Using Photolithography to Mass-Produce Rings of Controlled Size

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Primary CNF Tools Used: Heidelberg DWL2000, GCA AS200 i-line Stepper

Abstract:

The CNF user of the project trained on photolithography tools. We established that photolithography of SU-8 was an acceptable process to achieve our end goal of mass-producing rings of controlled size and aspect ratio, above ten micrometers, to use in rheology experiments of dense suspensions. We refined a recipe for the proper spinning, exposure and collection of said rings. We started the mass-production of one size of rings, that we have been able to use in rheology experiments. These experiments showed that, as we expected, the high aspect-ratio of these shapes induced a large additional stress in the rheology of the suspension, in the form of a rolling resistance in the contact between particles.

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Summary of Research:

Our research focuses on the rheology of dense suspension, and more specifically on the role of rolling friction between particles. This rolling friction is purely geometrical [1], so we decided to focus on square cross-section ring-shaped particles because of their high symmetry. The rolling friction is then controlled by the aspect ratio between the thickness of the ring and its outer diameter. With rings, a large rolling friction coefficient can be achieved, which in turn will induce a large change in the jamming solid volume fraction for a contact-driven flow of a suspension [2,3].

We first prepared a photolithography mask with the Heidelberg DWL2000 mask writer that had rings of multiple sizes and aspect ratios to test the range of shape we could achieve. We spun SU-8 10 on 100 mm silicon wafers and refined the spinning speed to achieve a reproducible thickness of 20 μm, homogeneous on the wafer with a relative variation under 2%. We then exposed the wafers using the GCA AS200 i-line Stepper. We adjusted the exposure procedure to obtain polymerized devices of a good quality, both in adequation with their size on the mask and with large enough stiffness, as shown on Figure 1.

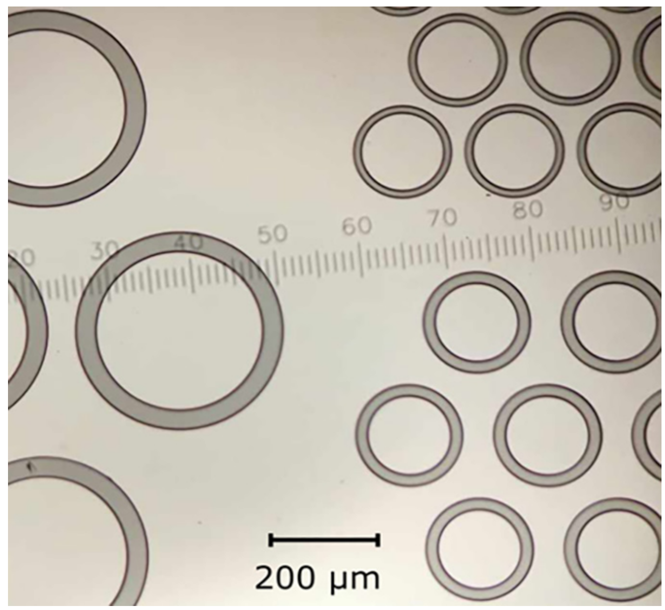

Figure 1: View of SU-8 rings on a wafer through a microscope, with two different diameters and aspect ratios.

We then moved on to one specific size of rings for the mass-producing: rings of an outer diameter of 200 μm and a thickness of 20 μm. This aspect ratio of 10 is directly proportional to the rolling friction coefficient and translates to a rolling friction coefficient of 5, much higher than the sliding friction coefficient. With this, we expect the rolling friction to be dominant in the rheology of dense suspensions with a large contribution from the contacts between particles. Our objective was to produce a few millions of these rings, and we managed to produce 50.000 per wafer. The main difficulty has been the ability to collect the rings and lift them off the wafers. We found that adding a layer of Omni-Coat before spinning SU-8, then hard baking the rings at 190°C after developing, and shaving the wafers with a sharp razor blade in a water bath allowed us to collect most of them without undermining their structural integrity (Figure 2).

We just started doing rheology experiments using this batch of rings in a somewhat dense regime. The preliminary results show that for high shear-rates almost no contacts between particles are established, and we retrieve usual rheological behavior for suspension in the divergence of the viscosity with respect to the solid volume fraction. However, at low shear-rates the flow is mostly contact-driven, and we see the appearance of yield stresses at volume fraction much lower than what is usually seen for suspensions of spheres (Figure 3), as we expected when we settled on the ring-shape for the particles. Figure 2 also shows that the rings tend to align with each other, while having their main axis perpendicular to the flow direction.

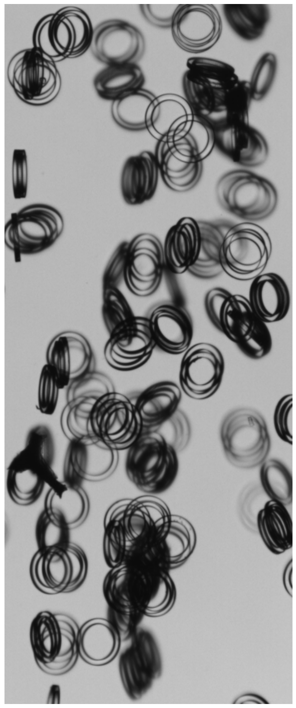

Figure 2: Photo captured of a flowing suspension made using SU-8 rings. The flow is in the downwards direction.

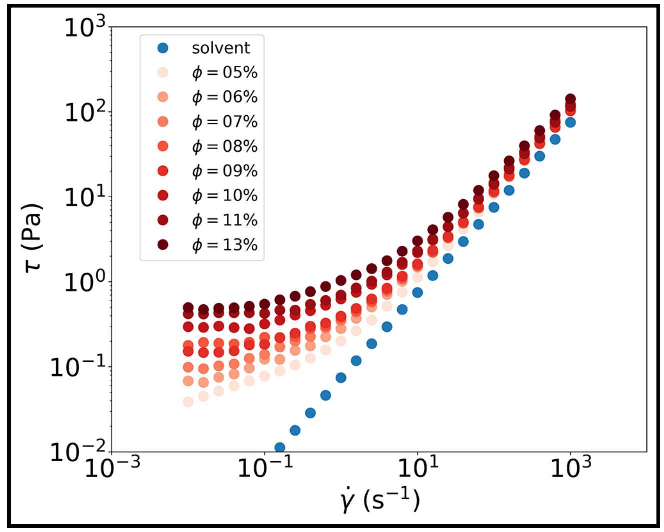

Figure 3: Shear stress as a function of shear-rate for different volume fraction, compared to the solvent alone.

References:

[1] Agarwal, et al. (2021). Rolling friction measurement of slightly non-spherical particles using direct experiments and image analysis. Granular Matter, 23(3), 60.

[2] Singh, et al. (2020). Shear thickening and jamming of dense suspensions: the “roll” of friction. Physical Review Letters, 124(24), 248005.

[3] d’Ambrosio, et al. (2023). The role of rolling resistance in the rheology of wizarding quidditch ball suspensions. Journal of Fluid Mechanics, 974, A36.