

Refractive Index Manipulation of 3D Printed Lenses using ZrO₂ Nanoparticle Doping

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Abstract—We investigated the creation of optical elements with user-defined refractive index (RI) through low-cost 3D printing. The RI of the elements was adjusted by mixing ZrO₂ nanoparticles with off-the-shelf consumer grade photopolymerization resins, enabling the potential for designing more advanced additively manufactured optical components with low-cost print approaches. Multiple resins were evaluated as base material for the nanoparticle embedding, with solubility and RI changes tested with the un-cured resins, leading to measured RI changes of up to 0.06. Plano-convex lenses of 25mm diameter and with 20mm focal length were created using 10% ZrO₂ wt% loading and imaging performance was tested in a custom brightfield microscope.

Keywords—additive manufacturing, lens technology, nanoparticles, 3D printing, refractive index

I. INTRODUCTION

3D printing of optical elements has seen a significant interest in recent years, with comparably expensive two photon polymerisation (TPP) approaches demonstrating viable optical element creation with high accuracy, e.g. on the tip of optical fibres [1], but requiring a complex and expensive

laser and printer setup. Affordable consumer grade resin printer have also recently demonstrated print qualities sufficient for biological imaging [2]. These approaches in general use single photopolymerization materials, limiting optical design elements to singlet lenses and lens arrays. To allow widening of the design space, multi refractive index (RI) solutions are desirable.

Nanoparticle doping of resins has been used for a variety of applications and use cases, including for the modification of RI. TiO₂ was found to increase the RI of a photocurable resin by 0.13 [3], while ZrO₂ doped resin has been used to create an achromatic Fraunhofer doublet lens using TPP [4]. Off-the-shelf resins/glues with different RIs have also been used to create doublet lenses using a consumer-grade Vat Photopolymerisation (VPP) printer [5]. However, combining the high RI changes possible using nanoparticle doping and low-cost 3D printing has not yet been explored, which can enable accessible custom optics with multiple RIs.

II. METHODS

Various methods of nanoparticle mixing were evaluated, with the most effective results obtained by sonicating ZrO₂

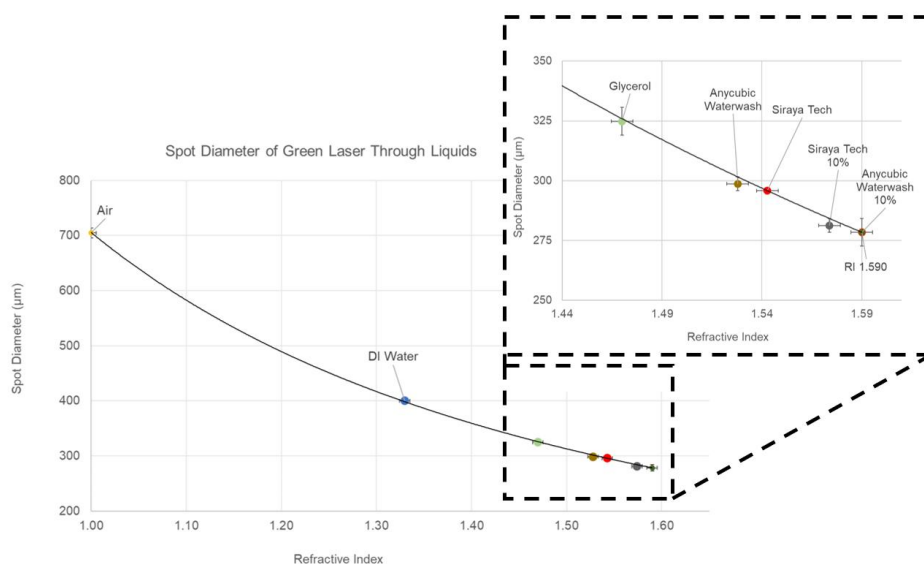


Fig. 1 Graph showing the relationship between defocused laser spot diameter and RI of various substances including nanoparticle doped resins.

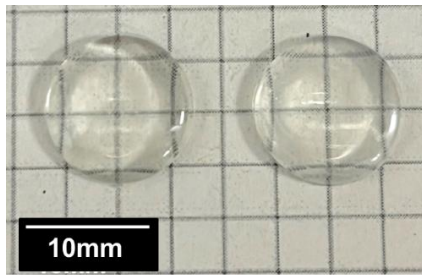


Fig. 2 Moulded lenses using undoped and doped consumer-grade 3D

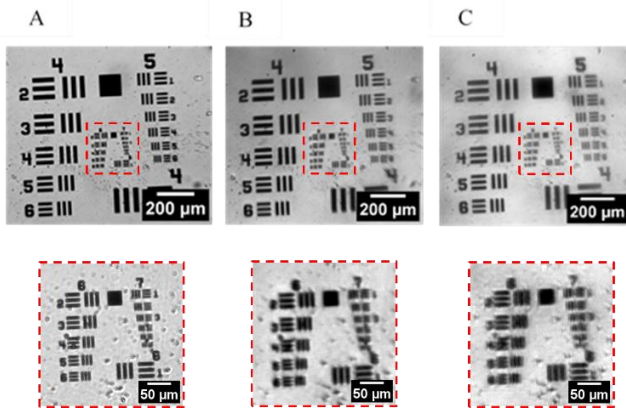


Fig. 3 (A) 1951 USAF Target imaged using a commercial 20 mm glass lens, (B) a Siraya Tech moulded 20 mm lens, and (C) a 10 wt% ZrO₂

nanoparticles in a 50% propylene glycol monomethyl ether acetate (PGMEA) solution for even dispersal. This was followed by adding the sonicated ZrO₂-PGMEA solution into consumer grade resins (Siraya Tech Craft Clear or Anycubic Waterwash) with a 20 wt% ratio. The Resin-ZrO₂-PGMEA mixture was then vortexed for 30 seconds, and sonicated for a further 2 hours at room temperature.

An RI measurement setup was constructed using a 532nm laser (Thorlabs CPS532-C2), a focusing lens arrangement, an industrial CMOS camera (IDS U3-3060CP), and a custom 3D printed rail-mounted cuvette. The effect on the refractive index was evaluated by measuring the change in diameter of a defocused laser spot which passed through the liquid in the cuvette [4]. By using liquids of known RI, a calibration curve was established, and subsequently RIs of resins could be calculated.

To test the initial optical performance of the doped resins, moulded lenses were created both from pure resin, and resin with 10 wt% ZrO₂ added. The master for the mould was a spin-coated VPP 3D printed plano-convex lens of 12.5 mm diameter and 20 mm focal length, as per the methods presented by Christopher et al [2]. This was then cast in silicone to allow isolation of the material property influences when evaluating the performance of the geometrically identical lenses. The imaging performance was trialled by integrating the lenses into a basic widefield imaging set up with Köhler illumination.

III. RESULTS

Figure 1 shows the non-linear trend of the measured laser spot diameter in relation to RI, as previously demonstrated by

Weber et al. [4]. The two tested consumer-grade resins show the same effect in varying degrees; the RI of the Siraya Tech resin changed from 1.54 to 1.57 with the addition of 10 wt% ZrO₂ nanoparticles, and the Anycubic Waterwash showed a greater increase from 1.53 to 1.59 with the same doping.

Figure 2 shows a side-by-side comparison of the clarity of the nanoparticle enhanced resin and basic resin, indicating that the nanoparticles have been distributed in the resin without clouding or chemical changes affecting the transparency. Figure 3 shows the comparison between the images obtained using the moulded lens for each resin. The current results indicate the ZrO₂ nanoparticles do not significantly interfere with the light transmission or lens performance, and no additional artefacts or vignetting are observed. The minimum resolvable detail for the basic Siraya Tech resin moulded lens was 13.92µm, and 12.40µm for the 10 wt% doped Siraya Tech resin moulded lens, indicating a slight resolution increase.

IV. DISCUSSION

It has been demonstrated that ZrO₂ doped consumer-grade 3D printing resins can be used for printing millimetre scale lenses using low-cost manufacturing techniques. By applying nanoparticle mixing of resins to low-cost, accessible 3D printing methods, the barrier to entry for customisable lens characteristics can be significantly reduced. Using consumer grade VPP equipment, the equipment cost can be reduced by a factor of approximately 1000 when compared to TPP, and larger lens diameters are possible without requiring excessive print times. Having validated the resin doping protocol and quantified the RI changes, further work will include directly printing the lenses using VPP printing, and characterising lens performance. This will allow the creation of custom doublet lenses, fully 3D printed using low-cost techniques.

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