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NUMERICAL SIMULATION AND PROCESS STUDY OF LASER INDUCED CHEMICAL LIQUID DEPOSITION

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Abstract. Laser Induced Chemical Liquid Deposition (LCLD) is the technology using thermal effect and luminous effect of laser to enhance and stimulate the chemical plating process in order to get micro-area plating on metal or semiconductor substrate without mask. A new type of RP system graph based on LCLD and its work process are introduced on detail. The process of LCLD is controlled by thermal transfer if the heights of liquid and metallic material are changeless. The thermodynamics model of the region of laser facular in the reaction process during LCLD is established, the spatial distribution and changing of temperatures in part area are studied, and the engineering analysis software is adopted to solve and emulate the model. On the basis of theoretic analysis, the researches on the LCLD metal depositing are developed on the experimental system according to the techniques and scan strategy of RP. The main parameter indexes of the experimental system are: 50 W optical fiber coupling semiconductor laser, three-axis linkage 3D plat with positioning accuracy of 0.05 mm. These researches can lead to the conclusion that the highest temperature of plating liquid can be found if the diameter of the facular laser beam is unchangeable. The relation between temperature and power of laser is linear on the whole. The locomotory speed of the laser beam does little influence on temperature of plating liquid; the thermal area of plating liquid influenced by laser is very small; the temperature in the thermal area is asymmetrical. The results make clear that the process of the LCLD-RP can carry through under the normal temperature and pressure, it is a kind of 3D solid shape manufacturing technology which can support the metal and alloy shape directly and has higher applied value.

1. INTRODUCTION

Chemical plating is also called self-catalysis deposition plating. It is an important realm of material science. It is a kind of surface disposition technology of surface protection, surface altering properties, and surface function for materials [1]. Chemical plating is a process of producing metal deposition by controlling chemical reducing reaction under the catalysis of metal. Metal ion in plating liquid Mez+ absorbs electron provided by reducing agent Rn+, then restores to Me, finally deposits on part surface.

The technology of Laser-induced Chemical Liquid Deposition (LCLD) is chemical plating process that is reinforced or encouraged by heat or light reaction of Laser. It is a kind of new technology that does not need cover model and realities metal plating minute area on metal, semiconductor and insulator. IBM corporation firstly researched the electric deposition process by Laser reinforced Ni, Au, Cu, the researches continuously bring people interest and attention. America, Germany, and Japan all made a lot of works on this region.

Many scholars have done lots of research. P.V. Anastasia introduced the laser-induced chemical liquid phase deposition method for precipitation of Au-Cu alloy [2]. F. Christian studied influence of

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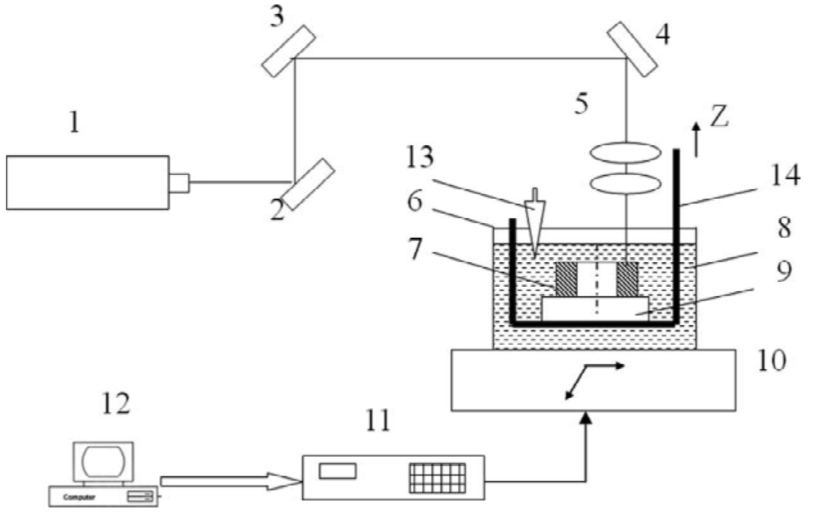

Fig. 1. Schematic drawing of RP system of LCLD. 1 - laser device; 2, 3, 4 - reflector group; 5 - lens group; 6 – container; 7 - forming parts; 8 - plating liquid; 9 - floor plate; 10 - X-Y action platform; 11 – controller; 12 – computer; 13 - ion density detecting and plating liquid added device; 14 - Z worktable.

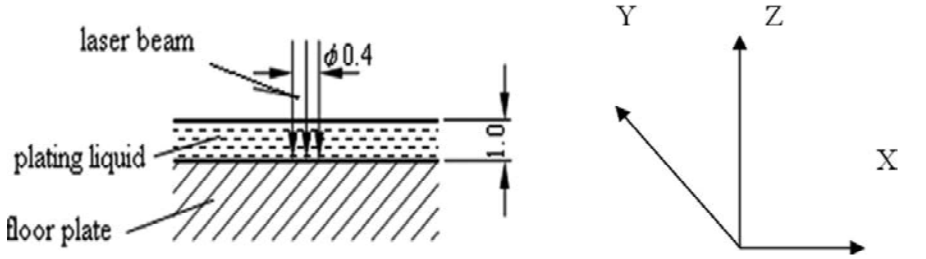

Fig. 2. Physical model of LCLD.

solution parameters for the fast growth and fast synthesis of ZnO nanostructures by LCLD [3-4]. A.A. Manshina realized the deposition of copper from both $CuSO_4$ and $CuCl_2$ based electrolyte solutions. Continuous copper structures were precipitated on microscope cover glasses by the laser-induced chemical liquid phase deposition method [5-8]. M.L. Huang studied the influences of laser power, irradiating time, compositions, and concentration of plating solution on chemical localized depositions of nickel by using 1079.5 nm Nd:YAP laser as inducing light source, and common ceramic as substrates [9]. K. Ke demonstrated direct 3D machining of submicrometer diameter, subsurface fluidic channels in glass [10]. L.B. Liu studied on the microfabrication by laser-induced selective chemical deposition based on rapid prototyping [11].

Compared with traditional electro-plating technology, LCLD technology has some properties, such as high selection, broad adaptability, working under the condition of general temperature. But, all these researches focused on substrates of ceramic and glass, and the thermodynamics model of the region of laser facular in the reaction process during LCLD was not discussed.

2. RP SYSTEM BASED ON LCLD

According to the features of LCLD, the graph about a new type of RP system based on this technology is shown in Fig. 1.

Basic working procedure of the system: the laser beams emitted by laser device comes to the working liquid level through reflector group and lens group; then arrives at the floor plate through liquid level, and then in virtue of light-heat effect, produces auto catalytic deposition reaction in micro-area and separates out metal or alloy. Second, by CAD model of a part, use dedication (special purpose) laminated cutting sheet software, request cross section form of each layer of part model, computer controls high accuracy X-Y action platform by scanning locus, selectively produce auto catalytic deposition reaction forming a layer of part. Finally, worktable falls a distance of a layer after finishing a layer, and the X-Y action platform is played by computer for deposition a new layer. Circulating like such, stacking layer by layer, then a 3D part is gained.

During processing, ion density detector real-time detects density of plating liquid, and auto controls external connection pump lines that supplement chemical reaction liquid. In order to ensure ion uniform distribution in container, ultrasonic oscillator can be used.

3. THERMODYNAMICS MODEL OF LCLD AND FINITE ELEMENT ANALYSES

3.1. Physical model of LCLD

Physical model of LCLD is shown in Fig. 2.The diameter of the facular laser beam is 0.4 mm; the height of plating liquid is 0.1 mm; the material of floor plate is steel 45#. Laser beam irradiates on the plating liquid vertically and moves linearly with a changeless speed. As is shown in Fig. 2, the origin of the reference frame is the center of the facular laser beam. When the temperature around facular laser beam reaches about 70-85 °C, the process of chemical deposition between plating liquid and floor plate will start. So, if the power and speed of laser is changeless, analyzing orderliness of distributing around facular laser beam has great significance for speed and precision of deposition.

3.2. Analyzing and predigesting of the main physical process.

- The attenuation trait of the beam of light in water. If the distance is short, the attenuation orderliness of one homochromatic parallel light in water accord with Lambert Exponential Theorem:

$$P = P_0 \exp\left[-\beta L\right], \qquad (1)$$

where P_0 and P are power of laser (W) when the transmission distances are 0 and L; β is attenuation coefficient (m^{-1}) including absorbing and dispersion. The height of plating liquid laser penetrates through is around 1 mm, according to Lambert Exponential Theorem, the attenuation of laser is little, to predigest calculating model, supposing that the energy of laser reached surface of metal is not loss.

- The process of laser heating. Time of the reaction between laser and metal is very short. The area influenced by heat is just around district shined by laser. The energy that materials eradiate after they absorbed energy form laser could be neglected compared to that absorbed from laser, the reflected coefficient which laser to surface of metal is difficult to be estimated because of so many factors, so it could be 0.9 when analyzing; Second, when laser irradiate the metal medium which is opacity, the metal would absorb laser within around 100 nm which is extremely shorter the size of model and facular laser beam. So, the heat effect between laser and material can be equaled by that of area-heat headstream on the surface of material. The area-heat headstream moves along x-axis by the speed V.

The whole process of LCLD heat effect can be divided into two parts: One part is heat- transfer of area-heat headstream in and out of the surface of metal, it can be regarded as the heat-transfer in infinite medium whose physical parameter is invariably; the other part is heat- transfer of area-heat headstream in liquid.

- Analysis of heat-diffusion. Primary analysis indicates that heat-diffusion is controlled by heat-transfer. The temperature rises rapidly; it can reach steady temperature within 10 ms. The convection of plating liquid can be neglected because it can become steady within 0.3 s, and the speed of convection is very low so it can hardly influence the distributing of temperature.

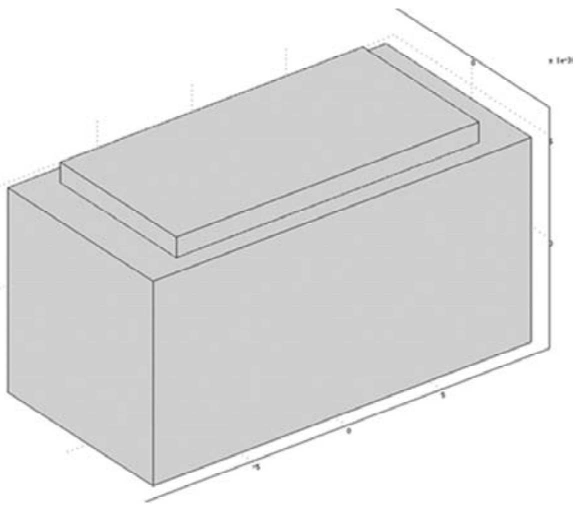

Fig.3. Model of analysis and calculating.

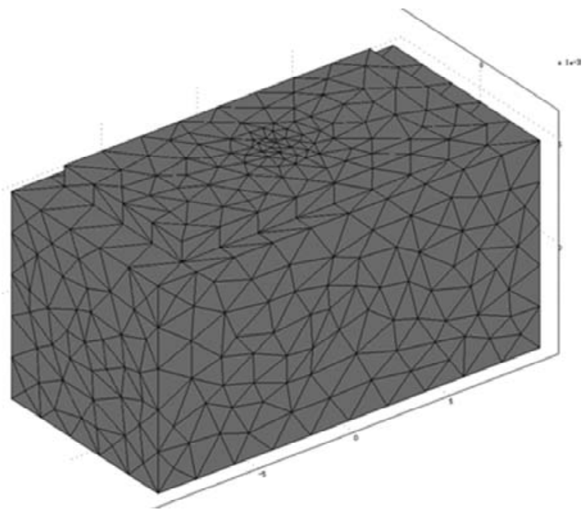

Fig. 4. Consequence of unit analysis.

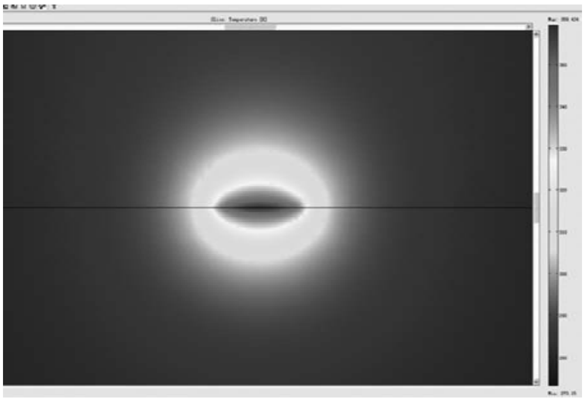

Fig. 5. Temperature along Z-axis.

● Chemical reaction. It can be assumed that the chemical reaction is influenced just by temperature; the influence of laser can be neglected. The influence of temperature by heat of reaction can be neglected because of the low speed of the reaction.

3.3. Finite element model of LCLD.

Primary analysis indicates that the area influenced by laser heat is just around part of the district shined by laser. 45 steel is chosen as the substrate with the size of 20×10×10 mm. The difference between temperature of area which is nine times away from center of facular laser and that of environment is very small, so the Fig. 3 can be used.

Limiting condition: primary analysis indicates that the distributing of temperature is not sensitive to boundaries of heat convection coefficient which could be 0.5 W/(mm^{2}K) when analyzing. The temperature of environment is 0 °C;

Unit analysis: the unit dimension of the inside facular laser is 0.02 mm, the unit dimension of external surface is 0.1 mm and transfers according to geometric progression. The consequence is shown in Fig. 4.

3.4. Results of numeric calculating and analysis

When analyzing , one group: the speed is 0.0 mm/s, the diameter of the facular laser beam is 0.4 mm, the respective power of laser is 25 W; The distribution of temperature is shown in Fig. 5 and Fig. 6. The other group: the speed is 1.0 mm/s and along X-axis, the diameter of the facular laser beam is 0.4 mm, the respective power of laser is 25 W, and the scan times are one in a single direction and five to move backwards and forwards respectively. The consequence is shown in Fig. 7 and Fig. 8.

According to the consequences of analyzing and calculating, some primary conclusions of LCLD whose floor plate is steel 45# can be made. The highest temperature of plating liquid can be found if the diameter of the facular laser beam is unchangeable. In the process of LCLD, the thermal area of plating liquid influenced by laser is very small, and in fact smaller because of Gauss Distributing. The temperature in the thermal area is asymmetrical;

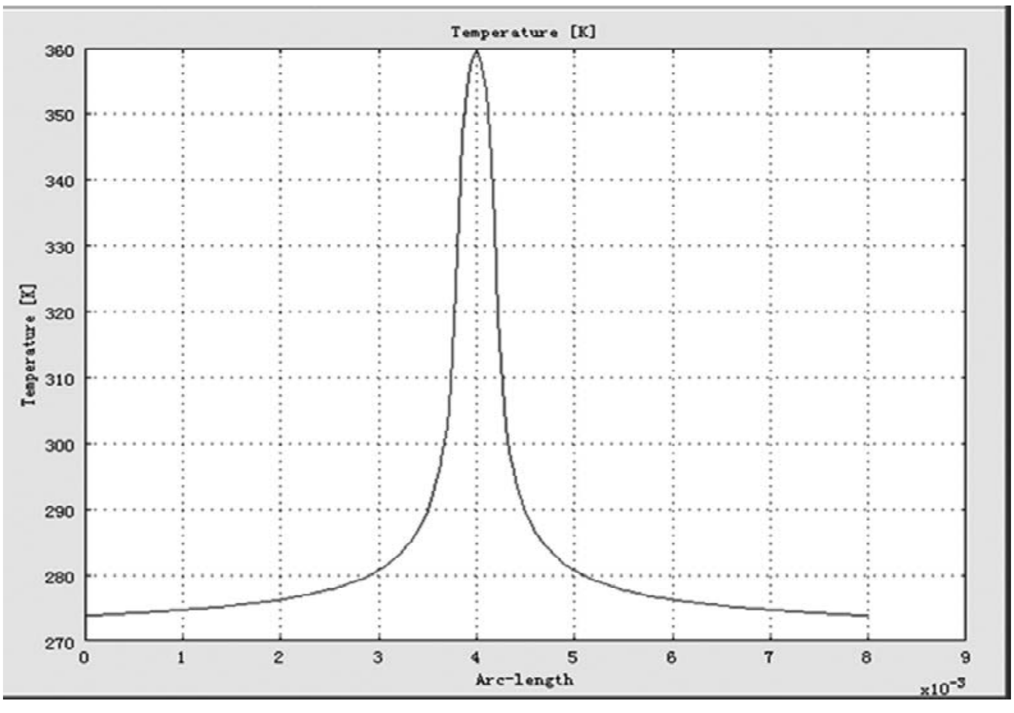

Fig. 6. Temperature along X-axis.

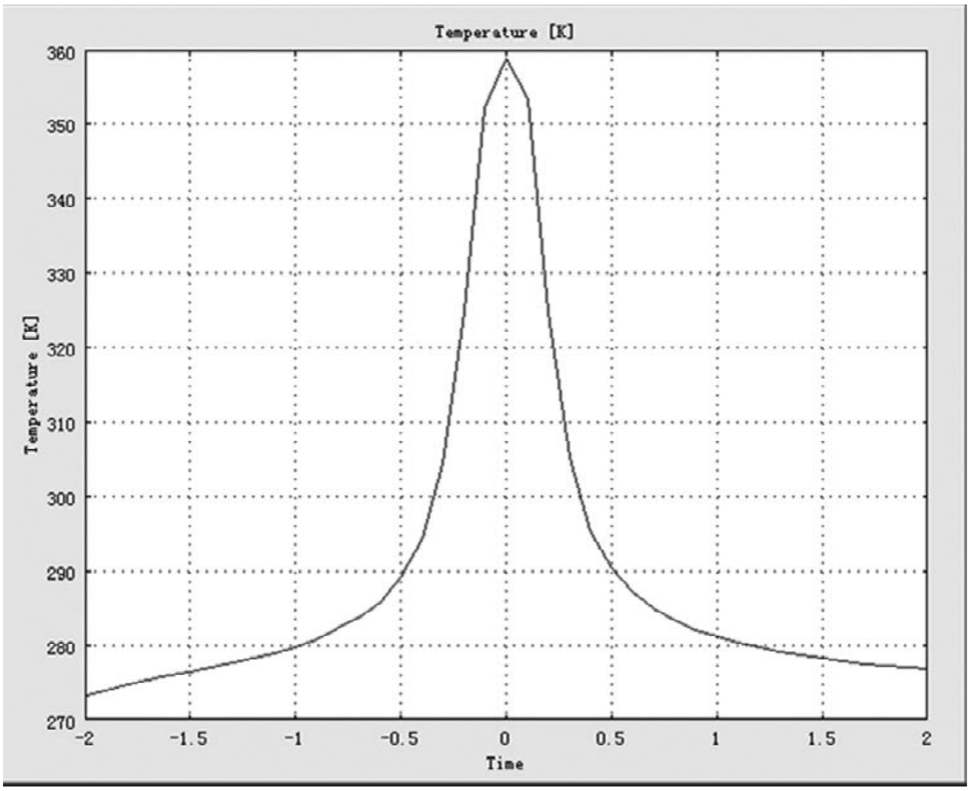

Fig. 7. Temperature along X-axis (*V*=1.0 mm/s, 1 times scan).

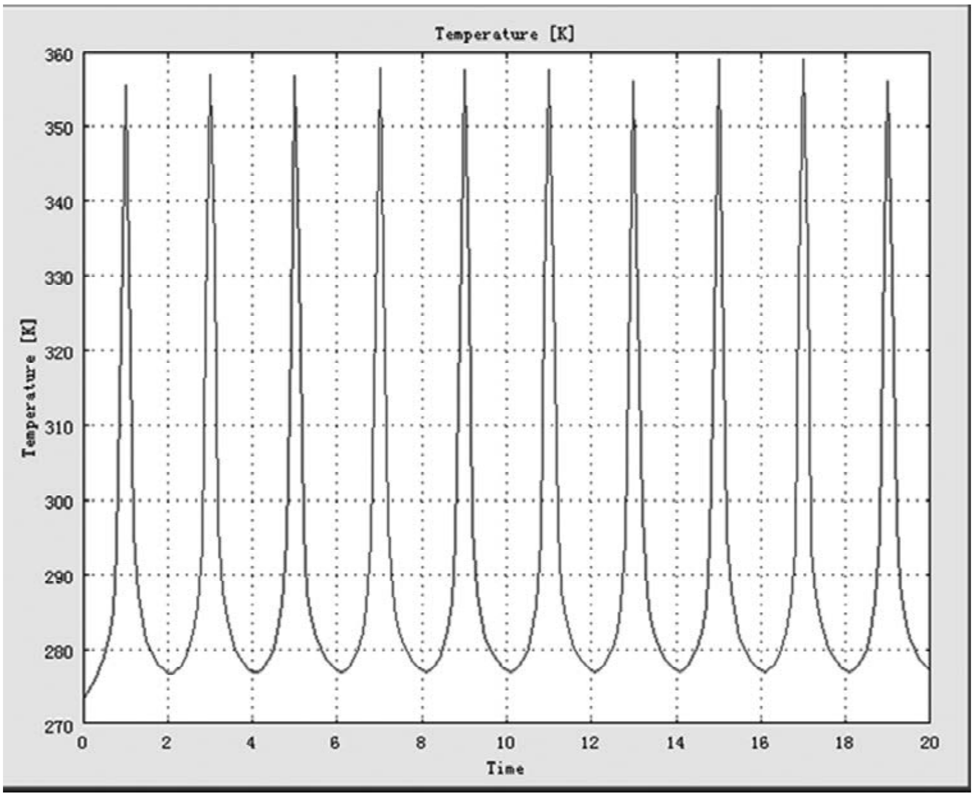

Fig. 8. Temperature along X-axis (*V*=1.0 mm/s, reciprocating 5 times).

the highest temperature appears in the center of facular laser beam around floor plate. The temperature would become lower rapidly as the distance become longer. The width of metal line of the deposition can be controlled at a certain extent by controlling the initial temperature of plating liquid and power of laser. By controlling the initial temperature of plating liquid and power of laser, the

Table 1. Solution for electroless plating.

Components	Concentration (g/L)
$NiCl_2 \cdot 6H_2O$	20
$CuCl_2 \cdot 2H_2O$	1
$NaH_2PO_2 \cdot H_2O$	20
$Na_3C_6H_5O_7 \cdot 2H_2O$	50
NH_4Cl	40
PH	8.9-9.1

instantaneous higher temperature can be found in the center of facular laser beam, so some not-electric substance in normal condition can become electric and act the reaction of chemical liquid deposition. It also indicates that LCLD can deposit metal and alloy on metalloids.

3.5. Experiment of LCLD

Three-dimensional motion of the experimental platform is structured using PMAC2A-PC/104 motion controller and Diode fiber laser system. Features of Diode fiber laser system consist of: wavelength 808 nm, beam diameter 400 μm, output power up to 50 W, operation mode CW.

The pretreatment is the same to the normal electroless plating. 45 steel is chosen as the substrate. During the machining, heat treatment and touching with air, there are maybe machining stress layer, oxide coating, grease and dirt on the surface of the sample, which has to be get rid of before depositing. The pretreatment includes grinding, degreasing, acid pickling and acid dipping and so on. Solution for electroless plating is shown in Table 1.

At the conditions of room temperature, laser output power 20 W, velocity of laser beam scan-filling 1 mm/s, height of liquid surface 1mm, laser beam diameter 400 μm, based on the 45 steel, the experiment of copper deposition through LCLD is performed, data of laser beam scanning path from CLI files. The result of experiment is shown in Fig. 9.

4. CONCLUSION

The process of LCLD is controlled by thermal transfer if the heights of liquid and metallic material are changeless. Modeling thermodynamics of the part of facular laser beam of the process of LCLD, calculating and emulating by engineering analytical software, these researches can lead to the conclusion that the highest temperature of plating liquid can be found if the diameter of the facular laser beam is unchangeable. The relation between temperature and power of laser is linear on the whole. The movement speed of the laser beam does little influence on temperature of plating liquid; the thermal area of plating liquid influenced by laser is very small; the temperature in the thermal area is asymmetrical. The width of metal line of the deposition can be controlled at a certain extent by controlling the initial temperature of plating liquid and power of laser.

The consequence of analysis indicates that technology of LCLD can work in the normal temperature and pressure. It is a manufacture technology of 3D solid model supporting metal and

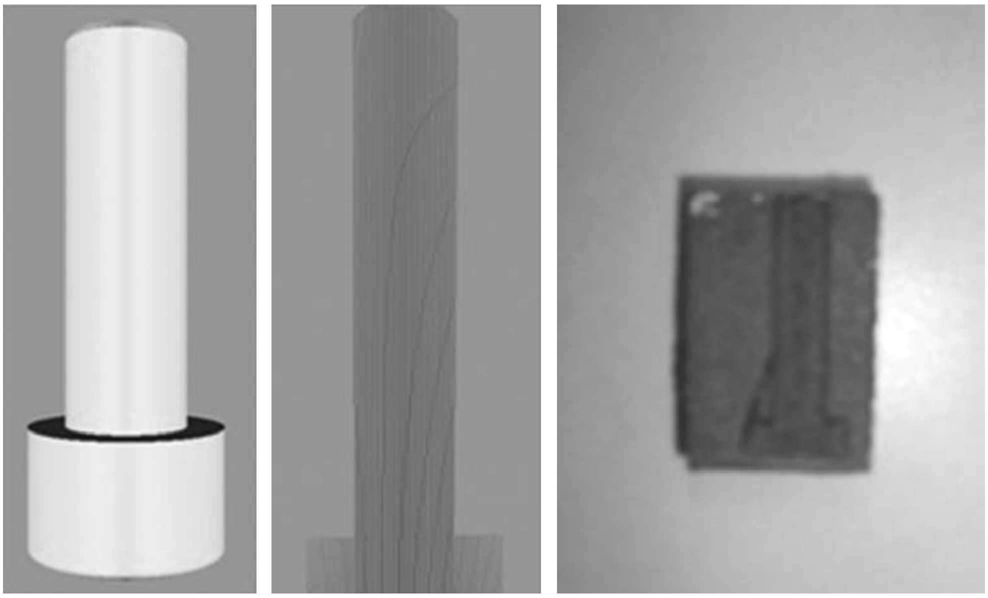

Fig. 9. Experiment of LCLD. a) Solid model; b) Scanning beams of 50^{th}; c) Copper deposition by LCLD.

alloy modeling directly. But further research should be done to know how to improve the precision and machining efficiency.

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