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Patentanmeldung Nr.

Patent application No.

Demande de brevet n°

17000219.0 / EP17000219

The organization code and number of your priority application, to be used for filing abroad under the Paris Convention, is EP17000219.

Der Präsident des Europäischen Patentamts;
Im Auftrag

For the President of the European Patent Office

Le President de l'Office européen des brevets
p.o.

V. Joseph

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Bezeichnung der Erfindung / Title of the invention / Titre de l'invention:
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Insitu metal matrix nanocomposite synthesis by additive manufacturing route

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Insitu metal matrix nanocomposite synthesis by additive manufacturing route

To form insitu metal matrix nanocomposite by additive manufacturing route. Examples are carbides, nitrides, oxides, borides or a combination of them in a metal matrix of feed stock material.

Prior Art:

Selective laser melting (SLM) is the work horse for additive manufacturing of metallic components. The process is thoroughly investigated and published in research articles like C. Y. Yap et al., Review of selective laser melting: Materials and applications, Appl. Phys. Rev. 2, 041101(2015) 041101. The state of the art process is schematically shown in figure 1. In brief, the process consists of spreading the powder (preferably atomized powder) followed by laser rastering to cause selective melting (Fig. 1a) . Powder spreading and laser rastering is re iterated until the desired shape is achieved (Fig 1b). Though the state of the art was claimed to mass produce metallurgically sound intricate geometrical designs in industrial scale, it suffers from limited compositional and micro-structural freedom. i. e, the phase constituents of the printed components are essentially defined by the feed stock material. The final micro-structure is often an equilibrium and metastable phase mixture of the constituents from the feed stock.

In contrast to the state of the art, in the proposed method an insitu nanoscale precipitate structure is formed in the metallic matrix of the feed stock in a uniquely designed process configuration as shown in Fig.2 . The proposed process consists of laser rastering on the powder bed in a reactive plasma environment, coupled with applying an electro static potential (bias) to the build plat form. By appropriately interfacing the laser rastering, reactive plasma and the bias voltage, a nanocomposite is formed insitu, in the metal matrix as schematically shown in figure 2. The proposed method has a very high compositional freedom, i. e. nano particles of nitrides, oxides, carbides, and silicides of various stoichiometry can be incorporated in almost any metal matrix. More interestingly, such a nanocomposite is thermally stable as the particle growth by the Ostwald ripening process is experimentally negligible due to relatively a low mutual solid solubility between the particles and matrix.

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It is known from the current literature, a homogeneous distribution of nanoparticles of nitrides, carbides, borides or oxides in a metal matrix will significantly enhance the high temperature structural properties by hindering the plastic flow, even with a volume fraction as low as 5 %.

Ex. (a) GJ. Zhang et al., Microstructure and strengthening mechanism of Oxide lathanum dispersion strengthened molybdenum alloy, Adv. Eng. Mater. 2004, 6, No.12, (b) http://www.ifam.fraunhofer.de/content/dam/ifam/en/documents/dd/Infobl%C3%A4tter/dispersion-strengthened_materials_fraunhofer_ifam_dresden.pdf)

In summary, 3D printed components in the proposed configuration are characterized with a thermally stable non-equilibrium mixture of nanoscale ceramic particles homogeneously distributed in the feedstock matrix. Such a nanoscale particle reinforced 3D printed components display significantly superior structural properties at room and elevated temperature of 0.7 Tm (Tm is the melting temperature of the matrix alloy)

The goal is to invent an additive manufacturing synthesis route to form metal matrix nanocomposite insitu almost with any metallic feed stock. The schematic of the proposed synthesis route is enclosed in figure.3

Step1: Reactive plasma is ignited in the chamber preferentially on the powder bed and simultaneously an electrostatic potential of several 100 eV is applied in the melt zone via the build plat form.

Step2: Laser rastering on the powder bed causes molten pool formation very locally .

Step 3: Reactive gas ions (N+, O+, Si+, B+, C+) are electrostatically driven in to the molten pool with an energy of several 100 eV.

Step 4: The chemical interaction between the molten feed stock and reactive gas ions causes ceramic compounds such as carbides, nitrides, oxides, silicides formation insitu by the following reaction path way Ex: {Me (l) +N+ (g) --> MeN (s)}.

Step 5: By tuning the laser power, rastering speed, bias voltage; plasma reactivity, hydrodynamic forces and fluid recirculation pattern of the molten feedstock is influenced to cause nitride precipitates break down preferentially to nanoscale before the liquid pool solidifies.

Step 6: Formation of metal matrix composite with nanoscale dispersion after solidification.

Though the process is illustrated for SLM process, experts in the field will agree that this can be applied in other melting based additive manufacturing route.

Figure 1: Schematic illustration of (a) layer spreading and laser melting, (b) forming desired shape by selective laser melting process

Figure 2: Structural differences of the additive manufactured component with the a) state of the art and b) the proposed synthesis route

Figure 3: Pictorial representation of insitu metal matrix nanocomposite formation in the proposed synthesis route. Numbers in the picture represents sequential process steps explained in the text.

Claims

1. Additive manufacturing synthesis route to form metal matrix nanocomposite, comprising the steps of:

- Reactive plasma is ignited in the chamber preferentially on the powder bed and simultaneously an electrostatic potential of several 100 eV is applied in the melt zone via the build plat form

- Laser rastering on the powder bed causes molten pool formation very locally

- Reactive gas ions (N+, O+, Si+, B+, C+) are electrostatically driven in to the molten pool with an energy of several 100 eV.

- The chemical interaction between the molten feed stock and reactive gas ions causes ceramic compounds such as carbides, nitrides, oxides, silicides formation insitu by the following reaction path way Ex: {Me (l) +N+ (g) --> MeN (s)}

- Formation of metal matrix composite with nanoscale dispersion after solidification

ABSTRACT

A unique and novel additive manufacturing route has been proposed to form a thermally stable in-situ metal matrix nano composite by interfacing reactive plasma in the selective laser melting process chamber. The proposed route gives very high compositional freedom, i. e. nitrides, carbides, oxides, silicides and other ceramics with different stoichiometries can be reinforced in nanoscale in any metallic matrix. Components with such a nanocomposite structure display superior high temperature structural properties.

Fig. 1

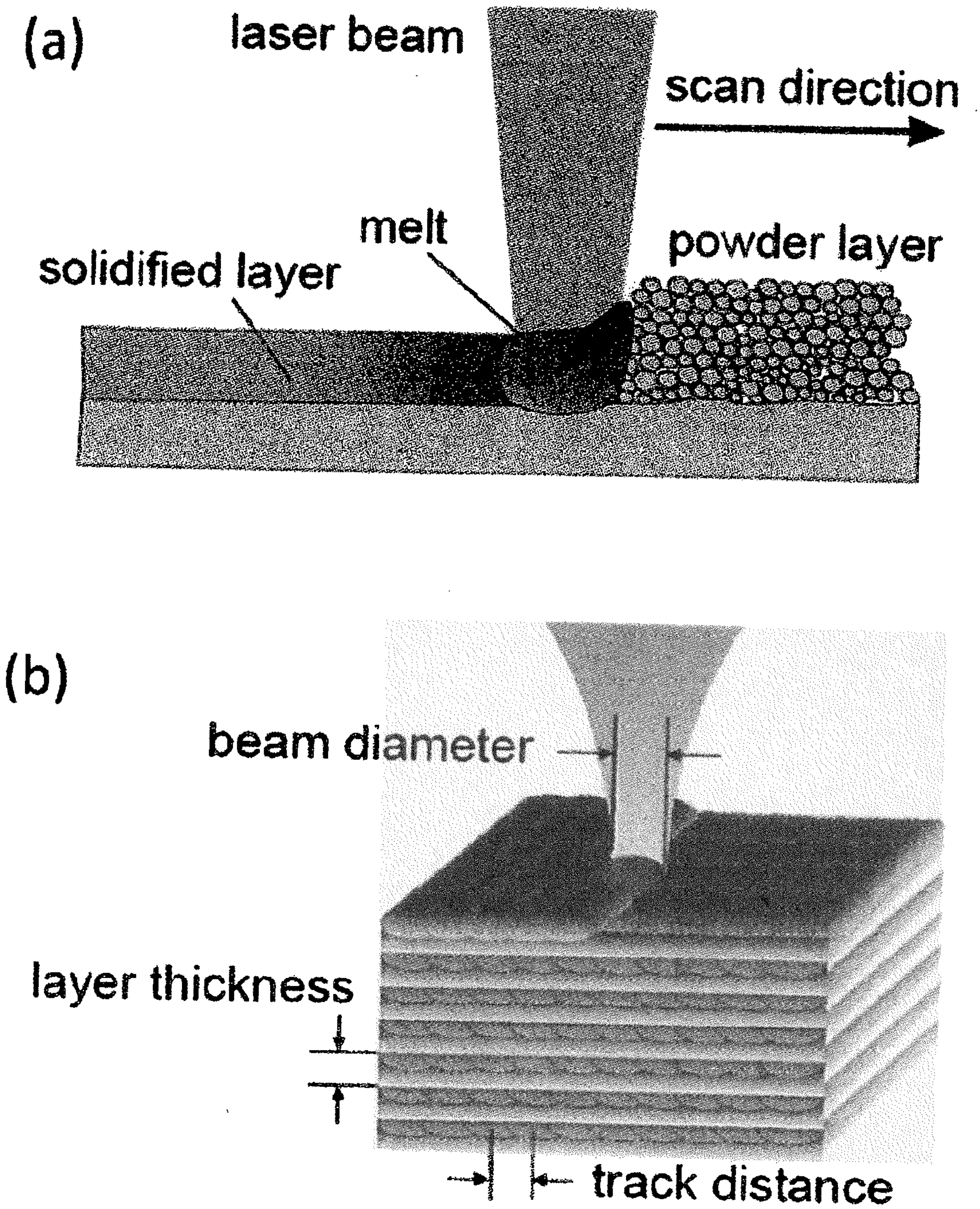

(a)
laser beam
scan direction
melt
solidified layer
powder layer
(b)
beam diameter
layer thickness
track distance

Fig. 2a

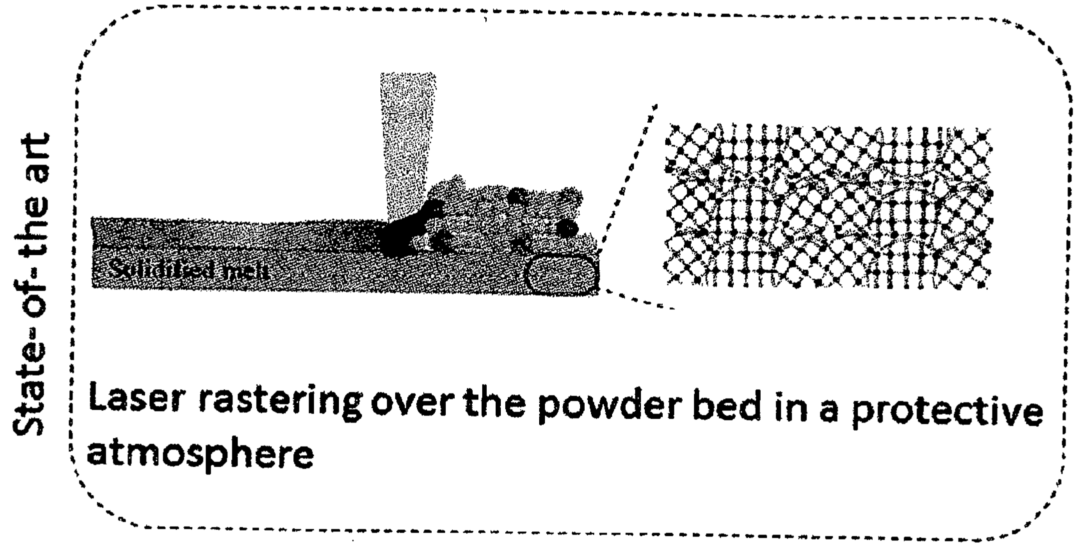

State-of- the art
Solidified melt
Laser rastering over the powder bed in a protective atmosphere

Fig. 2b

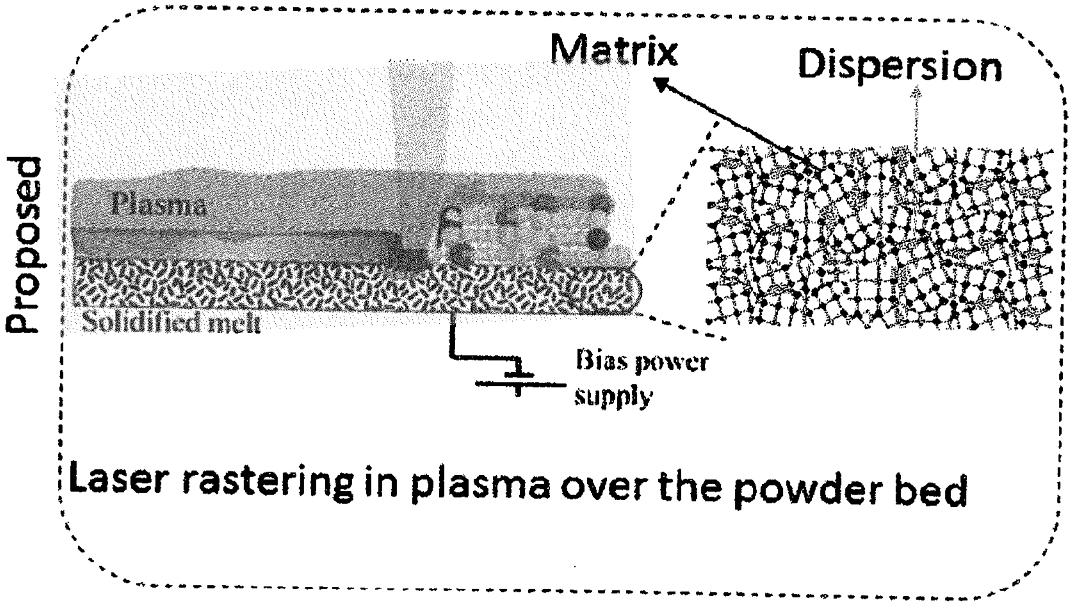
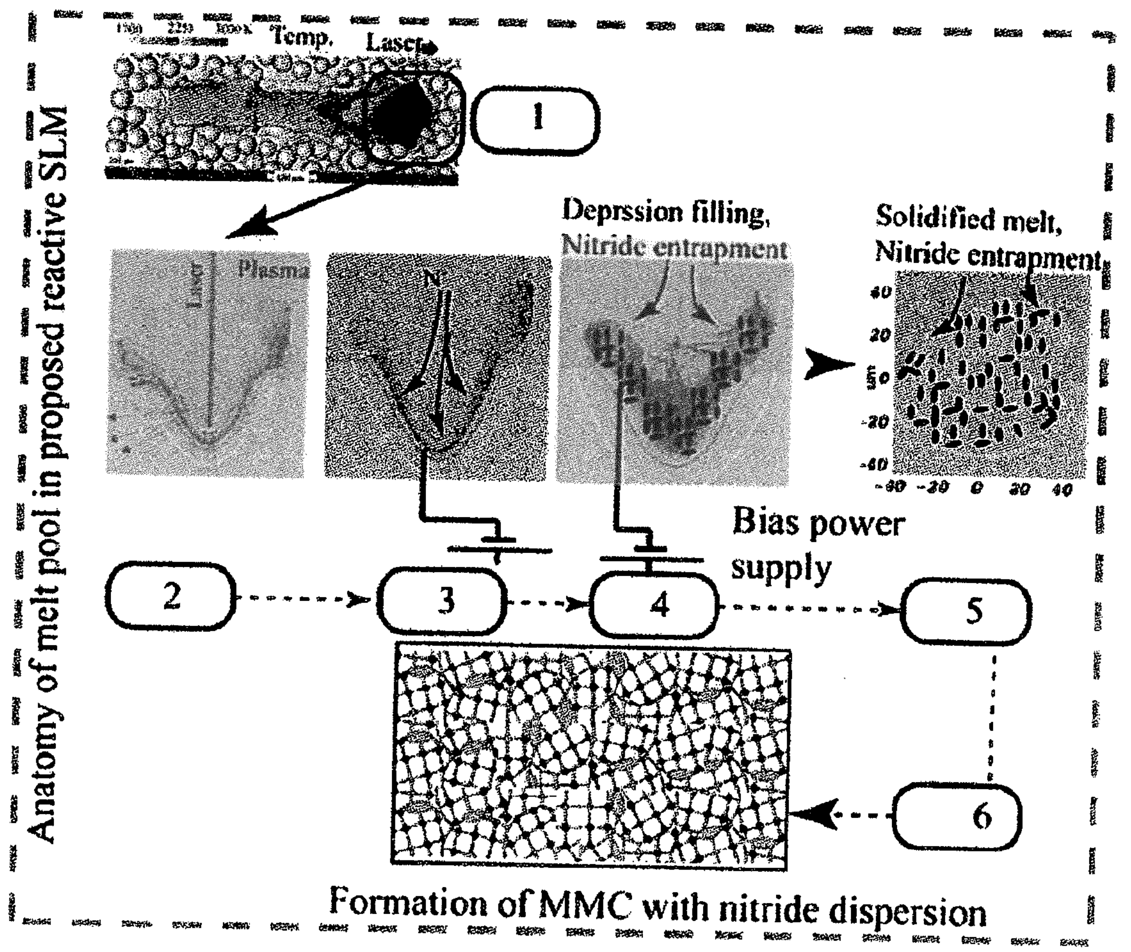

Proposed
Matrix
Dispersion
Plasma
Solidified melt
Bias power supply
Laser rastering in plasma over the powder bed

Fig. 3


Anatomy of melt pool in proposed reactive SLM
Temp.
Laser
1
Plasma
Depression filling,
Nitride entrapment
Solidified melt,
Nitride entrapment
Bias power supply
2
3
4
5
6
Formation of MMC with nitride dispersion