Positive greyscale photoresist for 3D patterning by direct writing or greyscale mask lithography

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3D patterning in lithography, i.e. the manufacture of patterns with a thickness gradient in contrast to planar patterns manufactured in binary lithography, has become more important in recent years, with applications in micro-optics or microelectromechanical systems (MEMS) [1], but also in microfluidic systems [2] or in integrated circuits.

3D patterning by greyscale lithography is required where a simple reflow of planar binary resist patterns is not sufficient any more. This is the case for example when the pattern density is too high, or when free-form 3D structures more complicated than e.g. convex lenses are needed.

Photoresists typically used for greyscale lithography are common thick positive photoresists which otherwise are designed for the use in binary lithography. The processing of these resists in greyscale lithography has to be especially adapted to obtain a thickness gradient instead of binary patterns, for instance by varying the softbake conditions outside the usual process window. The aim of the work presented here was to develop a thick positive photoresist designed specifically for the requirements of greyscale lithography. These include a reduced contrast and a response curve (film thickness=f(dose)) as linear as possible, nevertheless a pattern depth as high as possible. And the resist has to be applicable both for mask aligner exposure through a greyscale mask and for high energy laser exposure in direct writing lithography. Additionally, encouraged by market requirements, the resist to be developed should be processable in thicker films than conventional thick positive photoresists.

The result of the material development presented here is ma-P 1275G, a thick diazonaphthoquinone (DNQ)/novolak based positive photoresist with characteristics specifically adjusted to greyscale lithography. It allows to spin-coat and pattern higher resist films than conventional thick DNQ/novolak resists usually applied in greyscale lithography, with a film thickness of up to ~60 µm in one single spin-coating step. Pattern depths of 50...60 µm have been obtained both in direct writing lithography (see Figure 3) and with mask aligner exposure through a greyscale mask. High energy laser exposure is possible without outgassing. Response curves recorded with ma-P 1275G have a favourable wide linear range (see Figure 1), and the contrast is reduced compared to a conventional resist for binary lithography (see Figure 2).

Deep reactive ion etching is a common method of transferring the 3D resist pattern into the substrate [3]. For optical applications a pattern transfer by means of UV moulding into suitable polymer materials, e.g. with glass-like properties, is a very convenient approach, too, also enabling multiple replications of the 3D resist patterns. Such pattern transfer process has been demonstrated, first with the inorganic-organic hybrid polymer OrmoStamp® to form a working stamp, and in a second step with the inorganic-organic hybrid polymer OrmoComp® to form the glass-like final structure – as an example an array of concave lenses (see Figure 4). This demonstrates the capabilities of the described material and procedure to be used for the manufacture of complex 3D shapes for UV moulding processes.

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Figure 1. Response curve of 27 µm thick ma-P 1275G with almost linear characteristics over a wide dose range

Figure 2. Contrast curves of diluted ma-P 1275G, and ma-P 1240, a conventional photoresist for binary lithography

Figure 3. Exemplary 3D pattern showing ~53 µm pattern depth in ~58 µm thick ma-P 1275G [4]

Figure 4. a) 30 µm diameter concave lenses patterned in ma-P 1275G, b) UV moulding with OrmoStamp® – convex lenses, c) UV moulding with OrmoComp® – concave lenses, final structure