis 16 penetrates an entrance window 28 inserted in the wall of a vacuum chamber 26.

In the interior of the vacuum chamber 26, the optical axis 16 penetrates the aperture of a deposition-protection diaphragm 30 which is attached to the inner wall of the vacuum chamber 26 by means of a diaphragm mount 32 in such a way that the axis of symmetry of the aperture of the deposition-protection diaphragm 30 coincides with the optical axis 16. The deposition-protection diaphragm 30 serves to protect the entrance window 28 from stray deposits.

On the side of the deposition-protection diaphragm 30 which is remote from the entrance window 28, the optical axis 16 cuts the circular free surface 34 of a cylindrical target 36 at an angle of 45° relative to the direction of the normal to the target surface 34. The point of intersection of the optical axis 16 and the target surface 34 is located in the focus region of the collecting lens 18. The target 36 consists of any material that can be eroded by a laser, for example, of a pure metal such as aluminium or magnesium, or of an alloy and is seated in a cup-shaped target holder 38 which is open at one side.

The base of the target holder 38 is supported by one end of a first drive shaft 40 of a first electric motor 42 whereby the axes of symmetry of the first drive shaft 40 and the target 36 coincide with one another.

The first electric motor 42 is rigidly connected to a spindle nut 44 which is seated on a spindle 46 that is driven by a second electric motor 48.

The spindle 46 is aligned with its spindle axis in parallel with the straight line defined through the centre point of the circular target surface 34 and the point of intersection of the optical axis 16 with the target surface 34.

The threadless end of the spindle 46 that is remote from the second electric motor 48 is mounted in a bearing bush 50 which is arranged on an inner wall of a quadrangular target-moving housing 52 that surrounds the electric motors 42 and 48 as well as the spindle 46.

Each one of the normals to the surface of the quadrangular target-moving housing 52 is aligned in parallel with the first drive shaft 40 or the spindle 46. The first drive shaft 40 is fed out from the target-moving housing 52 through a slit which runs in the wall of the target-moving housing 52 in parallel with the spindle 46.

The second electric motor 48 is held on the inner wall of the target-moving housing 52 which is located opposite to the bearing bush 50. Furthermore, a guide rail 54, which runs in parallel with the spindle 46 and to which a region of the outer wall of the first electric motor 42 is adjacent, is arranged on the inner walls of the target-moving housing 52.

The target-moving housing 52 is attached to the inner wall of the vacuum chamber 26 by means of mountings 56 on the outer wall of the target-moving housing 52. A substrate 58 having a flat substrate surface 60 is arranged on the side of the target 36 which is remote from the target-moving housing 52, whereby the substrate surface 60 runs (approximately) parallel to the target surface 34 at a distance of approximately 50 mm from the target surface 34.

The substrate 58 may consist of any material, for example, steel or a microscope slide, and is held by a substrate mounting 62 which, for its part, is arranged on the inner wall of the vacuum chamber 26 with the help of mountings 64. Furthermore, a vacuum pump support 66, on which a vacuum pump 68 is flange-mounted, is disposed in the wall of the vacuum chamber 26.

Before a coating process takes place, the vacuum chamber 26 is evacuated with the help of the vacuum pump 68 until a residual pressure of preferably less than 10^{-3} mbar is achieved.

The two electric motors 42 and 48 are then started. The first electric motor 42 rotates the first drive shaft 40 whereby the target 36 is set into rotary motion. The second electric motor 48 rotates the spindle 46 which results in a displacement of the spindle nut 44 and hence of the first electric motor 42 along the spindle 46. Thereby, the guide rail 54 prevents any tilting of the first electric motor 42 about the spindle 46. The linear movement of the first electric motor 42 leads to a corresponding linear movement of the target 36. Thus, the first electric motor 42 acts as a target rotating means and the second electric motor 48 as a target displacing means.

The pulsed laser beam 70 produced by the laser 12 is focused onto the target surface 34 by the collecting lens 18. Each laser pulse erodes material from the target within a previously defined interaction area 72 in the form of particles, which then make up a particle stream 74 that is directed onto the substrate 58 and they are deposited on the surface 60 of the substrate as a layer.

The laser beam 70 exhibits an inhomogeneous power density profile which is schematically illustrated in Fig. 3a. In Fig. 3a, the fraction of the power density I exceeding the interaction threshold I_1 is plotted as a function of the distance x of the laser beam 70 from the optical axis 16.

The region in which the power density exceeds the saturation threshold I_3 is referenced A. The region in which the power density lies between the saturation threshold I_3 and the sublimation threshold I_2 is referenced B. The region in which the power density lies between the sublimation threshold I_2 and the interaction threshold I_1 is referenced C. The region in which the power density is located below the interaction threshold I_1 is referenced D.

Fig. 3a illustrates the alteration of the target due to a single laser pulse. The depth of erosion d is plotted as a function of the distance x of the laser beam 70 from the optical axis 16. The regions A to D of the target surface 34 correspond to the regions A to D of the laser beam cross-section in Fig. 3a.

The target 36 is eroded without any droplets in the region A at a spatially constant erosion rate.
The target 36 is also eroded without any droplets in the region B but at a spatially varying erosion rate so that the surface of the target 36 is inclined with respect to the surface 34 of the untouched target 36 due to the effect of the laser pulse.

The target 36 is fused by the laser pulse in the region C. The erosion of the target 36 is low in this region. When this re-solidifies following upon the laser pulse, surface irregularities (fusion structures) 76 are formed in the region sketched in dashed lines in Fig. 3b.

The laser beam 70 is reflected by the target 36 in the region D without causing any long-lasting changes to the target surface 34.

If now a plurality of laser pulses are effective on the same spot of the target 36 without the position of the target 36 being altered relative to the incident laser beam 70, then the fusion structures 76 become increasingly more prominent since the laser beam 70 is incident at an increasingly flat angle upon the fusion structures 76 whereby the power density received by the surface of the target here, and, as a consequence thereon, the erosion rate, diminishes.

The erosion depth d following a plurality of such laser pulses is plotted in Fig. 3c as a function of the distance x of the laser beam 70 from the optical axis 16. The regions A to D correspond to the regions A to D in Fig. 3b.

Due to the power density gradients of the different laser pulses being superimposed in the same sense, there merely occurs a uniform, droplet-free erosion of the target 36 in the region A while increasingly steep edges of an erosion crater having rod-like fusion structures 76, which exhibit an extension of a few μm, are created in the regions B and C. The target 36 is eroded mainly in the form of droplets on these edges of the erosion crater.

The formation of such steep edges, which lead to the unwanted formation of droplets, is prevented by the movement of the target 36 relative to the pulsed laser beam 70 with the help of the first electric motor 42 and the second electric motor 48.

At each interruption of the movement of the target 36, the laser 12 is switched off or its beam path is blocked in order to prevent an erosion crater being created due to a plurality of successive laser pulses.

Here, the average power density of the laser beam 70 is chosen such that, on the one hand, the fraction of target material which is eroded in the form of droplets during one laser pulse is as small as possible while, on the other hand, the total quantity of target material which is eroded during one laser pulse is as large as possible. For magnesium as the target material, the optimum average power density lies in the region of 10^{10} W/cm^2.

The interaction areas 72 of the successive laser pulses on the target surface 34 are disposed along a spiral path 78 because of the combined rotational and linear movement of the target 36, which is illustrated in Fig. 4 as a solid line. The transit direction of the spiral 78 is indicated by an arrow. The locations of the interaction areas 72 on the spiral 72 are marked by empty circles. One is able to ensure that the interaction areas 72 do not initially overlap, by suitably collating the rotational speeds of the first electric motor 42 and the second electric motor 48 to each other and to the repetition rate of the laser 12.

Eventually, either the edge or the centre point of the target surface 34 passes through the focusing region of the laser beam 70 by virtue of the linear movement of the target 36. When this is the case, the two electric motors 42 and 48 are manually switched-off independently of each other, reverse poled and then switched-on again. The rotational and the linear movements of the target 36 thereby change direction and the newly added interaction areas 72 are once more disposed along a spiral 80, which exhibits the same sense of rotation and the same winding pitch as the spiral 78 that was traversed before the reversal of the poles, but this one is traversed in the opposite direction. Since neither the switching-on nor the switching-off of the first electric motor 42 is synchronised with that of the second electric motor 48, the turns of the two spirals 78 and 80 are however mutually twisted in a random manner and are mutually displaced. In addition, as the switching-over of the two electric motors 42 and 48 does not occur in synchronism with the pulse sequence of the laser 12, the location of the interaction areas 72 are also displaced along the spiral path.

The spiral path 80 which is traversed after the switching-over has occurred is illustrated in Fig. 4 as a dashed line. The transit direction of the spiral 80 is indicated by an arrow. The locations of the interaction areas 72 on the spiral path 80 are marked by hatched circles.

Thus, after each switch-over of the two electric motors 42 and 48, a new distribution of the interaction areas 72, which is independent of the distribution of the previous interaction areas 72, is created on the target surface 34. If a plurality of interaction areas 72, whose creation times are each separated from one another by at least one switch-over operation, should be superimposed at one location of the target surface 34, then the erosion rate gradients of these interaction areas 72 are, on average, mutually compensating. Interaction areas 72 such as those where there is no switch-over between their creation times do not in any case overlap. As a consequence, the whole target surface 34 is uniformly eroded without steep edges being able to be created by the unwanted fusion structures 76.

If the rotational speeds of the two electric motors 42 and 48 are respectively constant with time, then the interaction areas 72 in the centre of the target surface 34 are closer together than at its edge i.e. the target 36 is eroded to an increasing extent towards the centre of the target surface 34. However, the inclination of the target surface 34 thereby occurring is so small that substantially no diminution of the power density received by the target surface 34 occurs and there is substantially no increase in the fraction of the material that is eroded in the form of droplets. If, however, an absolutely uniform erosion of the target surface 34 is desired in order to be able to erode the target 36 as fully as possible, then the rotational speed of the first electric motor 42 or of the second electric motor 48 has to be controlled such that it is reciprocally related to the instantaneous separation between the centre point of the target surface 34 and the focusing region of the laser beam 70.

The use of the field diaphragm 22 is optional. The size of its aperture is selected such that those regions of the cross-section of the laser beam 70 in which the power density lies below the saturation threshold (regions B, C and D in Fig. 3a) are masked out. As a consequence of this, the region of the interaction area 72 of a single pulse, in which an erosion rate gradient occurs, is reduced. In combination with the two-dimensional movement of the target 36, this leads to a further diminution of the fraction of material which is eroded in the form of droplets.

Comparative tests, in which a target 36 consisting of magnesium and an average laser power density of 2.3×10^9 to 14.7×10^9 W/cm^2 were used, have indicated that the relative fraction of droplets in the fused particles eroded from the target 36 can be reduced with the help of the method in accordance with the invention or the coating device in accordance with the invention to less than 10 % while it is always markedly over 50

% with the method or the device in accordance with the state of the art.

In the embodiment of a coating device 10 in accordance with the invention which is illustrated in Figs. 1 and 2, the relative movement between the target 36 and the incident laser beam 70 is produced by means of a movement of the target 36 alone. As an alternative to this, a pivotal deflecting mirror may be inserted in the beam path of the laser 70, for example, between the entrance window 28 and the deposition-protection diaphragm 30, and with its help, the interaction area 72 can be displaced on the target surface 34. One can then dispense with one degree of freedom for the movement of the target.

If a double axis pivotal mirror is used, then the movement of the target 36 can be dispensed with completely.

In both of these cases, the collecting lens 18 has to be servo-controlled such that the power density of the laser 70 on the target surface 34 is not altered because of different lengths of the beam paths.

Claims

1. A method of coating a substrate by eroding a coating material of a target by means of a pulsed laser beam which is incident on the target and exhibits an inhomogeneous power density profile having power density gradients, wherein each laser pulse continuously alters the surface of the target within an interaction area, wherein there is caused a relative movement between the target and the incident laser beam which is such that mutually overlapping interaction areas of different laser pulses overlap in such a manner that the power density gradients of the different laser pulses in the overlapping region of the interaction areas co-operate in such a way that on average the overlapping region of the interaction areas is substantially uniformly eroded so that a coating that is low in droplets is formed on the substrate.

2. A method in accordance with Claim 1, wherein the relative movement between the target and the incident laser beam is effected such that mutually overlapping interaction areas of each two laser pulses overlap in such a manner that the effects of the power density gradients of the two laser pulses are substantially compensated in the overlapping region.

3. A method in accordance with Claim 1 or 2, wherein the relative movement between the target and the incident laser beam is effected such that for each laser pulse, the region of the target, in which the power density of the incident laser beam lies between the interaction threshold and the sublimation threshold, overlaps as little as possible with the region of the target in which fusion structures have been created by earlier pulses.

4. A method in accordance with any of the preceding Claims, wherein the relative movement between the target and the incident laser beam is effected such that for each laser pulse, the region of the target, in which the power density of the incident laser beam lies between the sublimation threshold and the saturation threshold, overlaps as little as possible with the region of the target in which fusion structures have been created by earlier pulses.

5. A method in accordance with any of the preceding Claims, wherein the relative movement between the target and the incident laser beam is effected such that for each laser pulse, the region of the target, in which the power density of the incident laser beam lies between the interaction threshold and the sublimation threshold, overlaps as little as possible with the region of the target in which the surface of the target has become inclined with respect to the untouched surface of the target due to the effect of the earlier laser pulses.

6. A method in accordance with any of the preceding Claims, wherein the relative movement between the target and the incident laser beam is effected such that each possible relative position of each two mutually overlapping interaction areas of different laser pulses occurs on average substantially equally often.

7. A method in accordance with any of the preceding Claims, wherein the relative movement between the target and the incident laser beam is effected such that substantially the whole surface of the target is covered by the interaction areas of the laser pulses during every coating process.

8. A method in accordance with Claim 7, wherein the relative movement between the target and the incident laser beam is effected such that substantially the whole surface of the target is uniformly eroded during every coating process.

9. A method in accordance with any of the preceding Claims, wherein the incident laser beam is moved.

10. A method in accordance with any of the preceding Claims, wherein the target is moved.

11. A method in accordance with any of the preceding Claims, wherein the relative movement between the target and the incident laser beam exhibits more than one degree of freedom.

12. A method in accordance with Claim 11, wherein the relative movement between the target and the incident laser beam is produced by the superimposition of a rotational and a linear to-and-fro movement.

13. A method in accordance with Claim 12, wherein the rotational movement is periodically interrupted while continuing the linear to-and-fro movement.

14. A method in accordance with Claim 12 or 13, wherein the linear to-and-fro movement is periodically interrupted while continuing the rotational movement.

15. A method in accordance with any of the preceding Claims, wherein those regions of the laser beam cross-section in which the power density lies below the saturation threshold are masked out.

16. A method in accordance with any of the preceding Claims, wherein the laser beam is guided by diaphragms and that the shape and dimensions of these diaphragms and also the power density of the laser are mutually collated such that no secondary maxima, such as those wherein the power density

reaches the interaction threshold, occur on the surface of the target due to diffraction.

17. A coating device which comprises a substrate, a target consisting of coating material and a laser for producing a pulsed laser beam which is incident on the target and exhibits an inhomogeneous power density profile having power density gradients and the individual pulses of which continuously alter the surface of the target within a respective interaction area, wherein the coating device comprises a moving means for producing a relative movement between the target and the incident laser beam by virtue of which mutually overlapping interaction areas of different laser pulses overlap in such a manner that the power density gradients of the different laser pulses co-operate in the overlapping region of the interaction areas in such a way that the overlapping region of the interaction areas is on average substantially uniformly eroded so that a coating that is low in droplets is formed on the substrate.

18. A coating device in accordance with Claim 17, wherein the coating device comprises a moving means for producing a relative movement between the target and the incident laser beam by virtue of which mutually overlapping interaction areas of two laser pulses overlap in such a manner that the effects of the power density gradients of the two laser pulses are substantially compensated in the overlapping region.

19. A coating device in accordance with Claim 17 or 18, wherein the coating device comprises a moving means for producing a relative movement between the target and the incident laser beam by virtue of which the overlap, between the region of the target in which the power density of the incident laser beam lies between the interaction threshold (I_1) and the sublimation threshold (I_2) and the region of the target in which fusion structures have been created by earlier pulses, is minimised for each laser pulse.

20. A coating device in accordance with any of Claims 17 to 19, wherein the coating device comprises a moving means for producing a relative movement between the target and the incident laser beam by virtue of which the overlapping region, between the region of the target in which the power density of the incident laser beam lies between the sublimation threshold (I_2) and the saturation threshold (I_3) and the region of the target in which fusion structures have been created by earlier pulses, is minimised for each laser pulse.

21. A coating device in accordance with any of Claims 17 to 20, wherein the coating device comprises a moving means for producing a relative movement between the target and the

incident laser beam by virtue of which the overlapping region, between the region of the target in which the power density of the incident laser beam lies between the interaction threshold (I_1) and the sublimation threshold (I_2) and the region of the target in which the surface of the target has become inclined with respect to the untouched surface of the target due to the effect of the earlier laser pulses, is minimised for each laser pulse.

22. A coating device in accordance with any of Claims 17 to 21, wherein the coating device comprises a moving means for producing a relative movement between the target and the incident laser beam by virtue of which each possible relative position of each two mutually overlapping interaction areas of different laser pulses occurs on average substantially equally often.

23. A coating device in accordance with any of Claims 17 to 22, wherein the coating device comprises a moving means for producing a relative movement between the target and the incident laser beam by virtue of which substantially the whole surface of the target is covered by the interaction areas of the laser pulses during every coating process.

24. A coating device in accordance with Claim 23, wherein the coating device comprises a moving means for producing a relative movement between the target and the incident laser beam by virtue of which substantially the whole surface of the target is uniformly eroded during every coating process.

25. A coating device in accordance with any of Claims 17 to 24, wherein the coating device comprises a moving means for moving the laser beam which is incident on the target.

26. A coating device in accordance with any of Claims 17 to 25, wherein the coating device comprises a moving unit for moving the target.

27. A coating device in accordance with any of Claims 17 to 26, wherein the coating device comprises a moving means for producing a relative movement between the target and the incident laser beam having more than one degree of freedom.

28. A coating device in accordance with Claim 27, wherein the moving means for producing a relative movement between the target and the incident laser beam comprises a device for producing a rotational movement and a device for producing a linear to-and-fro movement.

29. A coating device in accordance with Claim 28, wherein the device for producing a rotational movement and the device for

producing a linear to-and-fro movement are operable independently of one another.

30. A coating device in accordance with any of Claims 17 to 29, wherein the coating device comprises a field diaphragm for masking out those regions of the laser beam cross-section in which the power density lies below the saturation threshold (I_3)

31. A coating device in accordance with any of Claims 17 to 30, wherein the coating device only comprises diaphragms in the path of the beam of the laser which are such that their shape and dimensions do not permit any secondary maxima, such as those wherein the power density reaches the interaction threshold (I_1), to occur on the surface of the target due to diffraction.

32. A method of coating substantially as herein described with reference to the accompanying drawings.

33. A coating device substantially as herein described with reference to the accompanying drawings.

Amendments to the claims have been filed as follows

1. A method of coating a substrate by eroding a coating material of a target by means of a pulsed laser beam which is incident on the target and exhibits an inhomogeneous power density profile having power density gradients, wherein each laser pulse permanently alters the surface of the target within an interaction area and wherein there is caused a relative movement between the target and the incident laser beam which is such that on average a section of the target surface is substantially uniformly eroded, wherein the relative movement between the target and the incident laser beam is effected such that for each laser pulse, the region of the target, in which the power density of the incident laser beam lies between the sublimation threshold and the saturation threshold, overlaps as little as possible with the region of the target in which fusion structures have been created by earlier pulses, and that for each laser pulse, the region of the target, in which the power density of the incident laser beam lies between the interaction threshold and the sublimation threshold, overlaps as little as possible with the region of the target in which the surface of the target has become inclined with respect to the untouched surface of the target due to the effect of the earlier laser pulses, so that a coating that is low in droplets is formed on the substrate.

2. A method in accordance with Claim 1, wherein the relative movement between the target and the incident laser beam is effected such that mutually overlapping interaction areas of each two laser pulses overlap in such a manner that the effects of the power density gradients of the two laser pulses are substantially compensated in the overlapping region.

3. A method in accordance with Claim 1 or 2, wherein the relative movement between the target and the incident laser beam is effected such that for each laser pulse, the region of the target, in which the power density of the incident laser beam lies between the interaction threshold and the sublimation threshold, overlaps as little as possible with the region of the target in which fusion structures have been created by earlier pulses.

4. A method in accordance with any of the preceding Claims, wherein the relative movement between the target and the incident laser beam is effected such that each possible relative position of each two mutually overlapping interaction areas of different laser pulses occurs on average substantially equally often.

5. A method in accordance with any of the preceding Claims, wherein the relative movement between the target and the incident laser beam is effected such that substantially the whole surface of the target is covered by the interaction areas of the laser pulses during every coating process.

6. A method in accordance with Claim 5, wherein the relative movement between the target and the incident laser beam is effected such that substantially the whole surface of the target is uniformly eroded during every coating process.

7. A method in accordance with any of the preceding Claims, wherein the incident laser beam is moved.

8. A method in accordance with any of the preceding Claims, wherein the target is moved.

9. A method in accordance with any of the preceding Claims, wherein the relative movement between the target and the incident laser beam exhibits more than one degree of freedom.

10. A method in accordance with Claim 9, wherein the relative movement between the target and the incident laser beam is produced by the superimposition of a rotational and a linear to-and-fro movement.

11. A method in accordance with Claim 10, wherein the rotational movement is periodically interrupted while continuing the linear to-and-fro movement.

12. A method in accordance with Claim 10 or 11, wherein the linear to-and-fro movement is periodically interrupted while continuing the rotational movement.

13. A method in accordance with any of the preceding Claims, wherein those regions of the laser beam cross-section in which the power density lies below the saturation threshold are masked out.

14. A method in accordance with any of the preceding Claims, wherein the laser beam is guided by diaphragms and that the shape and dimensions of these diaphragms and also the power density of the laser are mutually collated such that no secondary maxima, such as those wherein the power density reaches the interaction threshold, occur on the surface of the target due to diffraction.

15. A coating device which comprises a substrate, a target consisting of coating material and a laser for producing a pulsed laser beam which is incident on the target and exhibits an inhomogeneous power density profile having power density gradients and the individual pulses of which permanently alter the surface of the target within a respective interaction area, wherein the coating device comprises a moving means for producing a relative movement between the target and the incident laser beam by virtue of which a section of the target surface is on average substantially uniformly eroded, wherein the coating device comprises a moving means for producing a relative movement between the target and the incident laser beam by virtue of which the overlapping region, between the region of the target in which the power density of the incident laser beam lies between the sublimation threshold (I_2) and the saturation threshold (I_3) and the region of the target in which fusion structures have been created by earlier pulses, is minimised for each laser pulse and by virtue of which the overlapping region, between the region of the target in which the power density of the incident laser beam lies between the interaction threshold (I_1) and the sublimation threshold (I_2) and the region of the target in which the surface of the target has become inclined with respect to the untouched surface of the target due to the effect of the earlier laser pulses, is minimised for each laser pulse, so that a coating that is low in droplets is formed on the substrate.

16. A coating device in accordance with Claim 15, wherein the coating device comprises a moving means for producing a relative movement between the target and the incident laser beam by virtue of which mutually overlapping interaction areas of two laser pulses overlap in such a manner that the effects of the power density gradients of the two laser pulses are substantially compensated in the overlapping region.

17. A coating device in accordance with Claim 15 or 16, wherein the coating device comprises a moving means for producing a relative movement between the target and the incident laser beam by virtue of which the overlap, between the region of the target in which the power density of the incident laser beam lies between the interaction threshold (I_1) and the sublimation threshold (I_2) and the region of the target in which fusion structures have been created by earlier pulses, is minimised for each laser pulse.

18. A coating device in accordance with any of Claims 15 to 17, wherein the coating device comprises a moving means for producing a relative movement between the target and the incident laser beam by virtue of which each possible relative position of each two mutually overlapping interaction areas of different laser pulses occurs on average substantially equally often.

19. A coating device in accordance with any of Claims 15 to 18, wherein the coating device comprises a moving means for producing a relative movement between the target and the incident laser beam by virtue of which substantially the whole surface of the target is covered by the interaction areas of the laser pulses during every coating process.

20. A coating device in accordance with Claim 19, wherein the coating device comprises a moving means for producing a relative movement between the target and the incident laser beam by virtue of which substantially the whole surface of the target is uniformly eroded during every coating process.

21. A coating device in accordance with any of Claims 15 to 20, wherein the coating device comprises a moving means for moving the laser beam which is incident on the target.

22. A coating device in accordance with any of Claims 15 to 21, wherein the coating device comprises a moving unit for moving the target.

23. A coating device in accordance with any of Claims 15 to 22, wherein the coating device comprises a moving means for producing a relative movement between the target and the incident laser beam having more than one degree of freedom.

24. A coating device in accordance with Claim 23, wherein the moving means for producing a relative movement between the target and the incident laser beam comprises a device for producing a rotational movement and a device for producing a linear to-and-fro movement.

25. A coating device in accordance with Claim 24, wherein the device for producing a rotational movement and the device for producing a linear to-and-fro movement are operable independently of one another.

26. A coating device in accordance with any of Claims 15 to 25, wherein the coating device comprises a field diaphragm for masking out those regions of the laser beam cross-section in which the power density lies below the saturation threshold (I_3).

27. A coating device in accordance with any of Claims 15 to 26, wherein the coating device only comprises diaphragms in the path of the beam of the laser which are such that their shape and dimensions do not permit any secondary maxima, such as those wherein the power density reaches the interaction threshold (I_1), to occur on the surface of the target due to diffraction.

28. A method of coating substantially as herein described with reference to the accompanying drawings.

29. A coating device substantially as herein described with reference to the accompanying drawings.

Patents Act 1977 Examiner's report to the Comptroller under Section 17 (The Search report)	Application number GB 9502753.8
Relevant Technical Fields (i) UK Cl (Ed.N) C7F (FCAS,FCAV,FCAX,FCSE,FCSL, FCSM,FCSX,FCVE,FCVL,FCVM,FCVX, FCXE,FCXL,FCXM,FCXX (ii) Int Cl (Ed.6) C23C 14/28	Search Examiner P G BEDDOE Date of completion of Search 27 APRIL 1995
Databases (see below) (i) UK Patent Office collections of GB, EP, WO and US patent specifications. (ii) ONLINE: WPI, CLAIMS	Documents considered relevant following a search in respect of Claims :- 1-33

Categories of documents

X: Document indicating lack of novelty or of inventive step.

Y: Document indicating lack of inventive step if combined with one or more other documents of the same category.

A: Document indicating technological background and/or state of the art.

P: Document published on or after the declared priority date but before the filing date of the present application.

E: Patent document published on or after, but with priority date earlier than, the filing date of the present application.

&: Member of the same patent family; corresponding document.

Category	Identity of document and relevant passages		Relevant to claim(s)
X	EP 0469603 A2	(SUMITOMO) see especially Figure 4, page 5 line 57 to page 6 line 30	1,17 at least
X	EP 0445897 A1	(HERMANN) see especially Claim 1; Figure 1; column 2 line 20 to column 3 line 16	1,17 at least
X	EP 0398375 A2	(SUMITOMO) see especially page 5 lines 2-14; Figure 5	1,17 at least
X	WO 92/01079 A1	(HERMANN) see especially Claim 1; Figure 2; and English abstract	1,17 at least
X	US 5238546	(BALZERS) see especially Example 6	1,17 at least
X	US 5084300	(FORSHUNGSZENTRUM) see especially column 2 lines 38-46, Figure 1	1,17 at least
X	US 5049405	(ROCKWELL) see especially column 2 lines 41-62 and Figure 1	1,17 at least
X	US 5037521	(MATSUSHITA) see especially Figures 1, 2; column 2 line 45 to column 3 line 68	1,17 at least
X	US 4631197	(MOTOROLA) see especially column 4 lines 43-62	1,17 at least

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