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Fabrication of micro-conductive patterns on glass surfaces using a laser direct writing method

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A micro-conductive pattern was fabricated on an insulating substrate (SiO_2) surface using a direct laser writing method known as laser-induced forward transfer (LIFT). The LIFT process, employing a multi-scan mode laser, fabricated the micro-conductive pattern using an electroless nickel plating procedure as a method for improving the deposition process of the seed pattern on the insulating substrate surface and the electrical conductivity of the pattern. In the multi-scan mode LIFT process, when the laser beam irradiates a thin metal film, the photon energy is absorbed by the film and converted into thermal energy, and the thermal decomposition reaction produced by the resulting heat conduction forms a deposit on the substrate. This paper analyzes the impact of seed pattern formation by LIFT, and the impact of key variables in the electroless nickel plating process, on the micro-conductive pattern fabrication, using scanning electron microscopy (SEM) and an optical microscope. It also examines the impact of the process variables on the cross-sectional shape and surface quality of the deposited pattern.

Key words: Laser induced forward transfer (LIFT), Laser direct writing, Microdeposition, Electroless nickel plating, Deed layer, Micro patterning.

Introduction

With the rapid development of the semi-conductor industry, the need for electronic devices to become smaller, lighter, and more integrated has expanded tremendously, and together with this, the demand for greater miniaturization of basic electronic elements has grown. To meet such demands, there has been much research on micro-patterning technology, in order to develop high performing ultra-micro electronic elements. The representative methods in current micro-conductive pattern formation technology are photolithography and screen printing.

Although it can produce micro-conductive pattern of less than sub-micrometre in width, the photolithography method, requires a separate mask fabrication procedure in order to form the required pattern. Hence the flexibility of its process is diminished, and because of the associated equipment cost, it has the disadvantage of high fabrication cost for prototype or small-scale production. Also, since screen printing technology is only capable of producing a micropattern with a minimum line width limit of 100 μm, the photolithography process must be used for line widths less than 100 μm [1]. The area between these two production technologies is occupied by the laser direct writing method, which is a technology that can fabricate micro-conductive patterns with a line-width range of a few μm to 100 μm.

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In laser direct writing based micropattern production technology, research is being done on forming patterns through electroless plating or electro plating after the seed layer has been created on the substrate via laser beam irradiation. This technology can be divided largely into two categories: using additive materials and not using additive materials. The former refers to a method where organo-metallic materials such as Pd, Cu, and acetate are applied to the substrate and then it is irradiated by a visible or ultraviolet wavelength laser beam, and the resulting photolysis of the organo-metal forms a seed layer, and thereafter a metal layer is formed through electroless nickel plating [2, 3, 4]. The latter is the method where the substrate surface is irradiated by a laser beam and a seed layer is formed by the chemical composition change of the irradiated area, and then the micro-conductive pattern is formed through an electroless plating process. Here, ceramic materials such as AIN and SiC are used as substrates [5, 6]. As a representative production process among the laser direct writing methods, a hybrid process combining laser induced forward transfer (LIFT) and selective electroless plating was used to fabricate a micro-conductive pattern.

In this study, first the seed pattern was formed on an insulating substrate (SiO_2) using LIFT, and then the micro-conductive pattern was fabricated by applying selective electroless plating on the surface of the seed pattern. Since this technology does not use high cost organo-metals, it has high production flexibility, and is an environmentally-friendly processing technology. As the requirements of thermal conduction, heat resistance, and chemical properties differ depending on the specific electronic part, this technology may be used to produce microstructures on diverse materials; not only on photoresist-coated metal, ceramic, and silicon, but also on polymer and glass. However, thus far, research has focused mostly on short-pulse laser induced seed pattern formation, and the resulting deposition patterns do not possess the conductivity required for practical use. No research on producing conductive patterns by pulse deposition has yet been reported.

Accordingly, this study focused on developing a hybrid processing technology for producing micro patterns and structures that involve forming a seed pattern on an insulating substrate (SiO_2) surface by irradiating the thin metal film with a laser beam and then applying selective electroless nickel plating on the seed pattern formed. All experiments were carried out in the open air without expensive vacuum equipment. Scanning electron microscopy (SEM) and an optical microscope were used to examine the impact of the laser processing variables on the seed pattern formation and electroless nickel plating process, and to examine the surface quality of the micro-conductive pattern formed.

Experimental procedure

Seed pattern process

The seed pattern production process is divided into two stages. The pattern production stage involves the formation of the seed pattern on top of the acceptor substrate by irradiating a thin metal film with a laser beam in multiscan mode for layer-by-layer irradiation. The metallization stage involves enhancing the thickness and adhesion of the pattern and improving its electrical conductivity by applying selective electroless nickel plating to the pattern formed.

Fig. 1 shows a schematic of the seed pattern depositing process using LIFT. The LIFT process for fabricating the seed pattern utilizes a photochemical reaction, such that when a focused laser beam penetrates the transparent material and irradiates the metal thin film, the photon energy of the laser beam is absorbed by the conductive thin metal film and is changed into thermal energy, and the resulting thermal conduction creates a thermal decomposition reaction which produces deposition. This process has a weakness in that the deposited seed pattern has a low deposition rate because the thermal energy of the laser beam causes ablation and consequently the amount of evaporation is greater than the amount deposited; further, the physical characteristics of the thin metal film are changed by the heat of the laser beam. The specific electrical resistance of the seed pattern has been reported be more than 3 to 50 times the specific electrical resistance of pure metals [7, 8]. Because the seed pattern has a low conductivity and lacks uniformity, it is not suitable for use as an electrical conductor. To remedy this, a selective electroless nickel plating process is applied to form a uniform and thick conductive metal layer.

Electroless nickel plating

The electroless nickel plating process is a chemical plating method in which the nickel metal ions dissolved in the plating solution catalyze the anode oxidation reaction of the reducing agent, and the reductive precipitation of the metal thin film is selectively deposited on the catalyst-activated surface of the insulating substrate. The electroless nickel plating method uses a number of reducing agents,

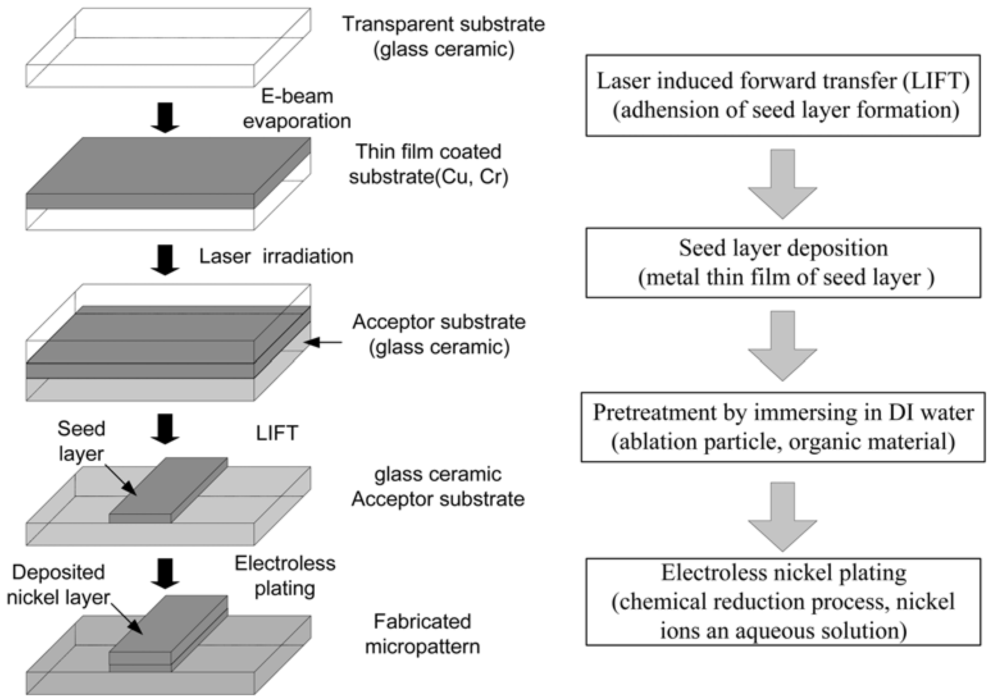


Fig. 1. Schematic diagram of the conductor micro-patterning process.

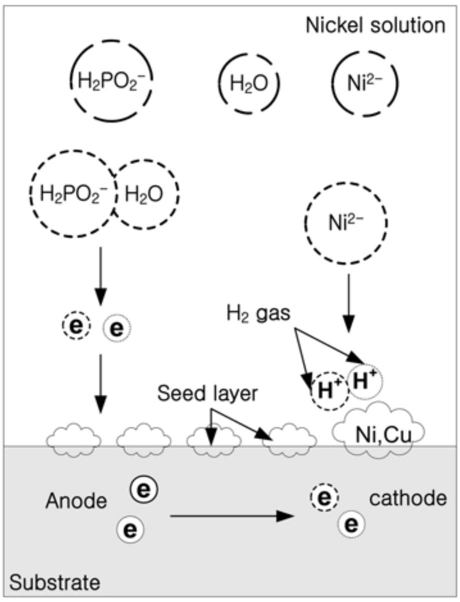
including sodium hypophosphite (NaH_2PO_2) and sodium boron hydride ($NaBH_4$). The use of sodium hypophosphite (NaH_2PO_2) as a reducing agent is representative of the most researched and practically applied methods at the present.

In the metal ion dissolved plating solution, when the nickel is set as the salt and sodium hypophosphite (NaH_2PO_2) is used as the reducing agent, the precipitation reaction is complex, but in the end, it can be summarized into the two reaction formulae described below. In the reaction formula (1), the nickel metal ion is reduced and precipitated as nickel metal, and with this autocatalytic reaction, uniform plating takes place continuously on the substrate surface. In reaction formula (2), hydrogen gas is produced. Phosphorous (P) is included in the nickel metal precipitation and an alloy of nickel and phosphorous is formed on the plated substrate surface.

$$Ni^{2+} + H_2PO_2^- + H_2O \xrightarrow{\text{catalyst}} Ni + H_2PO_3^- + 2H^+ \quad (1)$$

$$H_2PO_2^- + H_2O \xrightarrow{\text{catalyst}} H_2PO_3^- + H_2 \quad (2)$$

Fig. 2 is a schematic diagram showing electroless plating using sodium hypophosphite (NaH_2PO_2) as the reducing agent, on the seed layer deposited by the LIFT process. The electroless nickel plating consists of precipitating a metal film by reducing metal ions with electrons discharged in the oxidation reaction of the reducing agent in the plating solution, which holds both nickel metal ions and sodium hypophosphite (NaH_2PO_2) reducing agent; it does not depend on electricity. As such, it has the special characteristic of being unaffected by the electrical current flux and being able to plate non-conductive materials such as insulated substrates. Furthermore, since selective plating of an insulated substrate and uniform plating of complex surface shapes are possible, steps such as conductive layer formation in the LIGA-like process can be omitted. Thus it has the advantage of being able to reduce the number of fabrication procedures [9]. The metal layer formed by electroless nickel plating has a dense metal structure and can create a metal film of superior properties in terms of corrosion resistance, wear-resistance, and hardness. Because of such superior characteristics, it is used in the manufacturing of precision devices such as PCBs or hard disks and watches or cameras. However, since electroless nickel plating was developed as a technology for practical use based on experience rather than theoretical or quantitative support, it lacks theoretical knowledge, and thus a systematic analysis of the basic plating process is needed.



Anode reaction: $H_2PO_2^- + H_2O \rightarrow H_2PO_3^- + 2H^+ + 2e^-$

Cathode reaction : $Ni^{2+} + 2e^- \rightarrow Ni$

$2H^+ + 2e^- \rightarrow H_2\uparrow$

Fig. 2. Schematic diagram of electroless nickel reaction on a substrate.

Experimental setup

The laser employed in the experiment was a 355 nm wavelength Q-switched $Nd{:}YVO_4$ laser. This diode-pumped solid state, DPSSL laser with a maximum power output of 5 W was used as the energy heat source for activating deposition by inducing thermal decomposition of the thin metal film. The beam from the laser source passed through the PC-controlled beam attenuator, beam expander, beam splitter, and galvanometer mirror and was perpendicularly irradiated by a F-θ lens onto the transparent substrate surface where the metal thin film was deposited. The focused UV pulse laser beam has a maximum pulse repetition rate of 100 kHz and maximum power output radiation of 5 W with a Gaussian distribution. Generally, since the peak power of a UV pulse laser is high in comparison with a continuous wave (CW) laser, it has the advantage of more easily inducing photochemical and photothermal reactions.

Fig. 3 schematically shows the UV laser processing system for depositing a seed pattern on an insulating substrate surface. To increase the focussing efficiency

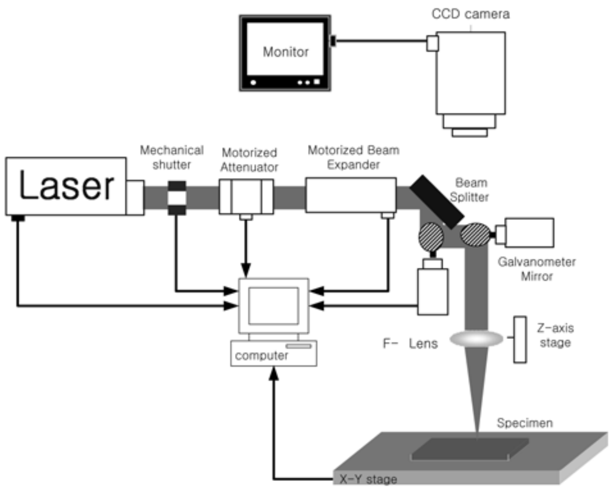


Fig. 3. Schematic diagram of the experimental system.

Table 1. Properties of glass substrate materials (At 5-300 °C)

Material	Softening point (°C)	Thermal expansion coefficient ($\times 10^{-7}K^{-1}$)	Transmission rate (%)
Soda-lime glass	735	99	Approximately 90
Pyrex glass	820	32	90-95

and to protect other optical instruments on the beam path, the laser beam, after passing through the beam expander, was transformed into a circularly polarized beam by going through a linear polarizer and a λ/4 plate. The reason for changing a linearly polarized laser beam into a circularly polarized beam was to prevent the laser beam from partially reflecting and going back into the laser system and damaging it. The diameter of the focused laser beam measured by the knife-edge method was confirmed to be about 30 μm.

In the experiment, 1 mm thick Pyrex glass was used as the transparent substrate which the beam penetrated to deposit a metal thin film of 0.2-0.8 μm thickness on one side of the glass substrate by using an e-beam evaporator. For the acceptor substrate on which the seed pattern was deposited, soda-lime glass and Al_2O_3 ceramic were used, and the target material and the metal thin film were fixed together for close adhesion. Superior optical and thermal properties make Pyrex glass and soda-glass the most widely used substrate materials, and Table 1 shows the physical properties of the glass types used in the experiment. A specimen created for seed layer deposition was installed to make precision positioning possible, by fixing it perpendicular to the laser beam on a laser processing machine X-Y positioning table with a repeatability of 0.1 μm.

For the deposition experiment of the seed layer, two different methods could be used: the fixed focus method of fixing the laser with the laser processing machine positioning table and then doing a layer-by-layer scan; or the moving focus method of inducing deposition by moving the focal position of the focused beam by using the Z-axis positioning instrument. This experiment used the fixed focus method. The experimental conditions, including the processing conditions used in the LIFT process to deposit the seed layer and the type and thickness of the metal thin film, are shown in Table 2. In the fixed focus method, the deposition reaction was induced by positioning the focus between the target specimen and the acceptor substrate and then changing the laser energy fluence and the pulse repetition rate to cause thermal decomposition of the thin metal film.

The deposition was formed in the direction of height (Z-axis) in accordance with the number of repeated scans of the continuous laser beam, and the seed layer was created by changing the laser energy fluence and the pulse repetition rate. The seed layer deposited on the insulating substrate was washed in acetone and distilled water with ultrasonic waves to prevent adulteration by foreign substances during the electroless nickel plating. Using Yu Shin Corp's YS 200 as the electroless nickel plating solution(Table 3), which was employed to improve the conductivity and the surface characteristics of the laser seed layer, selective

Table 2. Experimental conditions

Laser	Nd:YVO_4 UV pulse laser
Wavelength	355 nm
Energy fluence	2.8J/cm^2-14.1J/cm^2
Beam mode	TEM_{00}
Scanning speed	10-30 μm/s
Substrate	Soda-lime glass, Pyrex glass, Al_2O_3
Thickness of substrate	1 mm
Metal thin film	Al(400 nm), Cr(400 nm), Cu(400 nm),
Polymer coating layer thickness	1 μm

Table 3. Composition of electroless nickel plating bath

Component	Concentration
Nickel source($NiSO_4 \cdot 7H_2O$)	4.8-5.2 g/l
Reducing agent(NaH_2PO_2)	24-34 g/l
pH adjuster(NH_4OH)	4.6-5.2
Temperature	80-90 °C

electroless nickel plating was completed. The plating solution was made in the order of dissolving the complexing agent, which helps with the deposition of the nickel salt containing nickel metal ions; then putting in small amounts of reducing agent and stabilizer that help precipitate the metal ions. This was followed by completely dissolving them by slowly stirring the solution, and finally mixing in the pH controlling agent to control the pH. It must be noted here that, in contrast to other electroplating processes, the order in which the chemical solution is made is very important in the production of the electroless plating bath. If the dissolving order is changed, the chemicals may not dissolve or an autocatalytic reaction may occur during the production of the plating solution.

Using scanning electron microscopy (SEM) and an optical microscope, the surface characteristics and the 3-dimensional structure production technology potential of the micro-conductive pattern, formed on insulating substrates through the 2-stage combined process of LIFT and electroless plating, were verified. To minimize measurement error, the average values of the measurements from 5 specimens tested the under same conditions were analyzed.

Results and Discussion

To deposit the seed layer, a thermal decomposition reaction between the metal thin film and the thermal energy of the laser beam focused on the metal thin film was induced using the LIFT process, and the desired seed layer was selectively fabricated on the insulating substrate according to the scan path of the irradiated laser beam. Because laser beam irradiation on the thin metal film melts the irradiated area and changes its physical properties, the

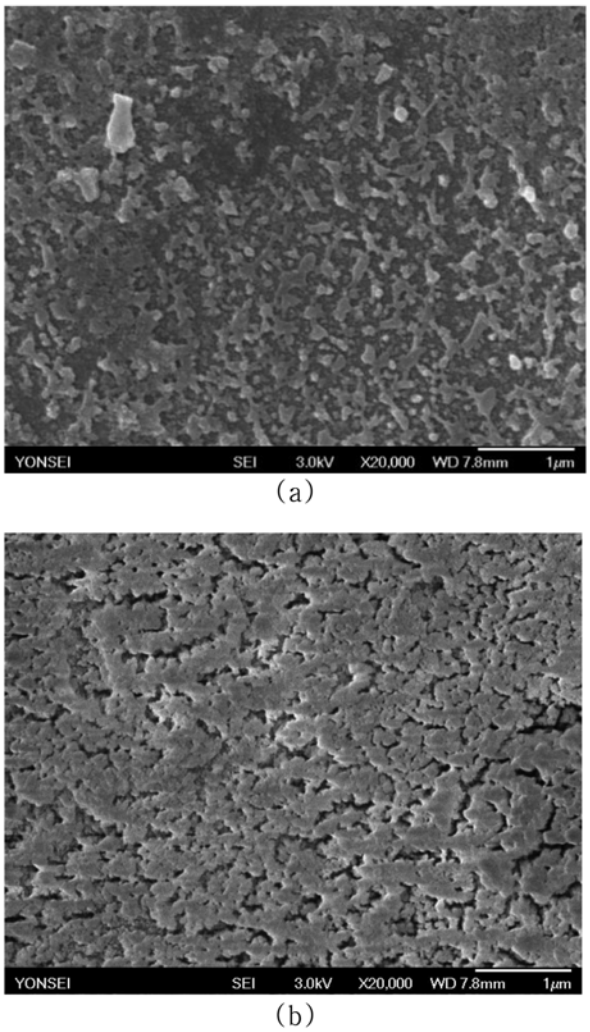


Fig. 4. SEM images of seed patterns as received(a) and after electroless nickel.

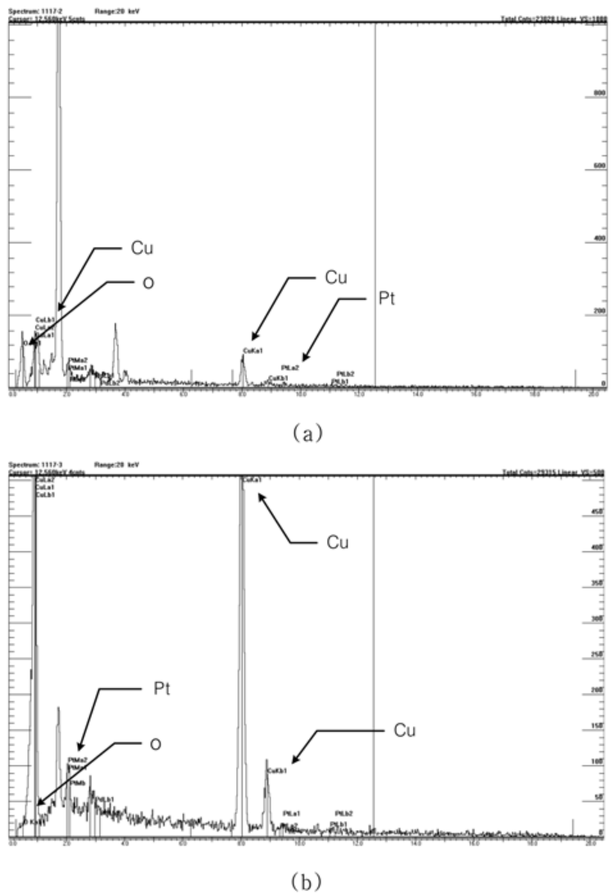


Fig. 5. EDX profile of the substrates as e-beam evaporated (a) and after electroless nickel plating (b).

seed layer deposited this way has a higher specific electrical resistance compared with the bulk state. Therefore, it is difficult to develop this into functional electrode material for electronic parts. However, it was confirmed that by applying a selective electroless plating process on the surface of the deposited seed layer, adequate conductivity can be obtained.

Fig. 4 shows the surface of the seed layer deposited on the Al_20_3 ceramic substrate with LIFT and the surface shape after electroless plating. As seen in the SEM image, the deposition surface of the seed layer formed from the thermal decomposition reaction of the thin metal film and laser beam has an uneven surface shape, but after the electroless plating, with the reductive precipitation of nickel metal, the surface shape became even and regular overall. To analyze the composition change of the surface metalized through electroless plating, the specimens were examined with an energy dispersive X-ray spectrometer (EDS).

Fig. 5 shows the EDS measurements of the surface composition before and after electroless plating. The surface composition of the thin metal film deposited by using an e-beam evaporator on the transparent substrate, as shown in Fig. 5(a), was made up of 95.36% copper (Cu) and 4.64% oxygen (O). But after the laser induced deposition, as shown in Fig. 5(b), the SiO_2 substrate deposited copper seed layer, with a composition of 63.18% copper and 36.87% oxygen, showed a reduced copper content in comparison with the thin film state, and contained a small trace of platinum (Pt) from the platinum coating for SEM observation. Here the copper, produced from the thermal decomposition reaction of the thin metal film induced by the laser beam, combined with oxygen in the air, formed an oxidation layer on the insulating substrate surface, and in so doing, increased the specific electrical resistance of the copper seed pattern. The seed layer formed in this way has the disadvantage of lacking density and has a weakened adhesive strength. However, as shown in Fig. 5(b), when the chemical composition is examined after electroless nickel plating, we can see that the reduction of the oxygen content in the seed layer surface is due to the porosity between the LIFT-formed seed layers becoming densely and evenly plated during the electroless plating, and that thus the electrical conductivity and adhesive strength have been improved.

Fig. 6 shows the results from examining the seed patterns, deposited on top of the SiO_2 substrates by changing the

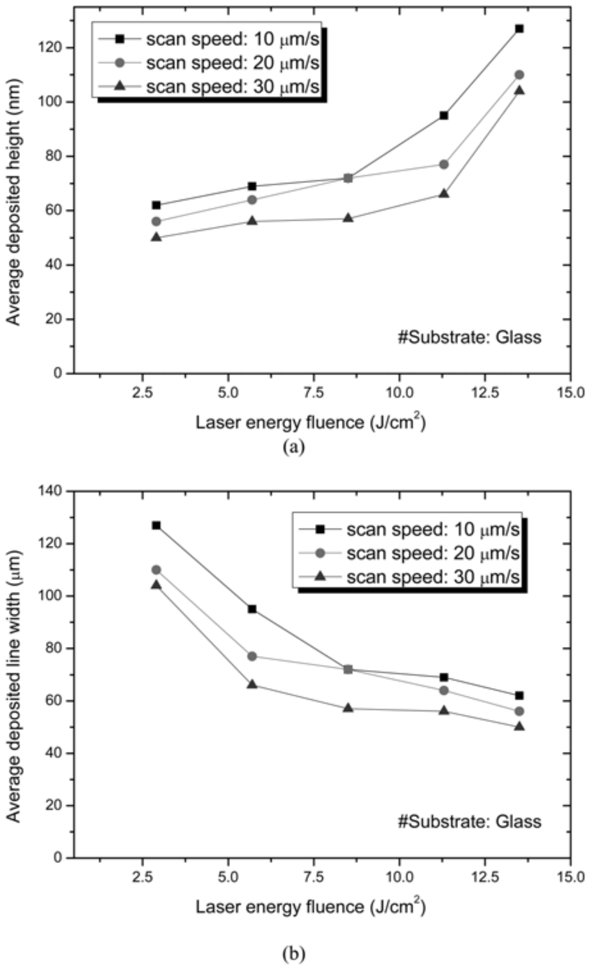


Fig. 6. Average height and line width of Cu microelectrodes as function of the laser energy fluence using different scan speeds.

scan speed of the laser beam, with a contact surface profiler (Alpha-step). To minimize experimental errors, the average value taken from 3 runs of the LIFT process, employed to deposit seed patterns on the insulated substrates, was taken.

Fig 6(a) shows the height of the nickel seed layer deposited according to the change in the laser beam scan speed, where soda-lime glass was used as the substrate. The experiment results showed that, as the scan speed increased, the height of the deposited seed layer also gradually increased. However, when the laser energy output was equal to or greater than 7.5J/cm^2, and as the scan speed increased, the deposition height increased rapidly. The deposition height of the seed layer and its surface shape changed substantially, depending on the scan speed of the laser focus. If the laser beam scan speed was slow, the dwell time of the beam increased and the deposition thickness increased accordingly, and as the scan speed increased, the deposition height decreased more and more. The reason the deposition height changed with a variation in the laser beam scan speed of the beam was that the slower the scan speed, the longer the dwell time of the beam and the thermal decomposition reaction subsequently occurred continuously.

Fig. 6(b) shows the line width of the deposited nickel seed layer against the scan speed of the laser beam. A deposition line width difference depending on the substrate type occurs due to the difference in substrate thermal conductivity. Because a glass substrate is an insulating material, the temperature rise in the area affected by the irradiated laser beam strongly activates the thermal decomposition reaction of the thin metal film. When the laser beam power output was 7.5J/cm^2 or higher, the centeral area of the high energy density beam re-evaporated and caused thermal damage to the substrate, and a trench phenomenon, with a peripheral area being deposited, was observed. The tendency of the line width of the deposited seed layer to decrease as the laser beam scan speed increased was also shown. The reason for this was that as the irradiation speed of the beam increased, the dwell time of the irradiation on the thin film was reduced, thus decreasing the area of the region causing the thermal decomposition reaction of the thin metal film. This experiment showed that when the laser energy fluence was below 7.5J/cm^2, a non-continuous and uneven seed layer was formed, while at or above 7.5J/cm^2, even deposition occurred.

At a fixed pulse energy, the line width has a close relationship with the laser beam overlap that depends on the scan speed, and this phenomenon, as shown in Fig. 7, can be observed through optical microscope images. When the optical microscope image of the seed layer for a pulse energy of 7.5J/cm^2 is examined, at a scan speed of 2 μm/s, when the energy emitted per unit area is relatively high, ablation occurred in the laser irradiated area and the minimum line width of the deposition was 49.62 μm. At a scan speed of 8mm/s, with the energy emitted per unit area decreased, the minimum line width of the deposition was 46.70 μm.

To find the critical value at which a deposited nickel seed layer is continuously formed, with a scan speed fixed at 30 μm/s and adjusting the Q-switching frequency's pulse repetition rate, the uniformity of the deposition surface was analyzed through an SEM image. As shown in Fig. 8, the examination results, with the pulse repetition rate increasing from 20 kHz to 80 kHz, indicate that a non-continuous nickel seed layer was formed below 80 kHz. Increasing the laser pulse repetition rate to 80 kHz to secure a uniformity of line width resulted in a more uniform nickel seed layer of Fig. 8(d), but a ripple pattern due to the pulse reiteration appeared on the surface.

One of the key variables in the electroless plating process is temperature and it has a significant impact on the plating speed. For electroless nickel plating, the plating temperature, along with the pH, is a factor that greatly affects the safety of the solution. To observe the impact of temperature, electroless plating was carried out at 80-90 °C, with the concentration and pH adjusted to the appropriate level. Fig. 9 shows the deposition thickness of the electro nickel plating layer according to the changes in plating duration and temperature; at 70 °C plating did not take place at all because plating bath activation did not occur. At 95 °C the plating solution is unable to do its work because of

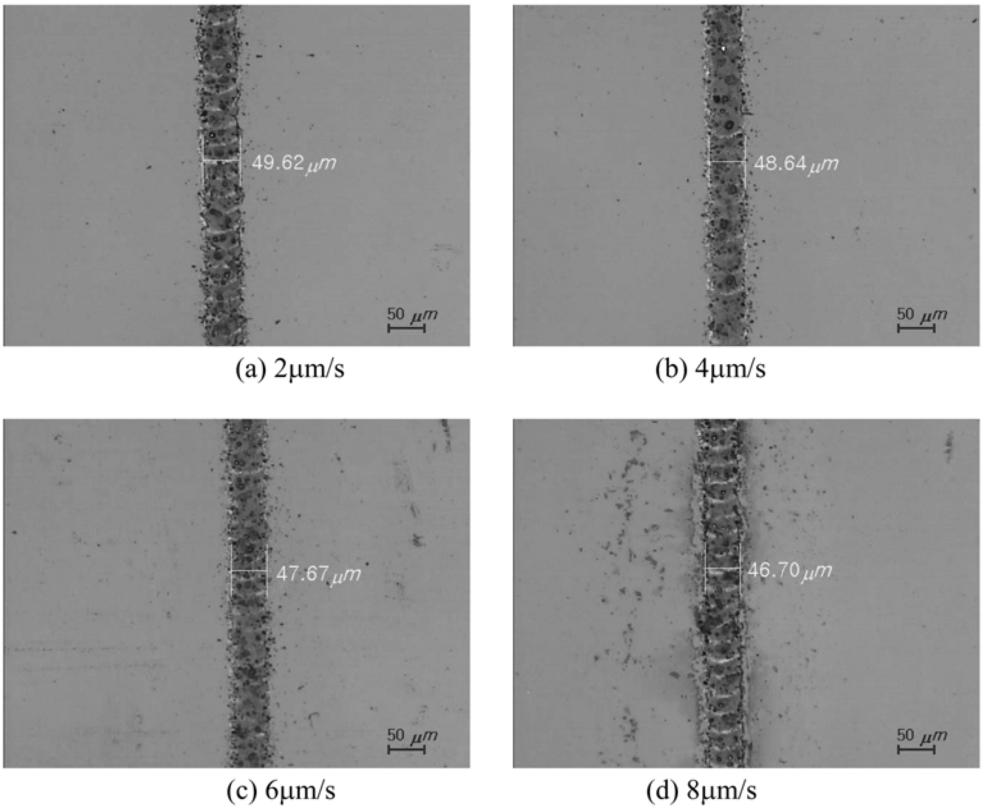


Fig. 7. Effect of scan speed on Cu seed layer (laser energy fluence: 7.5J/cm^2).

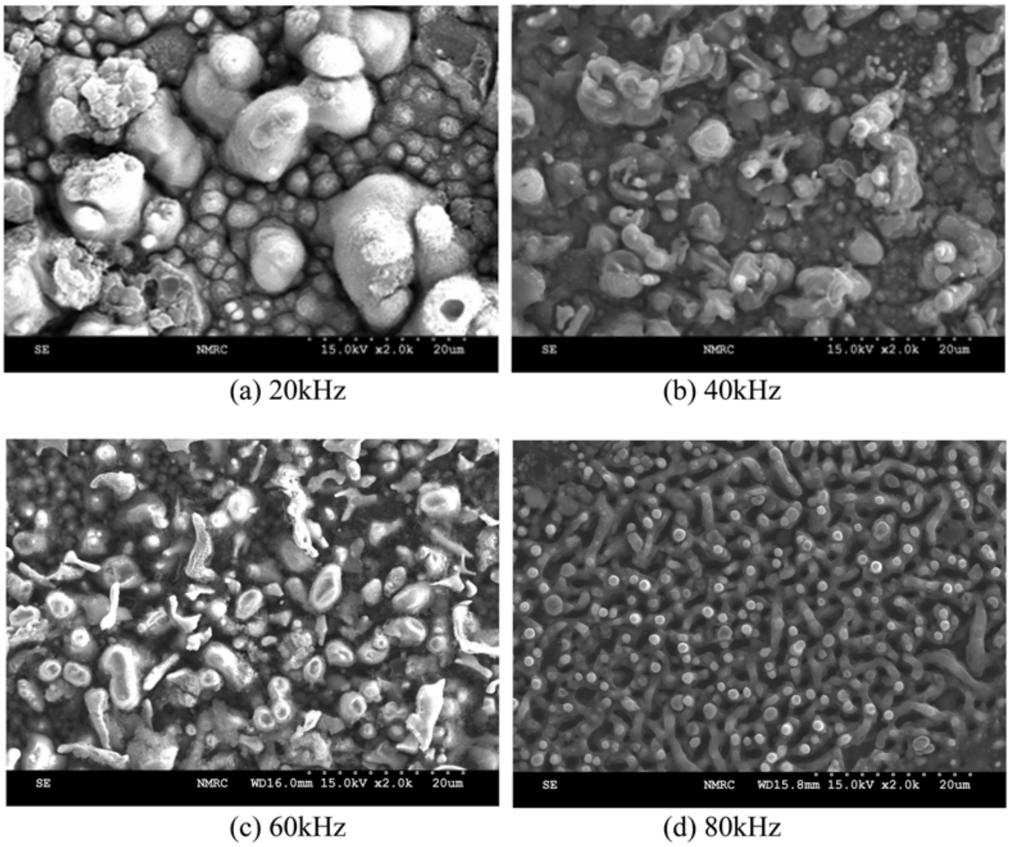


Fig. 8. Surface morphology of the Cr microelectrode surface as a function of the pulse repetition rate (laser energy fluence:7.5J/cm^2, scan speed: 30 μm/s).

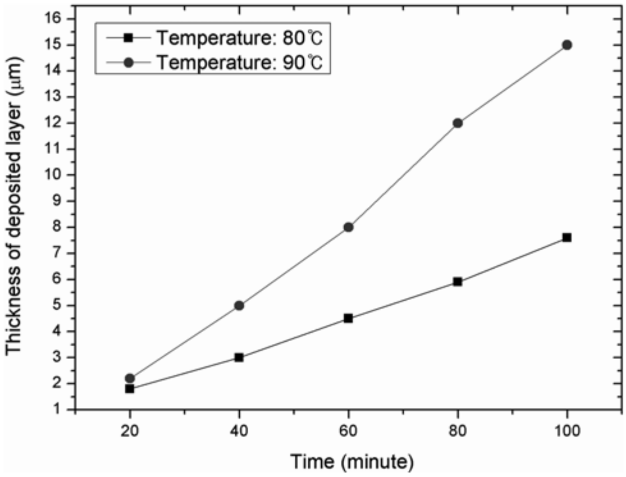


Fig. 9. Thickness of the deposited layer versus the electroless plating time.

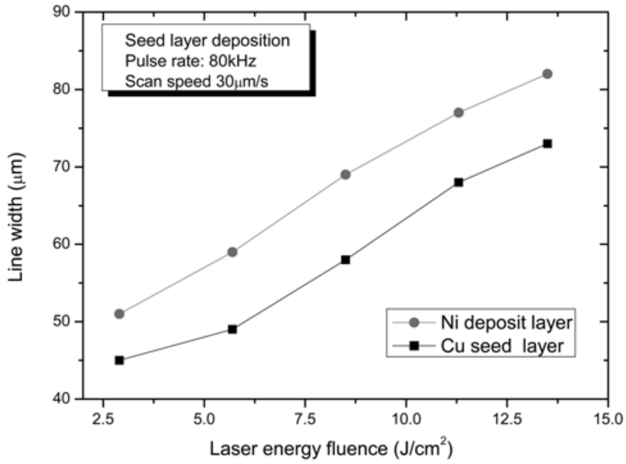


Fig. 10. Line width of Cu seed and Ni conductor line width after electroless nickel plating.

the decomposition of the solution, and thus plating was accomplished only in a temperature range of 80 °C to 90 °C.

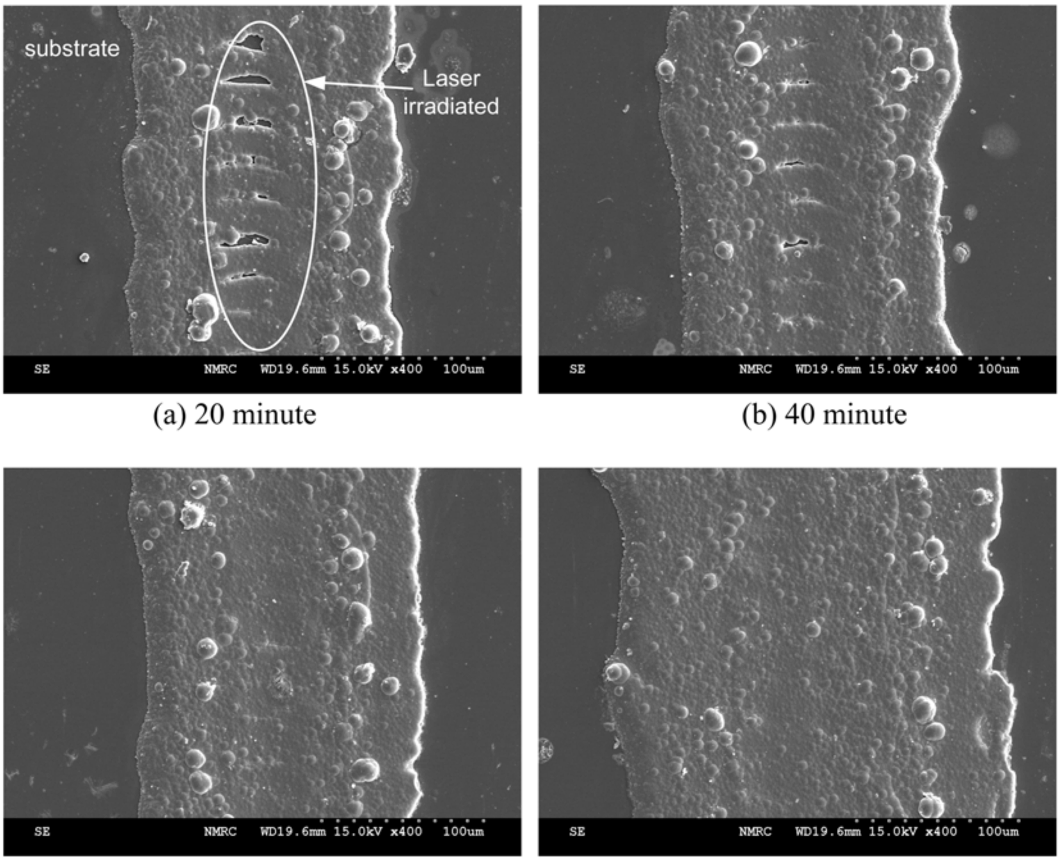
The experimental results show that the deposition thickness of electroless plating increased linearly as the temperature increased. This is a tendency similar to that shown in Gutzeit's research [10]; in general, in electroless plating, as the temperature increases, the precipitation speed increases almost twofold. Since the deposition speed of plating increased proportionally to the plating solution temperature, in order to achieve uniform nickel metal ion replacement in the initial plating by increasing the plating speed, plating was done at a plating solution temperature of 80 °C or higher. The pH of the plating solution was maintained at about 4.8, and to maintain the constancy of the plating solution concentration during the plating, plating solution was not re-used. The plating thickness changed according to the plating duration because the replacing agent replaced that much more nickel, and the amount of precipitation increased in a manner corresponding to the duration. In addition, to observe the adhesive strength of the plating layer, a 3 M tape test was used to test the adhesive strength, and the results showed that the plating layer did not detach from the substrate.

The conductive metal pattern that was plated using the electroless nickel plating process on top of the 47 μm seed layer produced in the copper seed layer deposition experiment, was measured with SEM images. The plating conditions were the aforementioned temperature of about 90 °C, pH of 4.8, and plating time of 30 minutes. The formation of a conductive metal layer with a 57 μm line width - an increase of 5 μm from a line width of 52 μm -was observed Fig. 10. As the line width of the seed layer increased, the line width of the metal layer also increased, and for a laser beam energy output density of 13.5J/cm^2, the line width of the electroless nickel plating layer increased to about 85 μm. It appears that during electroless plating, the nickel (Ni) metal was deposited not only in the direction of height, but plating also occurred on the sides. The specific electrical resistance value after the electroless plating was shown to be 1.2 to 2 times higher than that of the bulk state Ni, and it is expected to be further improved through future research on electroless plating process optimization.

Prior to creating a micro circuit pattern, a study of the line gap between two adjacent seed layers should be made. Here the line gap refers to the distance between the midpoints of two adjacent seed lines. To find out the formation conditions for the minimum possible line gap between seed layers, seed patterns with line gaps of 30 μm, 50 μm, and 100 μm were created and electroless nickel plating was performed in there experiments. The results showed that for seed patterns with line gaps of 30 μm and 50 μm, a connecting bridge between the seed lines was formed after the electroless plating, but for the seed pattern with a 100 μm line gap, an independent nickel conductive line pattern was formed. Research on further minimizing the line gap between the conductive nickel plating layers deposited by electroless plating and testing the reliability of conductive micro pattern is in progress.

SEM images showing the size of plating layer particles and plating surface shape after selective electroless plating was done on seed layers are shown in Fig. 11. From the surface form of the plating layer according to plating time variation shown in Fig. 11, it can be observed that when the plating duration was 80 minutes and the pH was 4.8, the surface condition was uniform and the surface shape had a uniform thickness. Moreover, when electroless plating was done with electrodes, it was confirmed through SEM images that only the areas with the metal layer selectively remaining on the seed layer deposited by LIFT were plated and a conductive pattern was formed.

As shown in Fig. 11, the line width increased after electroless plating, more than when the seed layer was deposited by LIFT. When the seed layer is thin, the edge area of the seed layer can be detached during electroless plating, however, the edge of the seed layer formed in multiscan mode thickened. It was deposited densely and



(a) 20 minute (b) 40 minute

(c) 60 minute (d) 80 minute

Fig. 11. SEM images of the surface as a function of time at 90 °C, pH 4.8 electroless plating condition.

thus the line width after plating increased. Furthermore, the characteristic resistivity - measured to apply a new deposition technology of forming an electrode on an insulating substrate by creating a 2 mm straight-line electrode through electroless plating - showed slight differences depending on the line width. At a line width of 250 μm, the characteristic resistivity was 10.14×10^{-8}, which is 1.3 times higher than that of pure nickel (9.36×10^{-8}).

Fig. 12 shows the micro conductive pattern fabricated through the electroless nickel plating process applied to the seed layer formed by LIFT deposition of a 10 μm thick copper seed pattern on a glass substrate. The optical microscope images shows that the conductive layer thickness was about 35 μm, and a pattern with a minimum line width of about 50 μm was confirmed to be deposited with superior adhesive strength on the soda-lime glass (SiO_2) substrate.

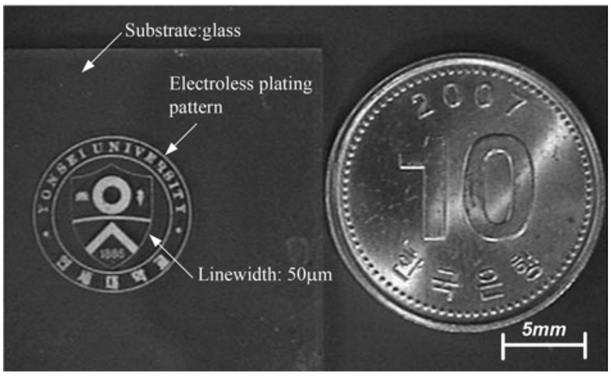


Fig. 12. Conductor micropattern after electroless nickel plating on Cu seed layer generated by LIFT process.

Conclusions

The laser direct writing method is an the additive process that can selectively produce patterns on insulating substrate materials. It is a process that can potentially meet the changing market needs of the electronics industry sector, including multi-type and small quantity manufacturing, and new product development cycle time reduction. This study examined the impact of key process variables on seed formation and conductive micro-pattern production for an integrated process, in which a nickel conductive layer is formed on top of a seed pattern through laser induced deposition-directly irradiating the surface glass and Al_2O_3 ceramic insulating substrate with a laser beam and depositing a seed pattern of a thin metal film - and subsequent electroless plating.

The research results involved analyzing the impact of process variables, laser power output, scan speed, and pulse repetition on seed formation and the electroless plating process, and deriving the minimum possible production line width and line gap with a proprietary processing system. To examine the practical potential, a Ni metal layer with a 50 μm line width and about 35 μm thickness was produced through a pattern production experiment, and the possibility of efficiently applying the process to the middle application area between thin film and thick film technologies was presented. In future, the reliability and reproducibility will be improved by further minimizing the line width and line gap and by enhancing the production system with processing surveillance and control equipment.

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