A chip-scale imprinter with integrated optical interference for calibrating models of NIL resists and resist–stamp boundary conditions

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We demonstrate a new experimental platform that enables greatly accelerated, real-time acquisition of residual layer thickness and stamp-filling data during imprinting. The platform can be used to characterise the nanoscale flow behaviour of imprintable materials.

Numerical simulation of NIL enables faster process development than experimentation alone, but simulations require accurate models of the imprinted material's flow parameters. We have previously developed a fast numerical simulation technique for NIL [1]. Here, we report that we have used our own NIL experiments together with simulations (Fig 1a) to extract resist viscosity as a function of temperature for five popular thermoplastic resists (Fig 1b). These viscosities are extracted under the widely held assumption that there is no slip between the resist and the stamp or substrate surfaces. We have verified that our simulation method gives accurate RLT results under a no-slip assumption by comparing simulations with standard analytical results for squeeze flow [2]. The viscosities that are extracted assuming no slip, however, are between 2.5 and 200 times *lower* than those reported based on bulk rheology of three of these resist materials [3]. One plausible explanation for this surprising result is that there may indeed be some slip between the resist and the stamp and/or substrate surfaces. Since stamps are often engineered to reduce adhesion with the resist, a certain amount of relative velocity at the resist/solid boundary seems reasonable. Analytical results [2] (Fig 1c) show that boundary slip can increase the rate of RLT reduction more than 100-fold, which would correspond to reduced apparent viscosity under a no-slip assumption.

The characterisation procedure described above relies on imprinting each resist material at three or more temperatures, followed by time-consuming optical profilometry. To enable faster and more thorough characterisation of many resist/stamp material combinations, we have designed a compact imprinting device (Fig 2a,d) that can be placed under an optical microscope. The imprinting load is applied hydrostatically to the back of the stamp, and can be controlled using, *e.g.*, a syringe pump. Thermal resists could be temperature-controlled by placing a thermoelectric element beneath the sample. The device uses Fabry-Pérot interferometry to image the evolving RLT and cavity-filling extent during imprinting. Multiple reflections from the top and bottom of the resist layer result in coloured interference patterns that are captured by the microscope. The mapping of colours to layer thicknesses (*e.g.* Fig 2b,c) depends on the refractive indices of the stamp, substrate and resist materials, and contrast may be enhanced by depositing a semi-reflective coating on to the transparent stamp. For sub-200 nm gap values, the integer intensity values of pixels in the captured images vary over a range of 100 for a ~100 nm change in RLT (Fig 2f), suggesting that RLT could in principle be measured by this technique with a resolution of ~1 nm.

We envisage real-time interferometry of resist thickness being used not only in materials characterisation, but also for endpoint detection in industrial NIL processes, and to detect gas bubbles trapped inside stamp cavities. Fabry-Pérot interferometry could also aid in the detection of particle defects on stamps and epitaxial defects on substrates. By pressing a transparent, compliant layer against a stamp or substrate, localised air gaps would be created around defects, and these gaps would be larger and easier to detect than the defect itself.

References

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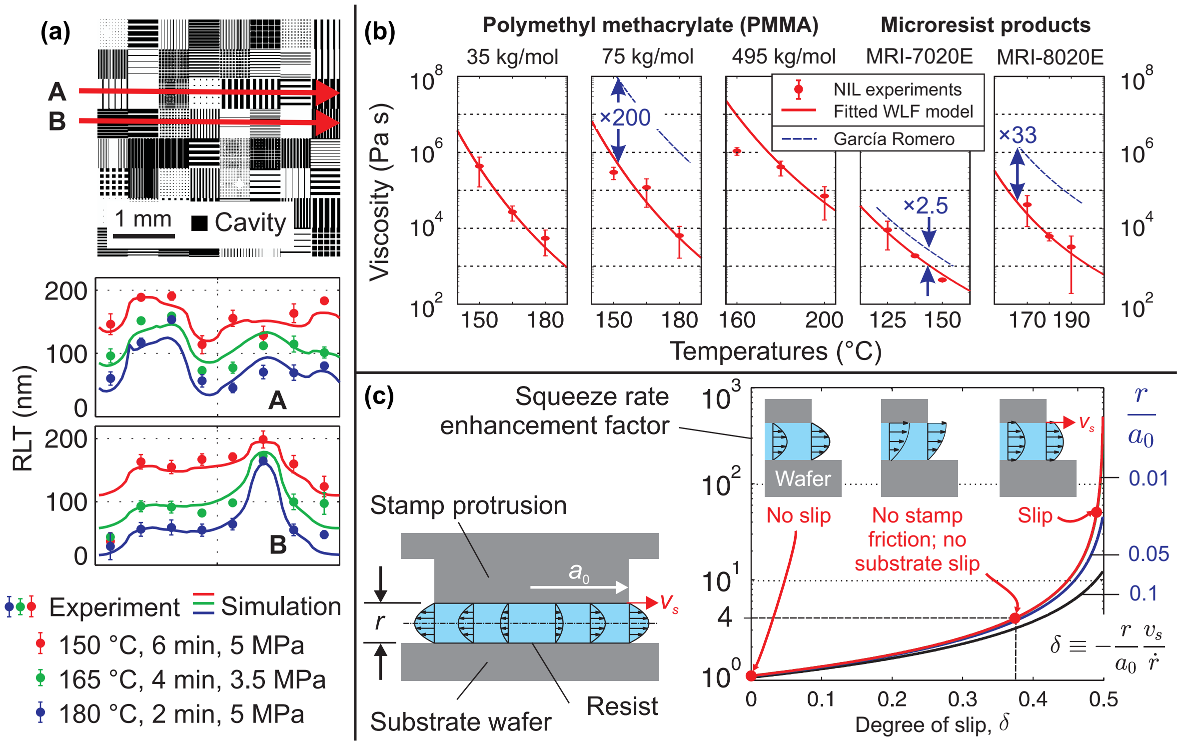

Figure 1. Resist viscosity calibration. Our existing simulation technique tracks RLT and cavity-filling variations with an RMS error of ~10% across heterogeneous patterns, multiple operating conditions, and five common thermoplastic resists: (a) shows the example of PMMA 35 kg/mol. We have extracted viscosities from the NIL experiments, under an assumption of no slip between the resist and stamp/substrate. We then fit Williams-Landel-Ferry temperature–viscosity models for the five materials (b). Both stamp and substrate were silicon and the stamp was silanised to reduce adhesion. Our extracted viscosities are substantially lower than those measured by García Romero via bulk rheology [3]. One plausible explanation for these differences is the existence of some slip at the resist boundaries, accelerating squeezing of the residual layer and lowering *apparent* viscosity (c).

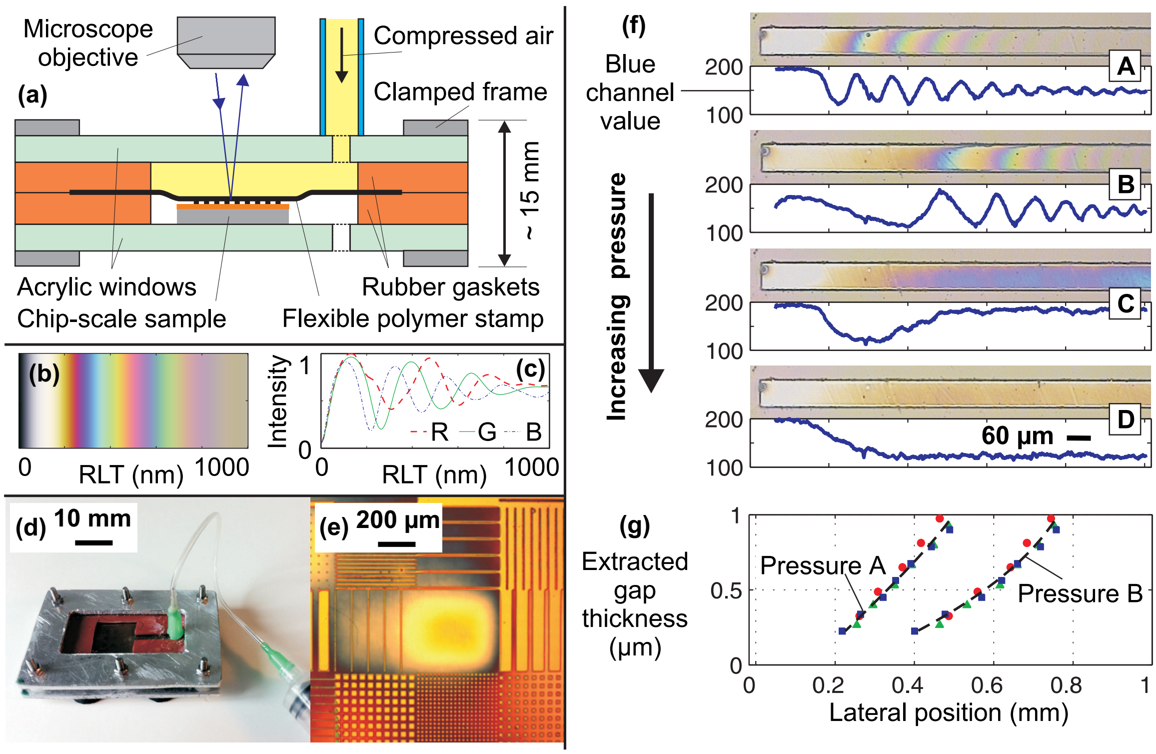

Figure 2. Real-time tracking of RLT and stamp deflections by Fabry-Pérot interferometry. The chip-scale imprinting tool fits beneath a white-light microscope (a). The relationship between colour fringes and RLT depends on material properties, and can be modelled (b,c). The prototype system is driven by compressed air (d). Interferograms of RLT reveal pattern dependencies (e). As stamp pressure increases, video frames capture the evolving gap between stamp and substrate (f). In this demonstration, the gap contains air. When multiple fringes are visible, intensity maxima and minima can be used to track gap size at the micron-scale (g).