Deposition of optical microlens arrays by ink-jet processes

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Abstract

Ink-jet processes using either a drop-on-demand or a dosing system have been applied to the deposition of single lenses and large arrays of high optical property refractive microlenses. The lenses are made of a silica based inorganic–organic material which can be densified either thermally or by UV irradiation at low temperature. Microlense diameter d and height h made with a *single* drop can be varied between approximately $d = 50$ μm and 2 mm, and $h = 6.25$ and 150 μm, respectively, conferring a focal distance varying between 100 μm and approximately 10 mm, respectively. Large arrays of lenses have been realized with a minimum separation between the lenses as small as 5% of their diameter. Single lenses and arrays of lenses made with *multidrops* were also obtained. Microdrops (1000) with $d = 50$ μm allow us to obtain lenses with diameter 800 μm, height 56 μm and focal distance of 2.9 mm. All the components have a high optical transparency (92%) within the wavelength range 300 nm–2.7 μm, are highly homogeneous and have very low stress and astigmatism. The index of refraction can be tailored by modifying the sol composition. The lens average surface roughness is $R_a \approx 40$ nm. Their shape measured by profilometry and their focusing properties, determined in and near the focal plane, are reported.

Keywords: Ink-jet; Microlens; Optical properties

1. Introduction

The techniques used to develop micro systems will be an important key technology for this century. Yet, the industrial production of micro components, except for a few exceptions, is still at the beginning and appropriate techniques for the production of high quality and low cost components are required.

Single and arrays of refractive microlenses are already used as laser-fiber collimators and in display techniques [1]. The production of convex structures on a substrate is realized either by a photolithographic or a melting process [2,3]. Various steps of exposure followed by an etching process have to be carried out, which results in high production costs.

This paper shows that UV-polymerizable hybrid organic–inorganic materials of low viscosity can be very precisely proportioned with an ink-jet system or a dispenser and that such technologies are adequate to produce high optical quality transparent refractive microlenses by simple and direct deposition and curing techniques.

2. Experimental

The steps to produce a typical sol for an ink-jet process are shown in Fig. 1. An organo-functionalized silane (e.g. 3-glycidyloxypropyl)trimethoxysilane-GPTS, Wacker Chemie) is first hydrolyzed in 0.1 N HCl (1.5 equivalents respective to Si). After stirring at 40°C and methanol removal by vacuum treatment, the pre-hydrolyzed silane was mixed in a solvent (e.g. water) in a concentration range 30–50 wt.% in order to obtain a desired viscosity and surface tension. A photostarter such as triarylsulfoniumhexafluorophosphate (UVI-6990, Union Carbide) can be added (< 1 wt.%) to help the polymerization by UV light irradiation.

Spherical drops with a diameter of 55 μm were generated with a Microdrop device equipped with a

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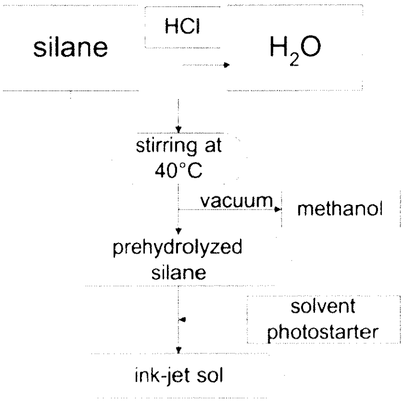

Fig. 1. The sol preparation.

nozzle of 50 μm diameter (model SP-K 130) [4]. Drops with diameter of 300–1000 μm were produced with a GLT-1500XL dispenser using a 150-μm nozzle diameter. Cleaned or silane coated glass substrates were placed on a movable x, y, z table, onto which the spherical drops are deposited in a dust-free atmosphere. Due to the surface tension, the drops take a plano-convex shape rapidly and can be polymerized and hardened under UV light or alternatively in an oven at a temperature of 130°C for 1 h.

The optical transmission of the precursor sols and polymerized coatings were measured by a Varian Cary 5E spectrophotometer. The surface roughness and the shape of the lenses were determined using atomic force microscopy (Topometrics Explorer 2000, AFM) and a profilometer (Tencor P10).

The focal length of the plano-convex lenses was determined using a light microscope. The intensity image profiles of a collimated light beam were measured at and near the focal plane of the microlenses by means of a He–Ne laser ($\lambda = 632$ nm) and a Spiricon 3D laser beam analyzer.

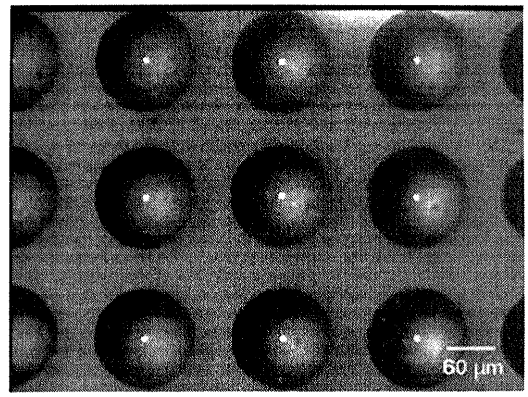

Fig. 2. Array of microlenses obtained with the Microdrops ink-jet apparatus observed with a light microscope. The white dots in the center of each lens are image of the focused light.

3. Results and discussion

The transmission spectrum of the sol and a 6-μm-thick polymerized coating shows a high transparency ($T > 92\%$) in a wavelength range of 300 nm $< \lambda <$ 2.7 μm. Their optical properties are therefore adequate for the preparation of lenses. Depending on the nozzle size, the type and the amount of the solvent (ROH, H_2O), the lenses have the following properties (Table 1).

Fig. 2 shows a light microscope picture of an array of microlenses, fabricated using the Microdrop system with only one drop per lens. The resulting lens radius is 60 μm and the height is 8 μm. The picture also shows the focus (white dots) observed under collimated white light.

Table 1
Parameter of lenses produced by the Microdrop (MD) and the dosing (GLT) system

Nozzle size (μm)	Amount of drops	Lens diameter (μm)	Lens height (μm)	Focal length (μm)
50 (MD)	1–1000	50–1000	6.25–120	100–2200
150 (GLT)	1	200–2000	25–150	425–10000

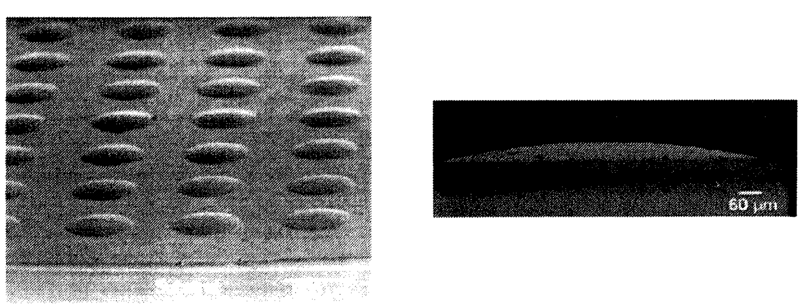

Fig. 3. SEM picture of an array of larger lenses made with the Microdrop ink-jet apparatus (left). The profile of one of the lenses is shown on the right side.

Larger lenses can be fabricated either by ink-jet with the deposition of many drops per lens or with the GLT dispenser which uses larger capillaries. Capillaries larger than 100 μm cannot be controlled anymore by the piezo controller of the ink-jet system as the piezoactor is too weak to eject the drops from the capillaries. The GLT dispenser uses a microprocessor to control and to adjust the pressure within a certain period of time to generate a defined drop with diameter ranging from 200 to 2000 μm.

Fig. 3 shows an array of lenses and the profile of a lens fabricated using the Microdrop system consisting of 1000 drops per lens. The lens parameters are: radius $r = 400$ μm, height $h = 56$ μm, spherical radius $R = 1450$ μm, focal length (at 632.8 nm), $f = 2.9$ mm. The average surface roughness $R_a = 40$ nm.

In order to determine the optical quality of the focusing of the microlenses, the image of the focal plane was measured using a laser, a beam expander and a Spiricon analyzer. The interferogram developed close to the focal plane (Fig. 4) shows a round homogeneous structure, an indication of a very low astigmatism and no mechanical tension.

A typical array of lenses with lens radius of 1000 μm, produced with the GLT dispenser is shown in Fig. 5. In order to fabricate an analog array of lenses by ink-jet, approximately 3000 drops per lens would have to be deposited.

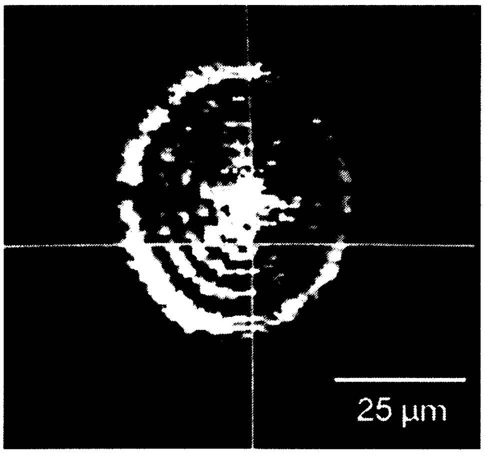

Fig. 4. Interferon pattern measured close to the focus plane of a single lens having a radius of 400 μm.

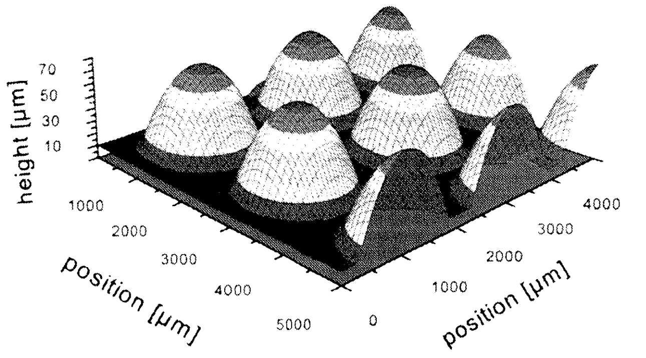

Fig. 5. Profilometer plot of an array of lenses produced, a single drop using, with the GLT dispenser. The lens radius is 1000 μm.

4. Conclusion

Single and arrays of refractive microlenses can be fabricated using an ink-jet device or a dispenser by depositing drops of a hybrid organic–inorganic sol on a glass substrate. Viscosity, solvent evaporation, drop-substrate wetting condition and substrate temperatures are the main parameters which govern the obtention of reproducible production. The lenses are plano-convex with an index of refraction $n = 1.5$. Their diameter varies from 50 to 2000 μm and their focal length from 100 to 10 000 μm. The smallest separation of the lenses in arrays is approximately 5% of the lens radius.

References

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