Grayscale positive photoresist

series ma-P 1200G

micro resist technology

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Micro resist technology GmbH (MRT) develops, produces and supplies innovative photoresists, special polymers and ancillaries for micro- and nanolithography, and micro-optical applications. MRT's materials are used for key technological applications: microsystems, microelectronics, micro- and nano-photonics, life sciences, etc. Serving the global high-tech markets for more than 25 years, MRT products enable processes like UV, Laser, X-ray, and e-beam lithography, nanoimprint lithography, and associated patterning technologies.

MOTIVATION

Grayscale lithography creates 3D film profiles with gradually varying thickness[1], see Fig.1. The grayscale lithography is especially advantageous for the micro-structures where reflow patterning[2] does not produce the desired result, e.g.:

- Applications with high structure density, where adjacent reflow patterns could merge;
- Complex shapes such as random microlense arrays;
- Additional patterns on bigger lenses;
- Microlenses with different heights, or patterns for diffractive optics;
- Other free-form profiles used for e.g. light-beam-shaping and steering, MEMS, MOEMS. etc.

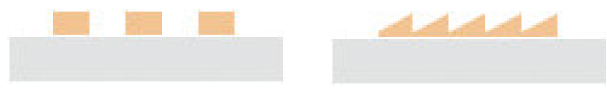

Figure 1 Resist profiles produced by binary (left) and grayscale (right) lithography.

REQUIREMENTS TO PHOTORESISTS FOR GRAYSCALE TECHNOLOGY

A standard positive photoresist exhibits an inhibition at low doses, i.e. the solubility in the developer (translating into the remaining film thickness after development) increases only after the exposure to a certain minimum dose. Above this dose, a standard photoresist shows a very steep decrease in thickness after development, the resulting thickness depending on the exposure dose in a non-linear fashion (Fig. 2).

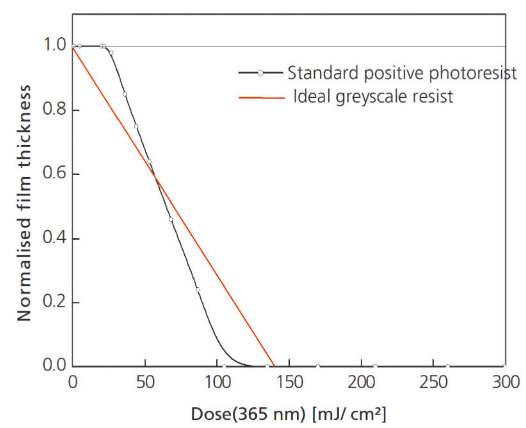

Figure 2: Response curves (normalized film thickness FT/FT_0 after development versus the exposure dose) of a standard binary positive photoresist and an ideal grayscale resist.

An ideal resist for grayscale lithography should have:

- A more linear response than a standard photoresist;
- A smaller contrast than that of standard binary resists to allow true grayscale response;
- Yet, the response curve should be sufficiently steep to avoid long exposure times;
- None or negligible initial solubility inhibition;
- Low residual absorption to enable exposure and development to the bottom even in very thick films.

Furthermore, due to the comparatively narrow process window, especially in grayscale mask lithography, the resist should have a high batch-to-batch reproducibility of the response curve.

Direct laser writing often uses high laser intensity during exposure, which can cause an „explosive" N_2 release from the resist. A resist suitable for direct laser writing in grayscale mode should have a strongly reduced tendency for this kind of outgassing during exposure.

MA-P 1200G SERIES: MATERIAL SOLUTIONS FOR GRAYSCALE LITHOGRAPHY

Micro resist technology GmbH developed a series of special positive resists for UV grayscale lithography:

- ma-P 1215G – 1.5 µm thickness @ 3000 rpm
- ma-P 1225G – 2.5 µm thickness @ 3000 rpm
- ma-P 1275G – 9.5 µm thickness @ 3000 rpm
- ma-P 1295G_XP – an experimental product for very high film thicknesses (100 µm).

[1] Binary lithography, on the other hand, aims at fabricating structures with the steepest possible sidewalls.
[2] Reflow patterning is a common method used to make rounded patterns by letting binary resist structure begin to melt.

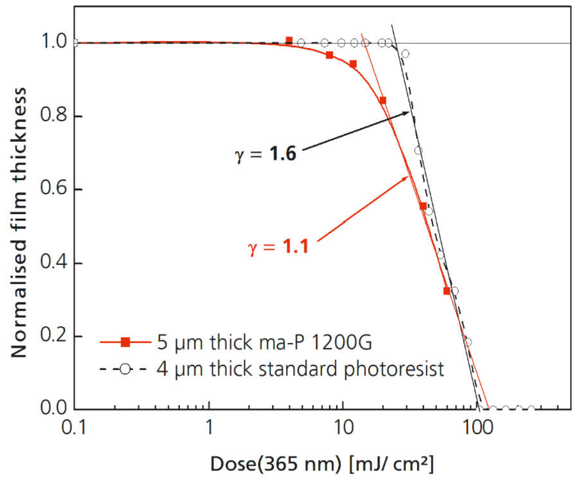

Figure 5: Contrast curves of 5 µm thick ma-P 1200G and of a 4 µm thick standard positive photoresist

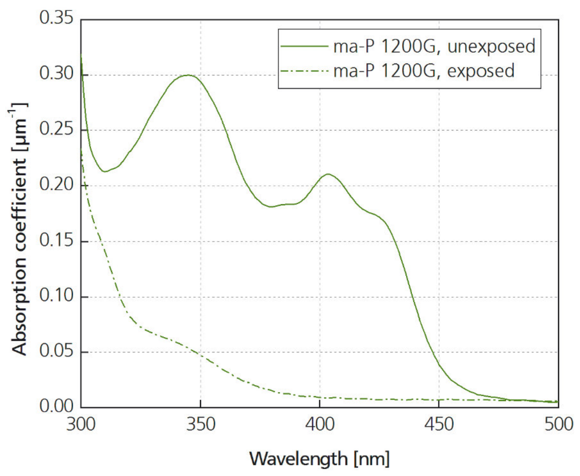

Figure 6: UV/vis absorption spectra of unexposed and exposed ma-P 1200G

Unique features of the ma-P 1200G series:

- Reduced contrast;
- Film thickness 1–60 µm in a single spin-coating step, 100–130 µm with ma-P 1295G_XP (single and double spin-coating);
- High-intensity laser exposure without outgassing;
- Reproducible grayscale pattern 50-60 µm deep;
- Up to 80 µm pattern depth in grayscale mode, up to 100–120 µm pattern depth (proven for binary lithography with a mask aligner);
- Aqueous alkaline development (TMAH for grayscale lithography, NaOH for binary lithography);
- Also well-suited for pattern reflow after standard binary lithography.

PROCESSING OF MA-P 1200G RESISTS

Grayscale lithography on thin resists

In thinner resists with a film thickness < 5 µm, such as ma-P 1215G and ma-P 1225G, the penetration depth of the exposure light is higher than the film thickness. As a result, the dose variation directly translates into the variation of photoactive compound conversion and of resist solubility in the developer (Fig.3 and 8).

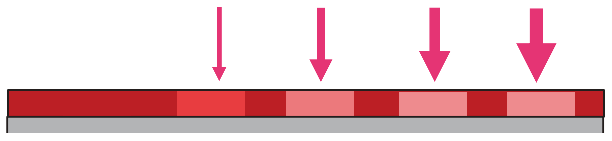

Figure 3: Grayscale exposure of thin film resist (FT ≤ 5 µm)

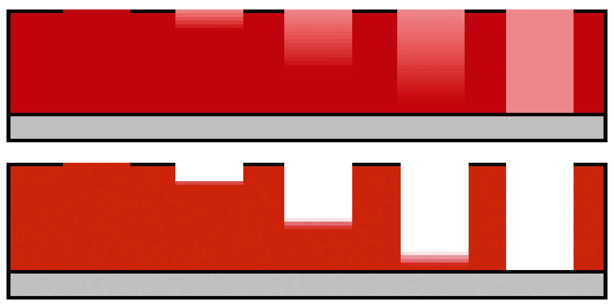

Figure 4 Top: Grayscale exposure of thicker resist films (FT ≥ 5 µm); Bottom: resist pattern after development.

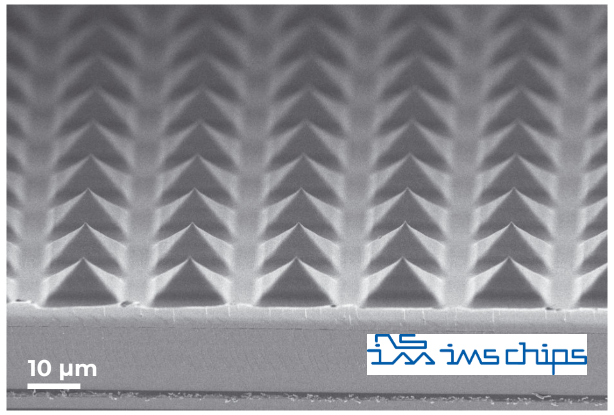

Figure 8: ma-P 1275G pyramid structure.Image courtesy of IMS CHIPS.

The resulting resist profile has a smaller contrast as compared to the standard positive photoresist (Fig. 5). ma-P 1200G grayscale resists also have significantly less initial solubility inhibition (no or hardly any film thickness reduction with increasing dose).

Grayscale lithography on thick resists

The composition of ma-P 1200G was optimized to drastically reduce the outgassing caused by the high laser energy density, which makes this resist suitable for creating deep structures.

In thick resists with a film thickness >5 µm (ma-P 1275G and ma-P 1295G_XP), the penetration depth of the exposure light is smaller than the film thickness. Resist bleaching contributes to the variation of the exposure depth at different doses (see the UV/vis absorption of unexposed and exposed resist film in Fig. 6). The resulting gradient of the dissolution rate in z-direction also results in a resist gradient after development (Fig. 4).

The reduced resist contrast is still large enough for reasonable writing times. Recent tests demonstrated 80-µm-deep grayscale patterns obtained by direct writing at 405 nm using a DWL 66+ laser lithography system from Heidelberg Instruments.

PATTERN TRANSFER

Lithography is often followed by pattern transfer into the target materials. ma-P 1200G resists are compatible with:

- Metallization and electroplating;
- Etching;
- UV moulding (Fig. 9).

SUMMARY

Resists of the ma-P 1200G series allow reliable grayscale patterning of 1-60 µm thick films and have the potential to be used in even thicker films of up to 100-130 µm. They can be used for direct-write laser lithography to produce complex micro-scale shapes in a reproducible and straightforward way.

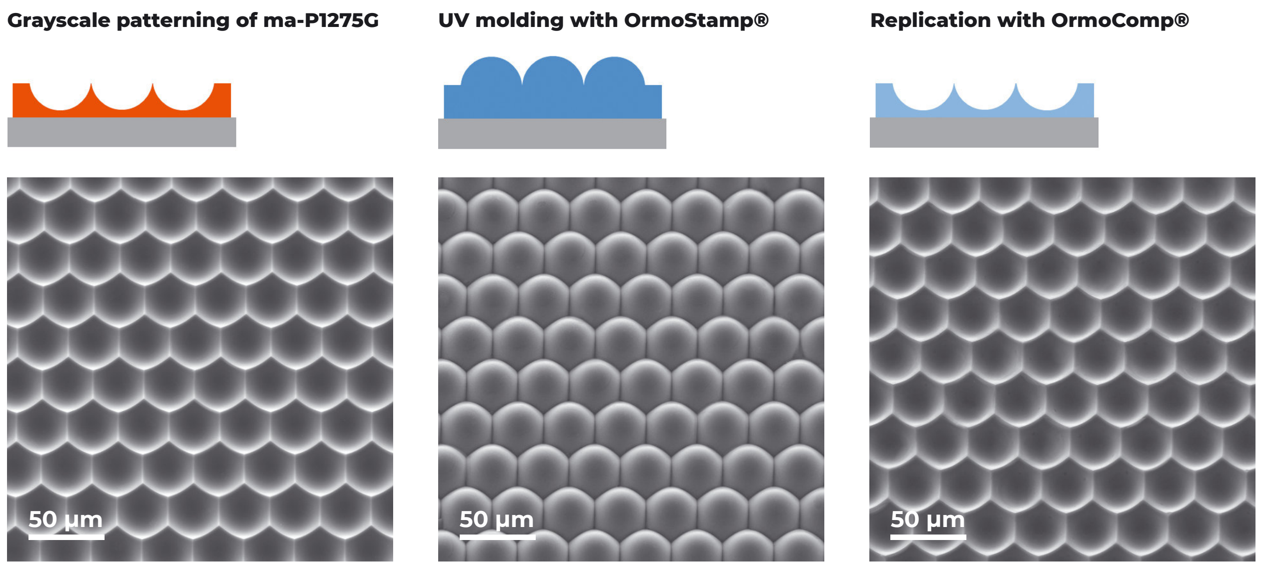

Figure 9: Pattern transfer of grayscale structures in ma-P 1275G by UV moulding with OrmoStamp® (left) to form a working stamp (center) and subsequently with OrmoComp® to form final concave lens structures (right).