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(54) **ADDITIVE MANUFACTURE OF TURBINE COMPONENT WITH MULTIPLE MATERIALS**

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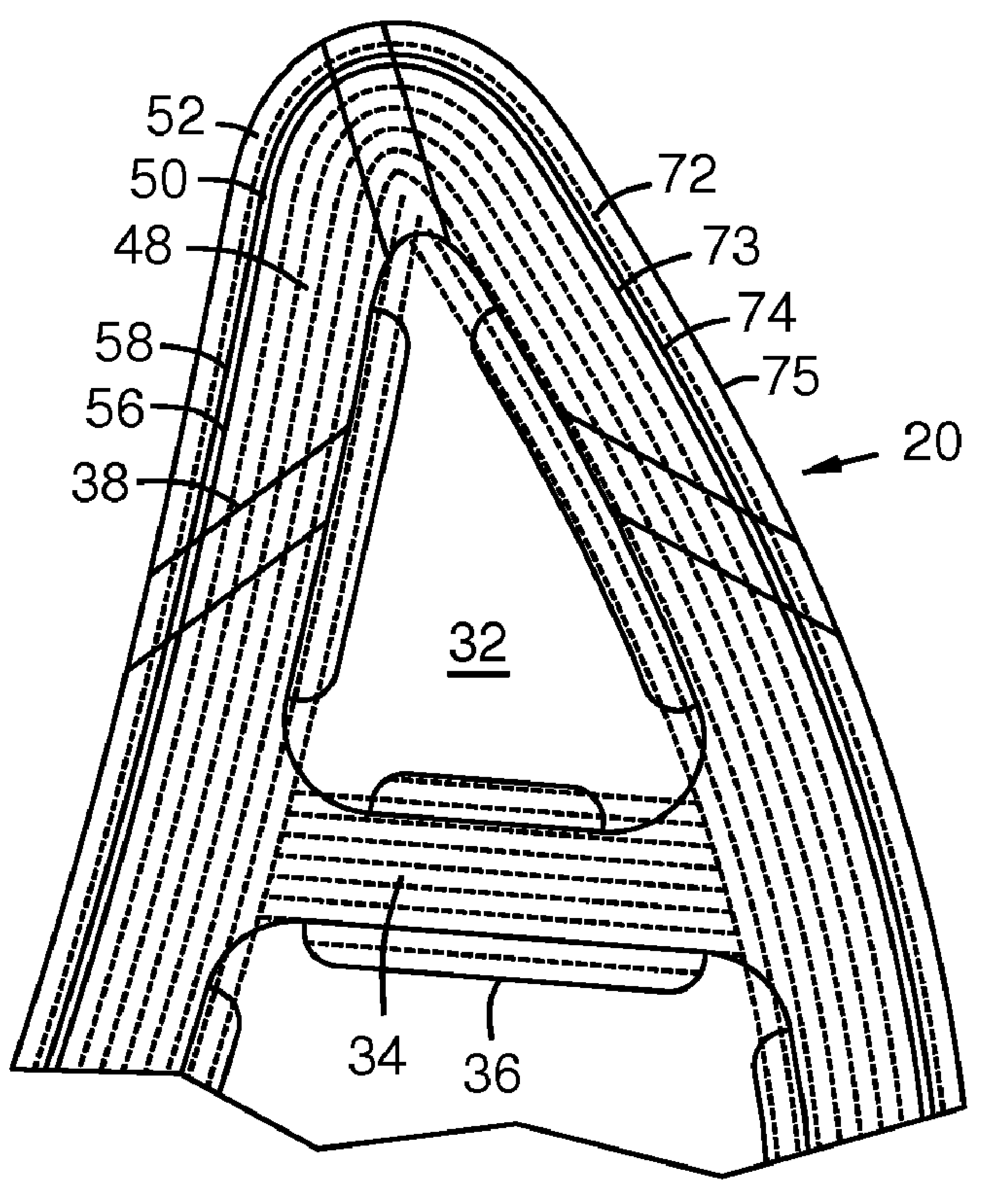
USPC **428/164**; 419/7; 428/450

(57) **ABSTRACT**

A method for additive manufacturing with multiple materials. First (**48**), second (**50**), and third (**52**) adjacent powder layers are delivered onto a working surface (**54**A) in respective first (**73**), second (**74**), and third (**75**) area shapes of adjacent final materials (**30**, **44**, **45**) in a given section plane of a component (**20**). The first powder may be a structural metal delivered in the sectional shape of an airfoil substrate (**30**). The second powder may be a bond coat material delivered in a sectional shape of a bond coat (**45**) on the substrate. The third powder may be a thermal barrier ceramic delivered in a section shape of the thermal barrier coating (**44**). A particular laser intensity (**69**A, **69**B) is applied to each layer to melt or to sinter the layer. Integrated interfaces (**57**, **77**, **80**) may be formed between adjacent layers by gradient material overlap and/or interleaving projections.



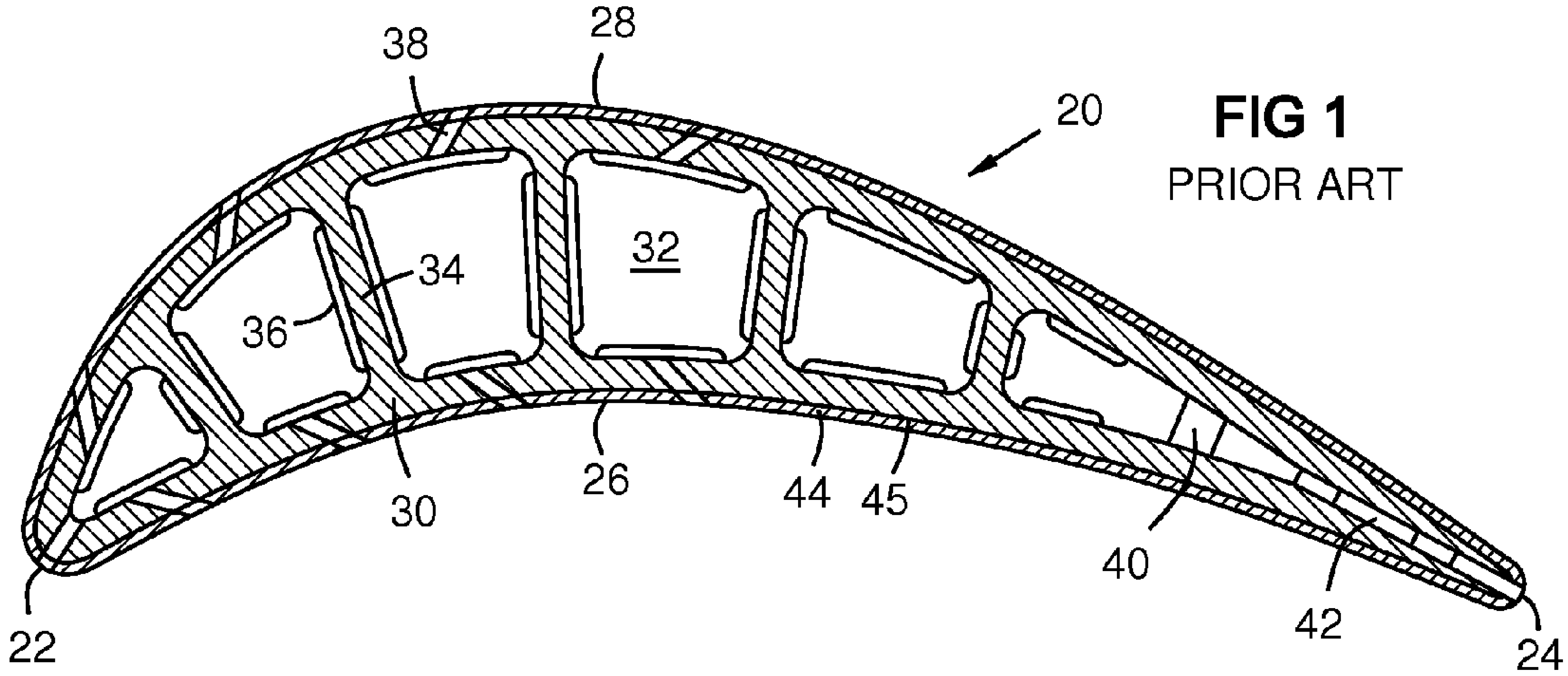


FIG 1
PRIOR ART

FIG 2

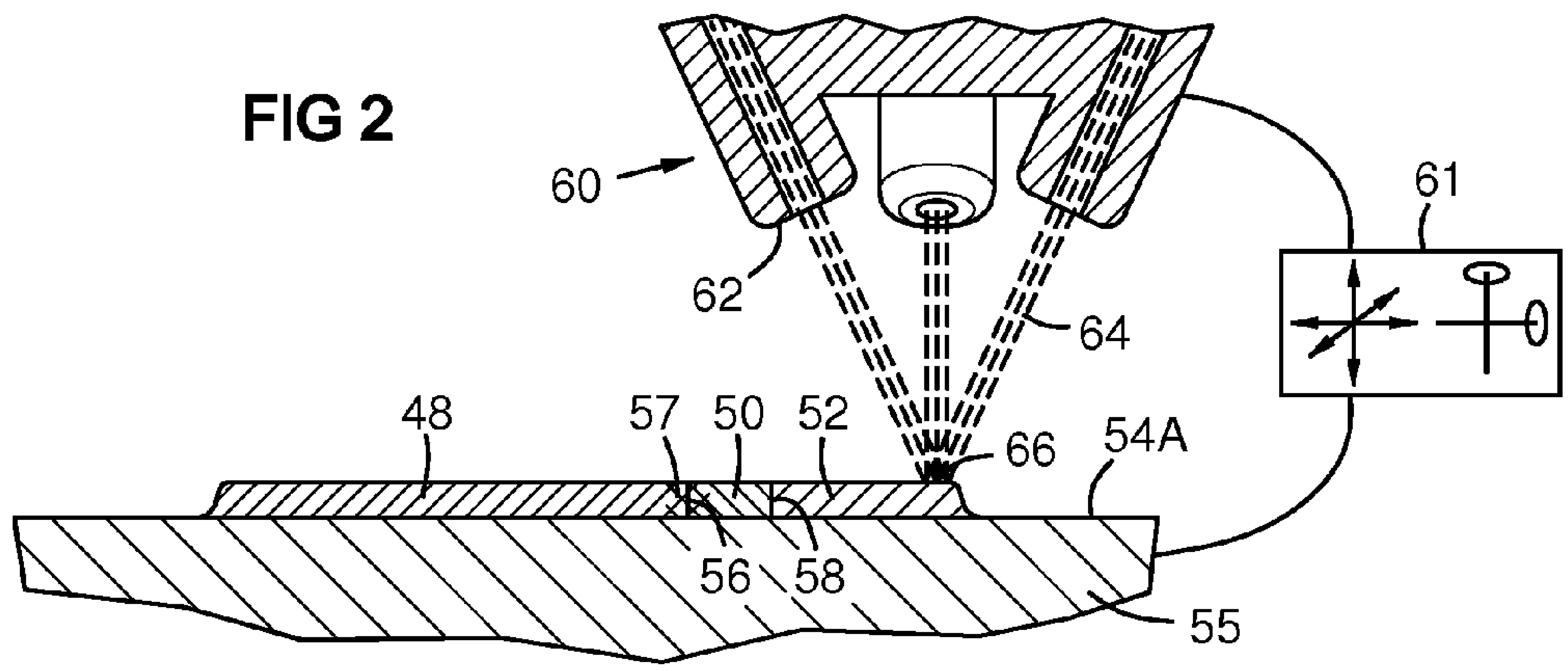


FIG 3

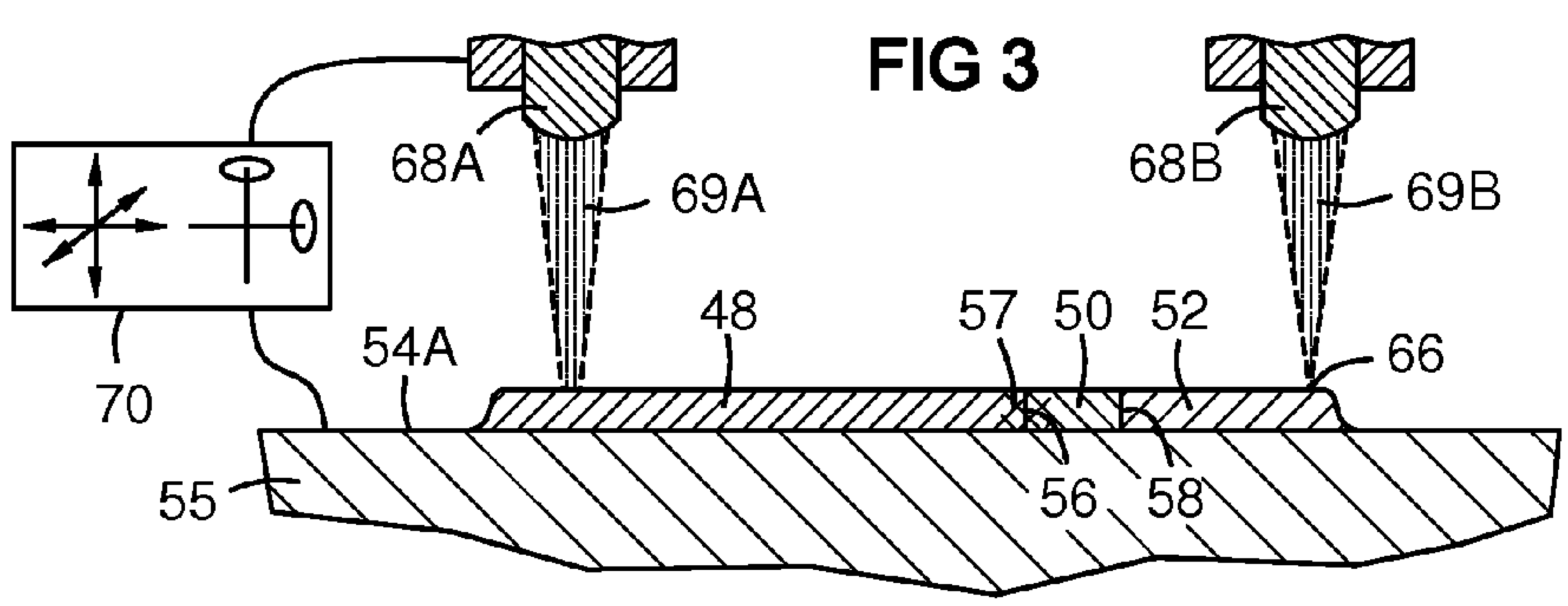


FIG 4

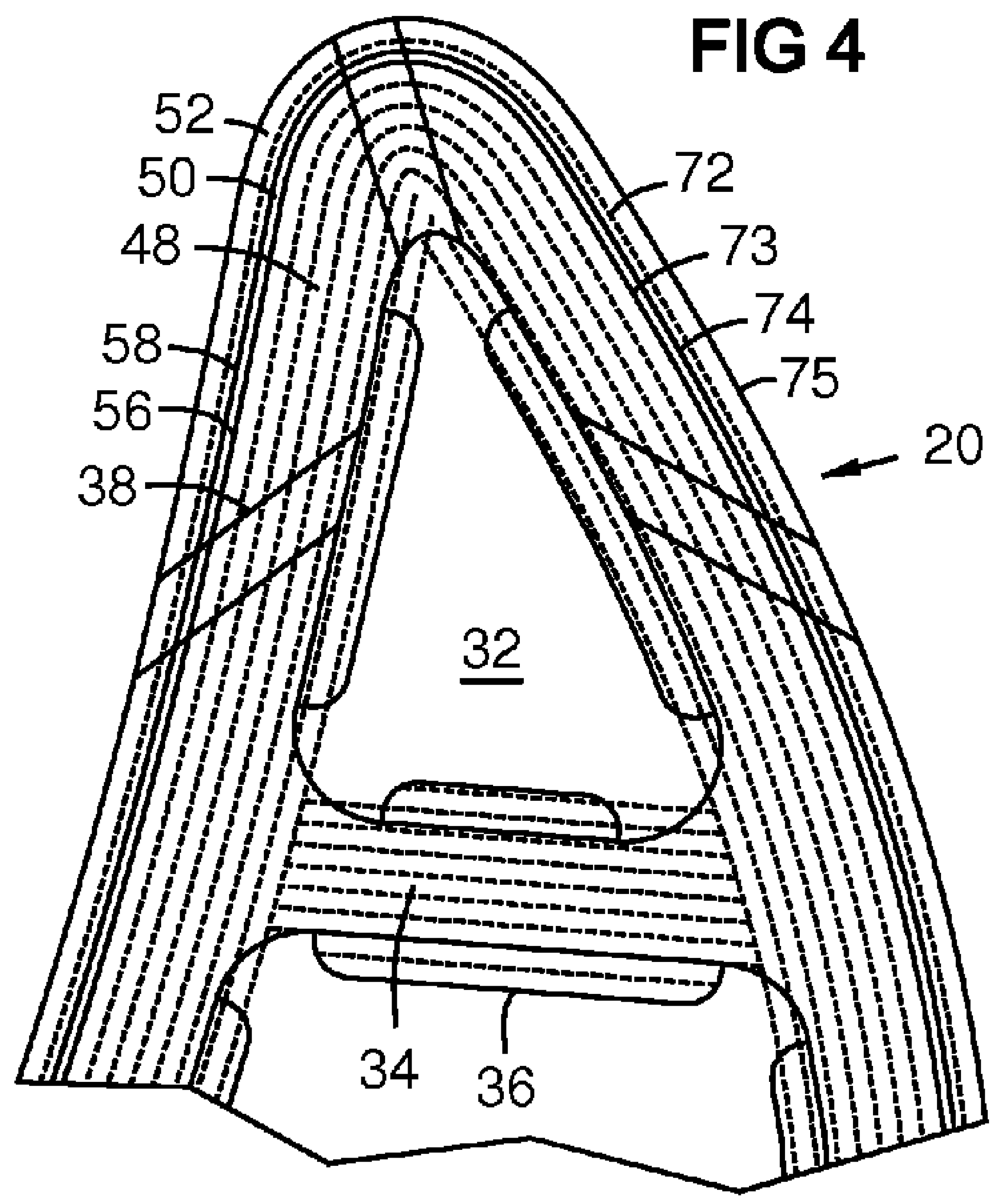


FIG 5

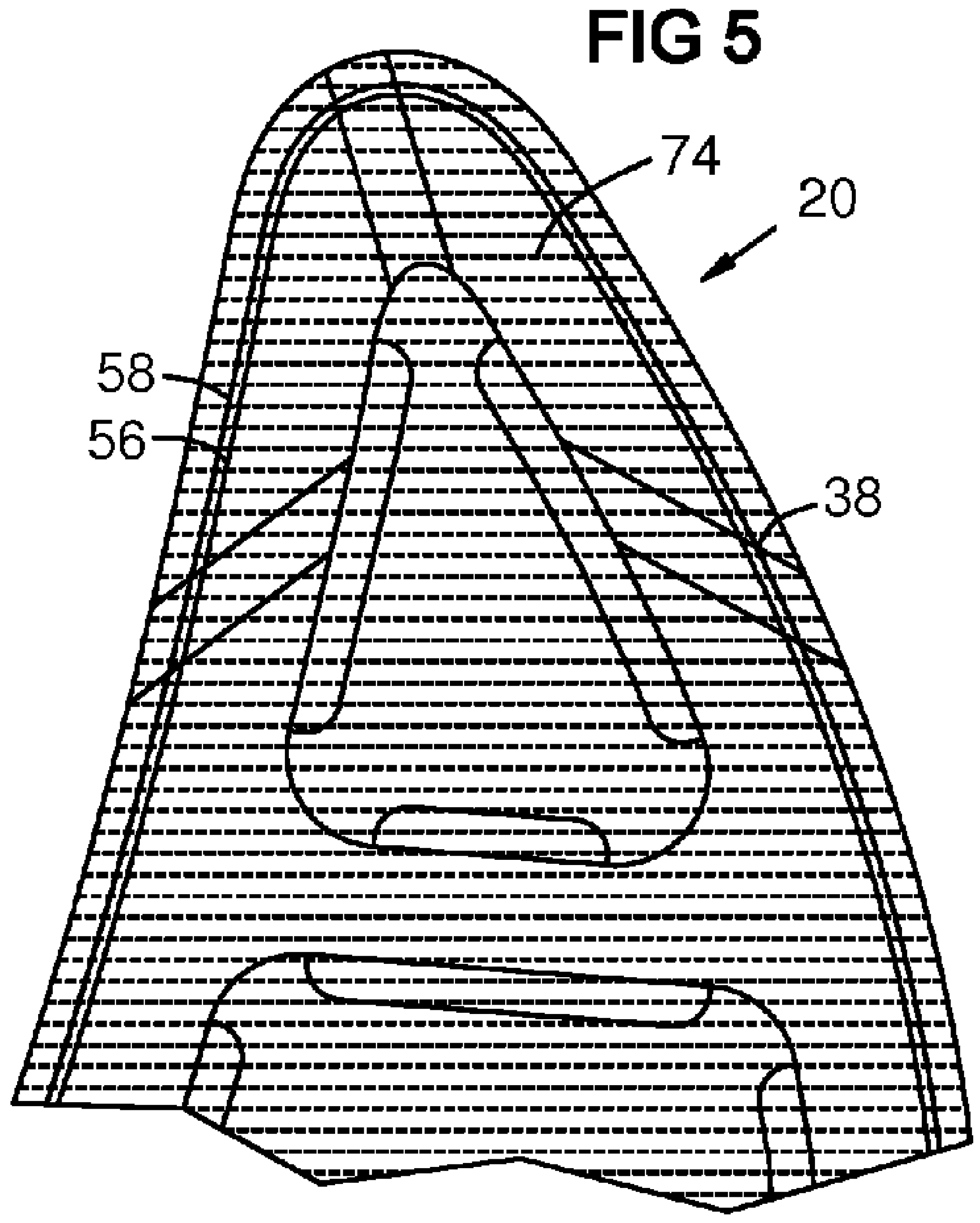


FIG 6

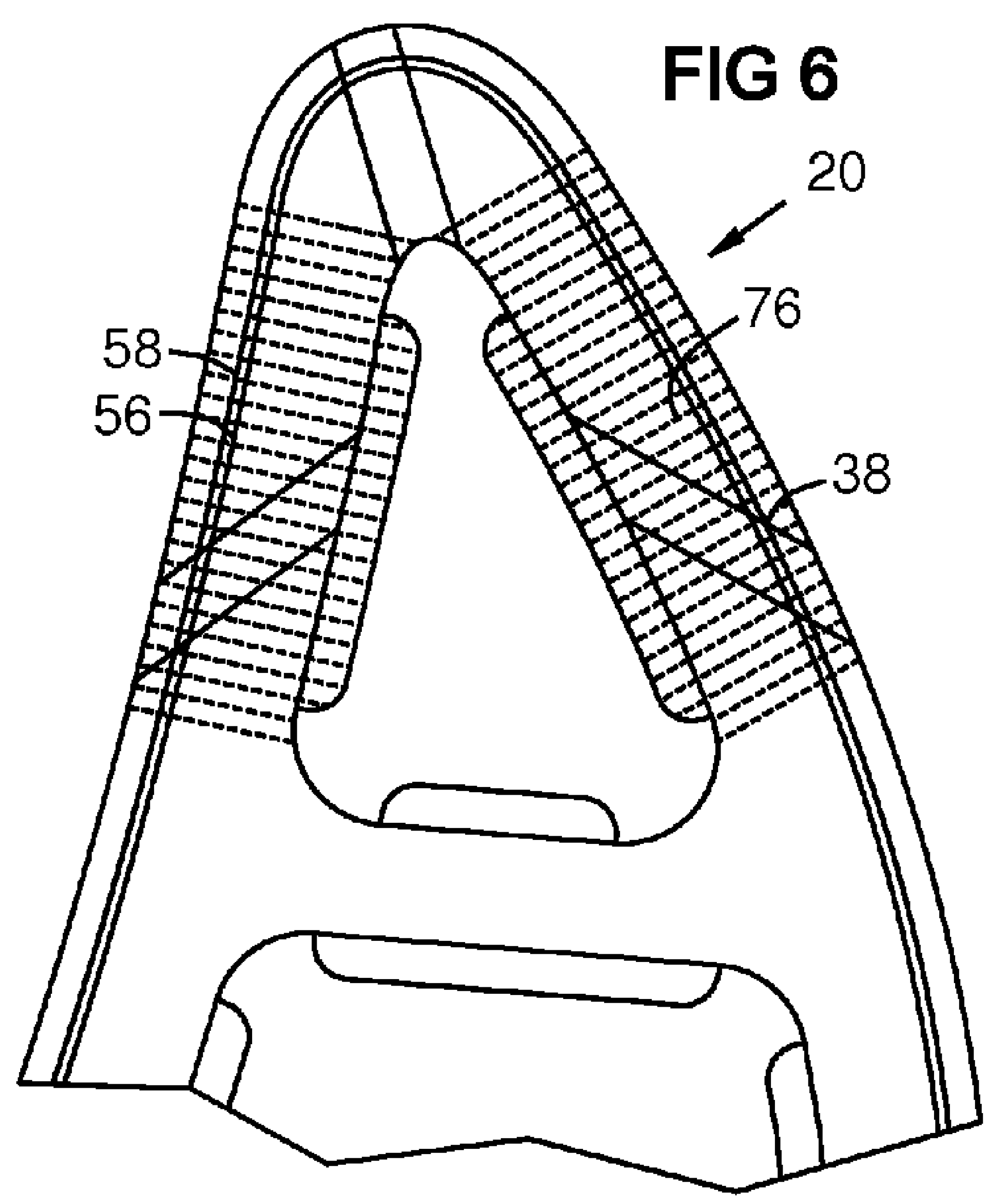


FIG 7

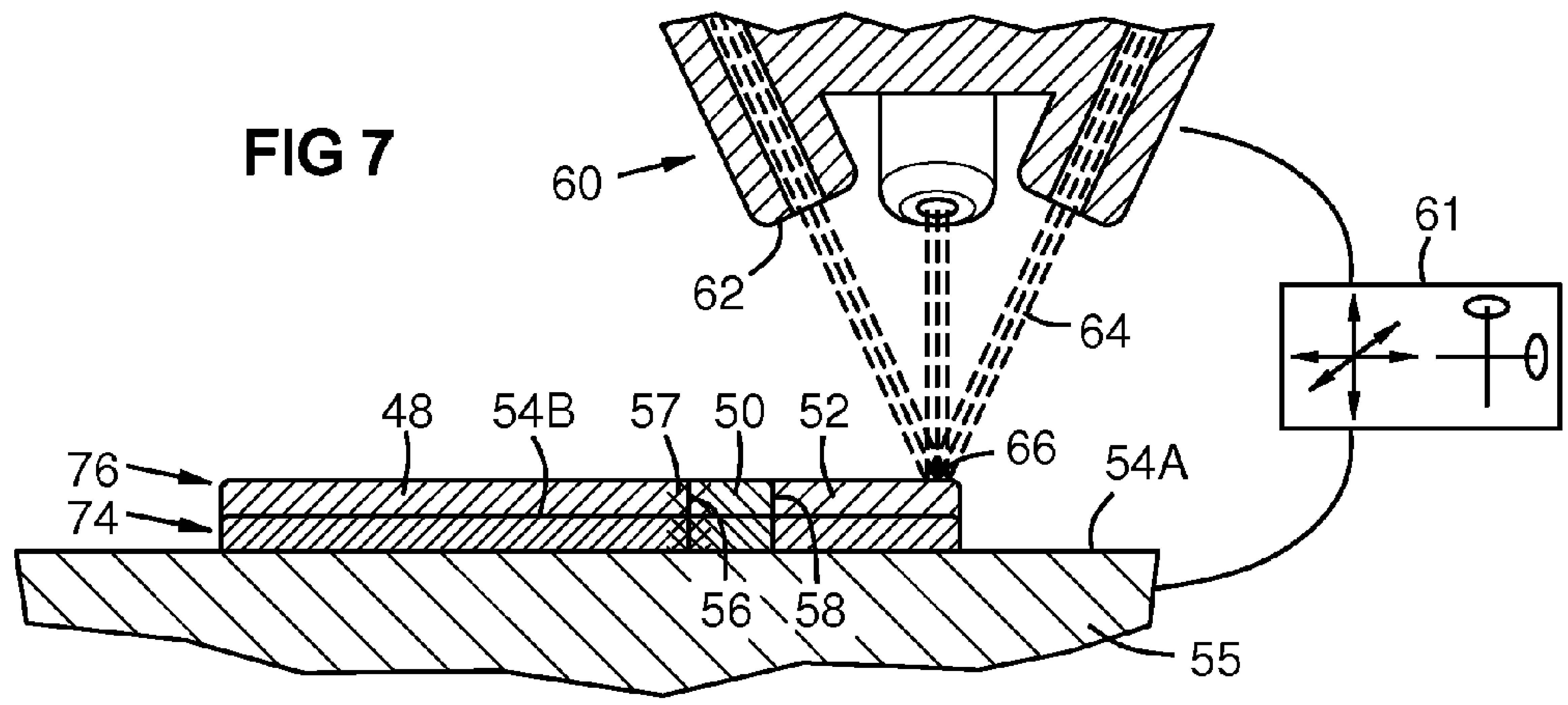


FIG 8

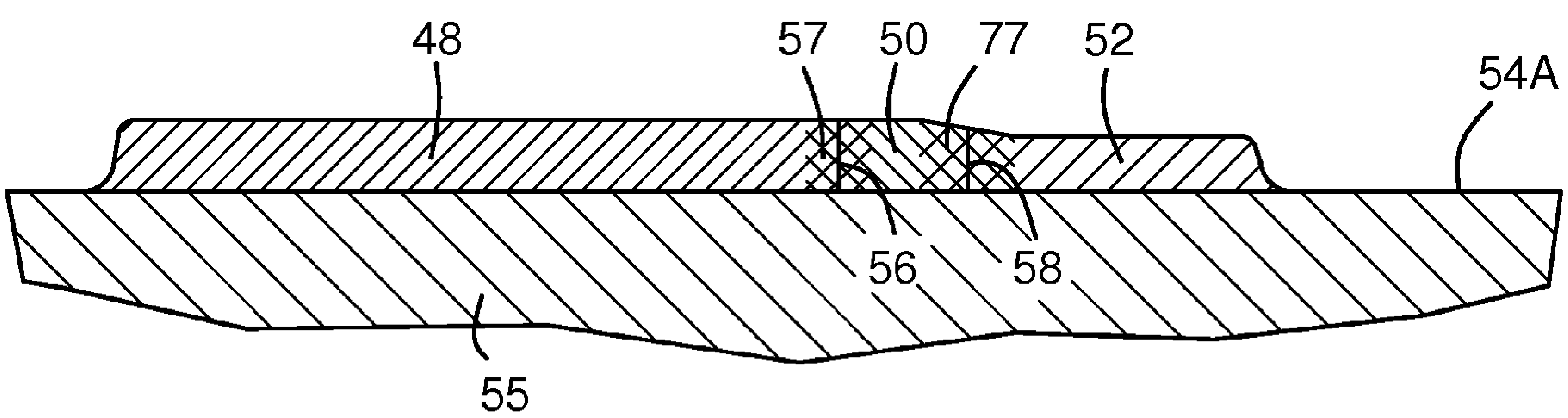


FIG 9

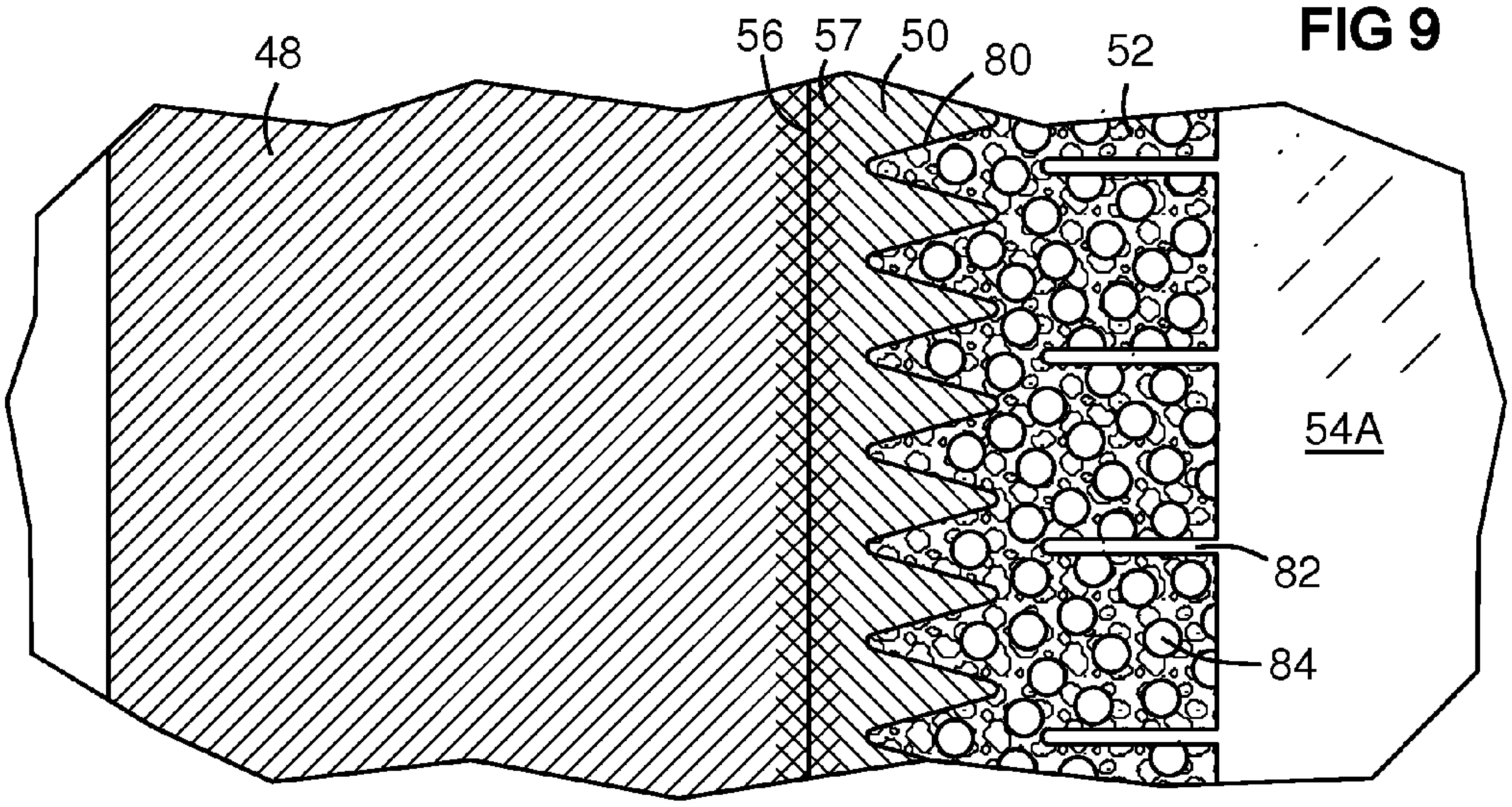
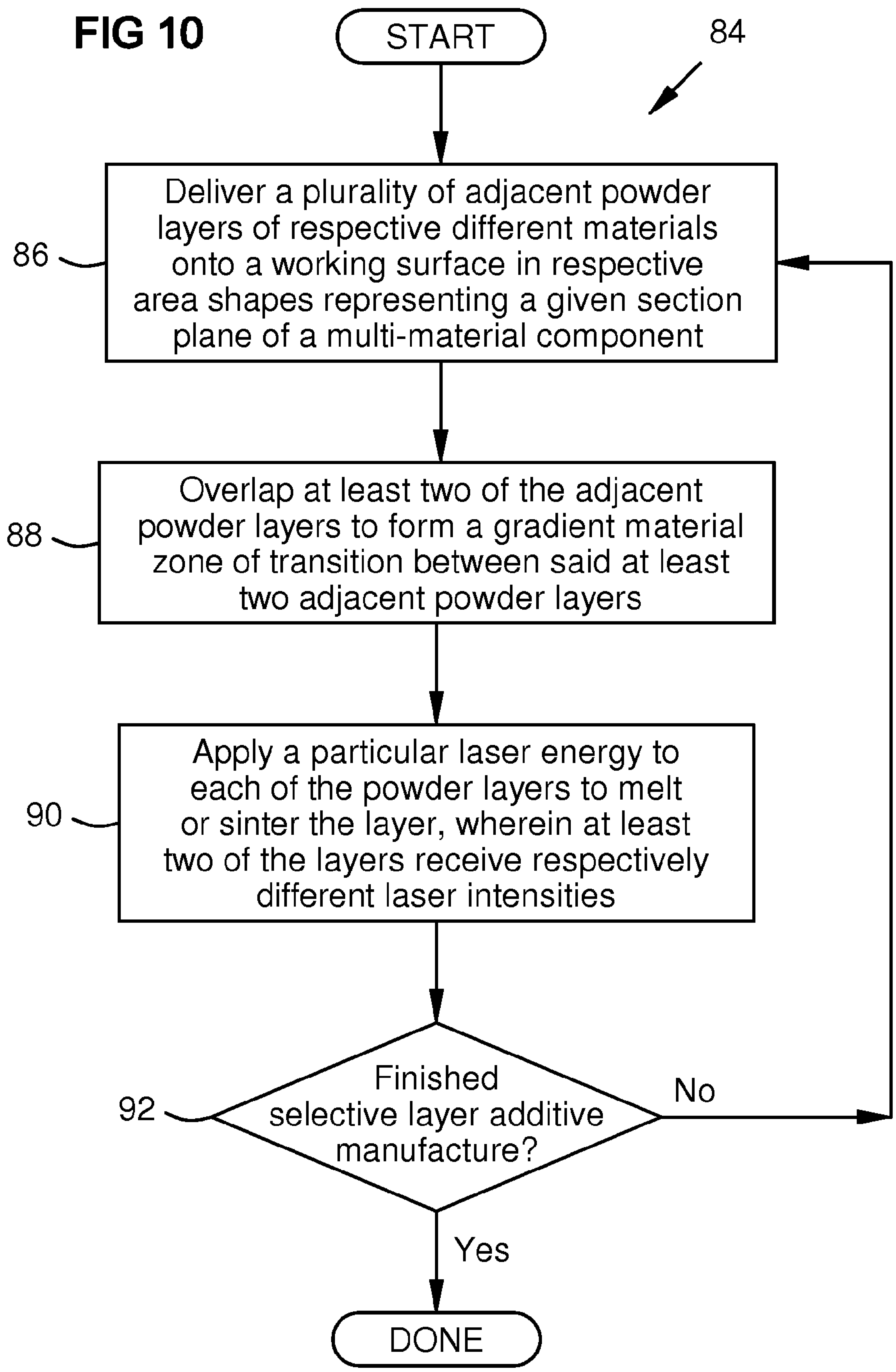


FIG 10


START
84
86
Deliver a plurality of adjacent powder layers of respective different materials onto a working surface in respective area shapes representing a given section plane of a multi-material component
88
Overlap at least two of the adjacent powder layers to form a gradient material zone of transition between said at least two adjacent powder layers
90
Apply a particular laser energy to each of the powder layers to melt or sinter the layer, wherein at least two of the layers receive respectively different laser intensities
92
Finished selective layer additive manufacture?
No
Yes
DONE

ADDITIVE MANUFACTURE OF TURBINE COMPONENT WITH MULTIPLE MATERIALS

[0001] This application claims benefit of the 8 Oct. 2012 filing date of U.S. provisional patent application No. 61/710,995 (attorney docket 2012P24077US), and the 10 Oct. 2012 filing date of U.S. provisional patent application No. 61/711,813 (attorney docket 2012P24278US), both of which are incorporated by reference herein.

FIELD OF THE INVENTION

[0002] This invention relates to additive layer manufacturing, and particularly to making multi-material metal/ceramic gas turbine components by selective laser sintering and selective laser melting of adjacent powder layers of different materials.

BACKGROUND OF THE INVENTION

[0003] Selective layer additive manufacturing includes selective laser melting (SLM) and selective layer sintering (SLS) of powder beds to build a component layer by layer to achieve net shape or near net shape. A powder bed of the component final material or precursor material is deposited on a working surface. Laser energy is selectively directed onto the powder bed following a cross sectional area shape of the component, thus creating a layer or slice of the component, which then becomes a new working surface for a next layer. The powder bed is conventionally spread over the working surface in a first step, and then a laser defines or "paints" the component sectional area on the bed in a following step, for example by raster scanning.

[0004] A related process, often referred to as micro-cladding, deposits a powder onto a component via a moving nozzle or other delivery device. A laser concurrently melts the powder at the deposit point, thus forming a bead of material on the component as the delivery device moves. Successive passes can build a layer or layers of material for repair or fabrication of a component.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] The invention is explained in the following description in view of the drawings that show:

[0006] FIG. **1** is a sectional view of a prior art gas turbine blade.

[0007] FIG. **2** is a sectional view of a powder delivery device forming adjacent powder layers on a working surface.

[0008] FIG. **3** is a sectional view of laser beams melting and sintering adjacent powder layers.

[0009] FIG. **4** shows a pattern of scan paths for powder delivery and/or laser delivery parallel to non-linear sectional profiles of a component

[0010] FIG. **5** shows an alternate scan pattern with parallel linear paths.

[0011] FIG. **6** shows scan paths that are normal, or approximately normal, to the walls of the component.

[0012] FIG. **7** shows a second slice being formed on a first slice of the component.

[0013] FIG. **8** shows adjacent powder layers deposited at different thicknesses.

[0014] FIG. **9** shows an interlocking interface between adjacent materials.

[0015] FIG. **10** is a flow chart showing aspects of an embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

[0016] The inventors have devised a method for additive manufacturing of a component having multiple adjacent materials of different properties. It produces a net shape or near net shape with strong bonding of the adjacent materials, including metal to ceramic. This is especially beneficial in fabricating gas turbine components such as superalloy blades and vanes with ceramic thermal barrier coatings. Such airfoils are difficult to fabricate, because they have complex shapes with serpentine cooling channels lined with turbulators and film cooling holes.

[0017] FIG. **1** is a transverse sectional view of a typical gas turbine airfoil **20** with a leading edge **22**, trailing edge **24**, pressure side **26**, suction side **28**, metal substrate **30**, cooling channels **32**, partition walls **34**, turbulators **36**, film cooling exit holes **38**, cooling pins **40**, and trailing edge exit holes **42**. The exterior of the airfoil substrate is coated with a ceramic thermal barrier coating **44**. A metallic bond coat **45** may be applied between the substrate and the thermal barrier coating. Turbulators are bumps, dimples, ridges, or valleys within the cooling channels **32** that increase surface area and mix the fluid boundary layer of the coolant flow.

[0018] FIG. **2** shows a process and apparatus for delivering first **48**, second **50**, and third **52** adjacent powder layers onto a working surface **54**A in respective first, second, and third section area shapes of first, second, and third adjacent final materials in a given section plane of a component. For example, the first powder layer **48** may be a structural metal delivered in the area shape of an airfoil substrate **30** as shown in FIG. **1**. The second powder layer **50** may be a bond coat delivered adjacent the first powder **48** in the area shape of a bond coat **45** on the substrate (FIG. **1**). The third powder layer **52** may be a thermal barrier ceramic delivered adjacent the second powder in the area shape of the thermal barrier coating **44** (FIG. **1**).

[0019] An interface **56** between the first and second powder layers may be delivered so as to form an overlap zone **57** that provides a material gradient transition between the two adjacent powder layers **48**, **50**. An interface **58** between the second and third powders **50**, **52** may be delivered so as to form an engineered mechanical interlock such as interleaved fingers projecting alternately from the second and third powders (later shown). The powder delivery device **60** may have one or more nozzles **62** delivering powder spray **64** to a focal point **66**.

[0020] The powder delivery device **60** may incorporate multi-axis movements **61** relative to the working surface **54**A, so that the nozzle can follow non-linear sectional profiles in a given horizontal plane, can move to different planes or distances relative to the working surface **54**A, and can deliver powder at varying angles. The axes may be implemented by motions of the work table **55** and/or the powder delivery device **60** via tracks and rotation bearings under computer control. Powder delivery parameters such as nozzle translation speeds, mass delivery rates, and spray angles may be predetermined by discrete particle modeling simulations to optimize the final slice geometry. After spraying, the powder may be compacted and stabilized by means such as electromagnetic energy and/or mechanical or acoustic vibration prior to laser heating.

[0021] The powder may be wetted with water, alcohol, lacquer or binder prior to or during spraying so it holds a desired form until the laser melts or sinters it into a cohesive slice of the component. As described more fully in co-pending United States Patent Application Publication US 2013/0140278 A1, attorney docket 2012P22347US, incorporated by reference herein, flux material may be included with the powder materials to facilitate the cladding process.

[0022] FIG. **3** shows a process and apparatus for melting and/or sintering different powder layers **48**, **50**, **52** with respective different laser energies. For example, the substrate superalloy powder **48** and the bond coat powder **58** may be melted with first and second laser energies, and the ceramic thermal barrier powder **52** may be sintered with a third laser energy that only partly melts the ceramic particles. The different laser energies **69**A, **69**B may be provided by a single laser emitter **68**A with variable output, or by multiple laser emitters **68**A, **68**B with different outputs for different powder layers. The laser emitter may incorporate multi-axis movement **70** relative to the working surface **54**A, so that it can follow non-linear sectional profiles in a given plane, can move to different planes or distances relative to the working surface **54**A, and can position and direct a laser beam for desired angles and spot sizes.

[0023] FIG. **4** shows a pattern of paths **72** that follow the non-linear sectional shape profiles **73**, **74**, **75** of the component **20**. The powder delivery focus **66** of FIG. **2** may be controlled to follow such paths. Such a scan pattern **72** parallel to the sectional shape profiles allows the powder type to be changed for each powder layer **48**, **50**, **52**.

[0024] The laser energy **69**A-B (FIG. **3**) may also follow non-linear scan paths such as **72** of FIG. **4**. This path type minimizes the number of changes in laser intensity for different powder materials. A first laser energy may be directed to follow a contour of the sectional shape **73** of the first powder layer **48**, a second laser energy may be directed to follow a contour of a sectional shape **74** of the second powder layer **50**, and a third laser energy may be directed to follow a contour of a sectional shape **75** of the third powder layer **52**. The laser may be cycled off as it passes over areas intended to remain as voids in the formed component, such as film cooling holes **38**.

[0025] FIG. **5** shows an alternate scan pattern with parallel linear paths **74** for the laser energy. FIG. **6** shows paths **76** that are normal, or approximately normal, to the walls of the component. Patterns **74** and **76** may require laser intensity changes at each crossing of the interfaces **56**, **58** for the different powder layers in addition to off/on cycling for the voids **38**. The spacing of scans **72**, **74**, **76** depends on the laser beam width or spot size at the powder surface. Multiple laser emitters may be used together to produce a wider swath to reduce the number of scans. The laser beam(s) may be adjusted in width by changing the distance of the emitter from the working surface, and/or the beam may be adjusted in size and shape by adjustable lenses, mirrors, or masks to better define small, sharp, or curved elements of the component such as fillets, without decreasing the scan spacing and spot size.

[0026] FIG. **7** shows a first solidified slice **74** of the component providing a new working surface **54**B on which to apply powder layers **48**, **50**, **52** for a second slice **76** of the component.

[0027] FIG. **8** shows powder layers **48**, **50**, **52** delivered at different heights depending on their respective process shrinkages to achieve a final uniform slice thickness. The powders of the first **48** and second **50** adjacent layers may be deposited in the overlap zone **57** such that the powders overlap in a gradient material transition. The overlap width may be at least 0.2 mm for example. The powders of the second **50** and third **52** adjacent layers may also be deposited in an overlap zone **77** such that the powders overlap in a gradient material transition. The overlap widths may be at least 0.2 mm or 0.4 mm or up to 1 mm or up to 2 mm, for examples.

[0028] FIG. **9** shows an interface between the second **50** and third **52** layers formed with engineered interlocking features **80** there between, such as interleaved profiles that form 3D interlaced fingers projecting alternately from the bond layer **50** and the ceramic layer **52**. Such an interlocking mechanical interface may be provided instead of, or in addition to, a gradient material zone **77** as shown in FIG. **8**. Fissures **82** may be formed in the ceramic layer **52** for operational strain relief by cycling the laser energy off/on as it scans the ceramic layer **52**. Hollow ceramic spheres **84** may be included in the material of the ceramic layer **52** to reduce thermal conductivity. Inclusion of hollow ceramic spheres in the thermal barrier layer **52** permanently reduces its thermal conductivity, since the sphere voids are not subject to reduction by operational sintering.

[0029] FIG. **10** is a flow chart of a method **84** showing aspects of an embodiment of the invention, including the following steps:

[0030] **86**. Delivering a plurality of adjacent powder layers of respective different materials onto a working surface in respective area shapes representing a given section plane of a multi-material component.

[0031] **88**. Overlapping at least two of the adjacent powder layers to form a gradient material zone of transition between said at least two adjacent powder layers.

[0032] **90**. Applying a particular laser energy to each of the powder layers to melt or sinter the layer, wherein at least two of the layers receive respectively different laser intensities.

[0033] **92**. Repeating from step **86** with successive section planes to fabricate the component by selective layer additive manufacturing.

[0034] Inclusion of nano-scale ceramic particles can reduce the sintering temperature of the ceramic layer by as much as 350° C. in some embodiments. This can facilitate co-sintering and bonding of the metal and ceramic layers. Temperature reduction occurs particularly when the ceramic powder comprises at least 2% and up to 100% by volume of particles being less than 100 nm average diameter, and it especially occurs with particles less than 50 nm average diameter. The present method allows sintering by only partially melting such nanoparticles. This is not possible when applying a ceramic coating with thermal spray technologies, because it tends to fully melt the smaller particles.

[0035] Nickel-based superalloys used in high temperature gas turbine components are often strengthened by a gamma prime precipitant phase within a gamma phase matrix. The properties of these superalloys that make them durable in high-temperature environments also make them difficult to fabricate and repair. However, they can be fabricated and joined to adjacent layers of different materials, including ceramics, by the method described herein. Casting of gas turbine blades having serpentine channels with turbulators and film cooling exit holes is difficult and expensive. The present method reduces cost while more fully joining the different material layers. It allows a complete multi-material component such as a turbine blade to be fabricated in one process, instead of casting a superalloy blade, then coating it in a separate process, such as thermal spray.

[0036] While various embodiments of the present invention have been shown and described herein, it will be obvious that such embodiments are provided by way of example only. Numerous variations, changes and substitutions may be made without departing from the invention herein. Accordingly, it is intended that the invention be limited only by the spirit and scope of the appended claims.

The invention claimed is:

1. A method for making a component, comprising the steps of:

delivering a plurality of adjacent powder layers of respectively different powder materials onto a working surface in respective area shapes representing respective final materials in a given section plane of a multi-material component;

overlapping at least two of the adjacent powder layers to form a material gradient zone between said at least two adjacent powder layers;

applying a first laser energy of a first intensity to a first of the powder layers, and a second laser energy of a second different laser intensity to a second of the powder layers; and

repeating from the delivering step for successive section planes of the component to fabricate the component.

2. The method of claim **1**, wherein the first powder layer comprises a metal, the second powder comprises a thermal barrier ceramic, the first laser energy is directed to follow a first plurality of scan paths parallel to a non-linear perimeter of the first powder layer, and the second laser energy is directed to follow a second plurality of scan paths parallel to a non-linear perimeter of the second powder layer.

3. The method of claim **2**, further comprising cycling the first and second laser energies on and off while following the first and second scan paths to form channels passing through the first and second final materials.

4. The method of claim **2**, further comprising cycling the second laser energy on and off while following second scan paths to form strain-relief fissures in the second final material.

5. The method of claim **1**, further comprising forming a mechanically interlocking interface between the first and second final materials by delivering the first and second powder materials onto the working surface with interleaved profiles there between, forming interleaved fingers across the interface.

6. The method of claim **1**, further comprising depositing the first and second powder layers onto the working surface in respective first and second thicknesses, and predetermining the respective laser energies to reduce the powder layers to a uniform thickness of the final materials in the given section plane.

7. The method of claim **1**, further comprising providing the first and second laser energies by a laser beam directed along successive linear scan paths that each pass over the first and second powder layers, and further comprising varying the intensities of the laser beam along each scan path to provide the first and second intensities.

8. A product formed by the method of claim **1**.

9. A method of making a component, comprising the steps of:

delivering respective powders of first, second, and third adjacent layers of respectively different materials onto a working surface in respective first, second, and third area shapes, which in combination represent a given multi-material section plane of the component;

wherein the first powder layer comprises a structural metal material, the second powder layer comprises a bond coat material, and the third powder layer comprises a thermal barrier ceramic;

applying a particular laser energy to each of the powder layers to melt or sinter the layer, wherein at least two of the layers receive respectively different laser intensities; and

repeating from the delivery step with successive section planes to fabricate the component by selective layer additive manufacturing.

10. The method of claim **9**, further comprising cycling the laser energies on and off while following scan paths parallel to respective profiles of the area shapes to form channels in the component.

11. The method of claim **9**, further comprising directing a first laser energy to follow scan paths parallel to a profile of the first shape, directing a second laser energy to scan paths parallel to a profile of the second shape, and directing a third laser energy to follow scan paths parallel to a profile of the third shape.

12. The method of claim **11**, further comprising cycling the third laser energy on and off to form strain-relief fissures in the thermal barrier ceramic.

13. The method of claim **11**, further comprising forming a mechanically interlocking interface between the second and third layers by delivering the second and third powders onto the working surface with interleaved profiles there between, forming interleaved fingers in the interface.

14. The method of claim **9**, further comprising overlapping the first and second powders by at least 0.2 mm, forming a gradient material zone.

15. The method of claim **11**, further comprising overlapping the second and third powders by at least 0.4 mm, forming a gradient material zone.

16. The method of claim **11**, further comprising depositing the first and third layers onto the working surface in respective first and second different thicknesses, and predetermining the respective intensities of the laser energies to reduce the three powder layers to a uniform material thickness.

17. The method of claim **11**, further comprising providing the first, second, and third laser energies by a laser beam directed along successive lines that each pass over the first, second, and third layers, and further comprising varying an intensity of the laser beam along each line to provide the particular energy for each powder layer crossed by the line.

18. A method of making a gas turbine component: comprising the steps of:

delivering first, second, and third adjacent powder layers onto a working surface in respective first, second, and third area shapes of first, second, and third adjacent final materials in a given section plane of the component;

wherein the first material comprises a structural metal, the second material comprises a bond coat metal, and the third material comprises a thermal barrier ceramic;

melting the first and second powder layers with respective first and second laser energies, and only partly melting the third powder layer with a third laser energy, wherein solidification forms a new working surface of the adjacent final materials; and repeating from the delivery step for successive section planes to fabricate the component of the structural metal with a porous ceramic thermal barrier layer;

wherein the first laser energy is directed to follow a contour of the first shape, the second laser energy is directed to follow a contour of the second shape, and the third laser energy is directed to follow a contour of the third shape.

19. The method of claim **18**, further comprising:

overlapping the first and second powders by at least 0.2 mm, forming a gradient material interface between the first and second layers; and

forming a mechanically interlocking interface between the second and third layers by delivering the second and third powders onto the working surface with interleaved profiles there between, forming interleaved fingers across the interface.

20. A product formed by the method of claim **19**.

* * * * *