Development and Precision Characterisation Of Broadband Anti-reflection-coated mm-wave Components

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1. Key Points

1) Future optical systems in the sub-mm range require low loss, low reflectance and broadband anti-reflection coatings.
2) Developed here: hot press technique for fabricating broadband multi-layer AR coatings for Ultra-High Molecular Weight Polyethylene (UHMW-PE) optical components.[1]
   I. Elevated temperatures affect lens and coating material's index and cause deformations due to polymer chain rearrangements.
   II. 3-4 annealing cycles prior to machining and coating treatment stabilises dimensions & stops deformation.
3) Using transfer matrix method (TMM) enables predictive modelling for ideal broadband/ minimal reflectance coating. ARC tests show reliable modelling results.

2. Overview

1. Development of plastic optics is important to the future sub-mm astronomy as it presents a desirable alternative to silicon optics. Material availability, dimensional constraints, cost, machining complexity, anti-reflection (AR) coating, and end-of-life disposal are all concerns that are benefited by use of plastics.
3. The study presented here investigates dimensional changes in the plastic substrate induced from the hot-pressing technique employed for AR coating.
4. Multi-layer coating solutions are modelled and then experimentally verified.

3. Experimental detail

1. UHMW-PE is selected because of a moderately high refractive index and low loss[2]
2. Test puck disks are ~10mm thick with ~70mm diameter, machined from 70mm diameter rod stock. The extrusion process employed forces molecular chains into a common orientation aligned with direction of flow.
3. Annealing procedure between 115-135 °C :
   I. Cycle from room temperature to annealing temperature over ~8 hours to ensure thermal equilibrium within test sample. Followed by unaided conductive & radiative cooling back to room temperature.
   II. Repeated cycles use the same set point temperature.
4. Transmission and refractive index recovered from continuous wave THz spectroscopy[3] in frequency range: 50~1000GHz.

4a. Metrology

1. Dimension change from annealing is due to the bonds between molecular chains weakening at higher temperatures. This freedom allows the chains to relax into new unaligned orientation. Overall thickness increases/ diameter decreases.
2. Mass change is negligible after repeated annealing[4].
3. *Fig 1.1 & 1.2* show:
   I. 131°C pucks show greater thickness change between cycles but are no quicker in settling than 121°C pucks. 116 °C requires a further cycle to settle.
   II. Similarly, 131°C & 121°C dimensional change is alike in settling at 3 cycles. 116°C settles with 4 cycles.
   III. Key result: Efficient annealing requires T>116°C but 121-131°C yields similar results.

4b. Volume & *Refractive Index*

1. *Fig. 2.1* indicates linear decrease in volume between cycle. *Fig.2.2* indicates linear increase in refractive index between cycle. Both show a steeper gradient for higher temperatures. A consistent relationship between gradient and temperature is seen.
2. Density (for constant mass[4]) and refractive index both increase with number of cycles.

4c. Interpolating V & n vs #cycles

1. *Fig 3* shows the approximately linear relationship between (1) volume expansion coefficient and temperature and (2) change in refractive index by cycle vs temperature. One could use this to infer the change of these properties at any given temperature for any number of cycles.

5. ARC Coating Test Puck

1. Transfer matrix method program applied to predict transmission through multilayer interfaces.[5]
2. Procedure: mount layers of coating material & annealed PE puck in a vacuum rig, heat to a set point of 120 °C for 12 hours at equilibrium. Low-density polyethylene (LDPE) used as a bonding layer (6µm thick).
3. *Table 1 & 2* show ARC recipe for a test puck prepared with 7 cycles at 125 °C set point /equilibrium at 121.2 ±0.1 °C. No shape deformation is seen after coating.
4. *Fig. 4* gives the comparison between the TMM model and VNA measurement for 3- and 5-layer recipes.

6. Next Steps and Future Missions

1. Perform 4 annealing cycles on larger PE blocks ready for machining to a test lens geometry.
2. Optimise 3- & 5-layer recipes for AR coating. Potential target frequencies include SO:UK MFT 70-180GHz, LiteBIRD HFT 166-448GHz, and MFT 89-225GHz *(Fig. 4)*.

References

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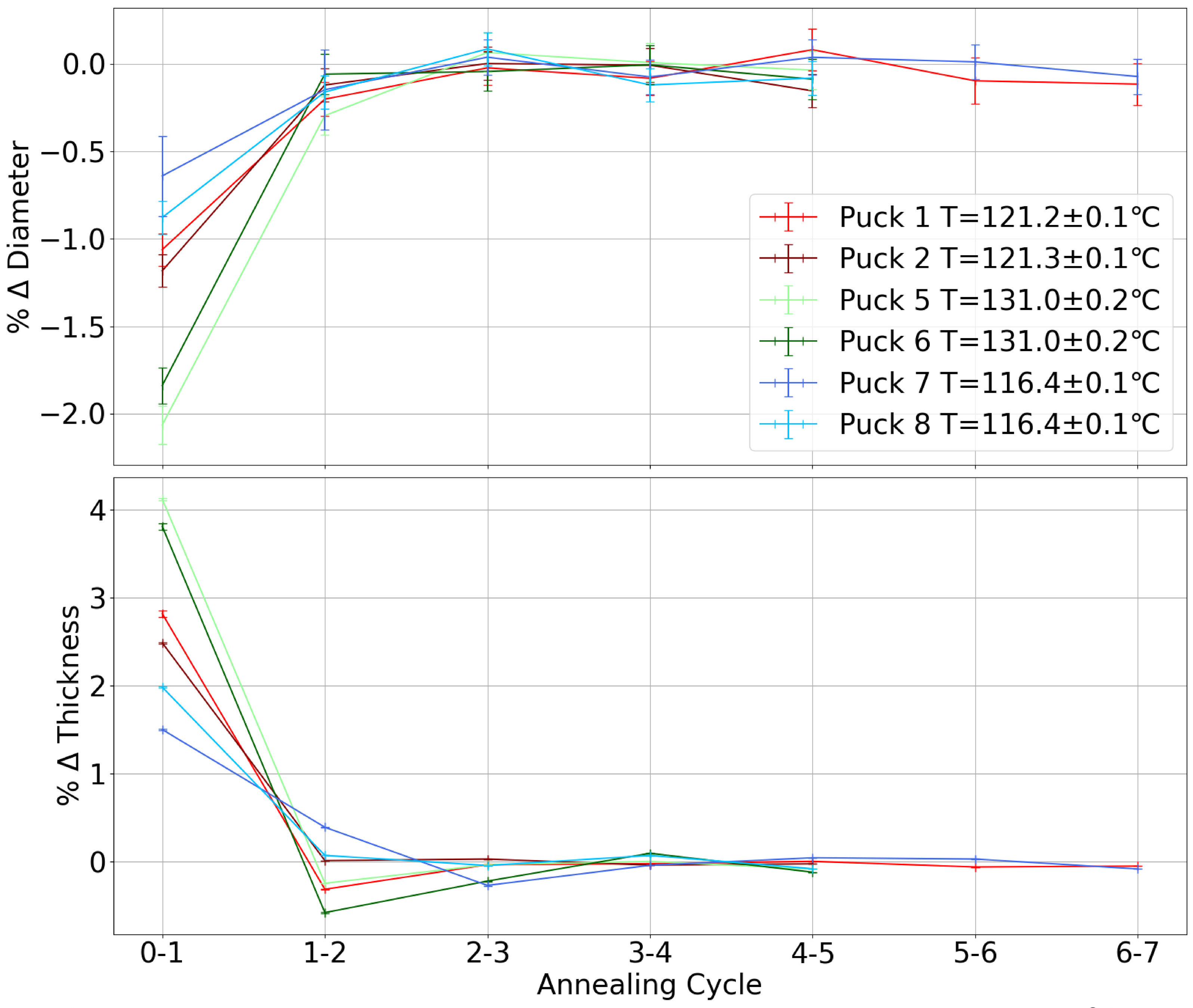

***FIG 1:* (1)** The % diameter change stabilises after 3 cycles within 115-130°C range.
(2) However, the % thickness requires 4 cycles to approach zero.

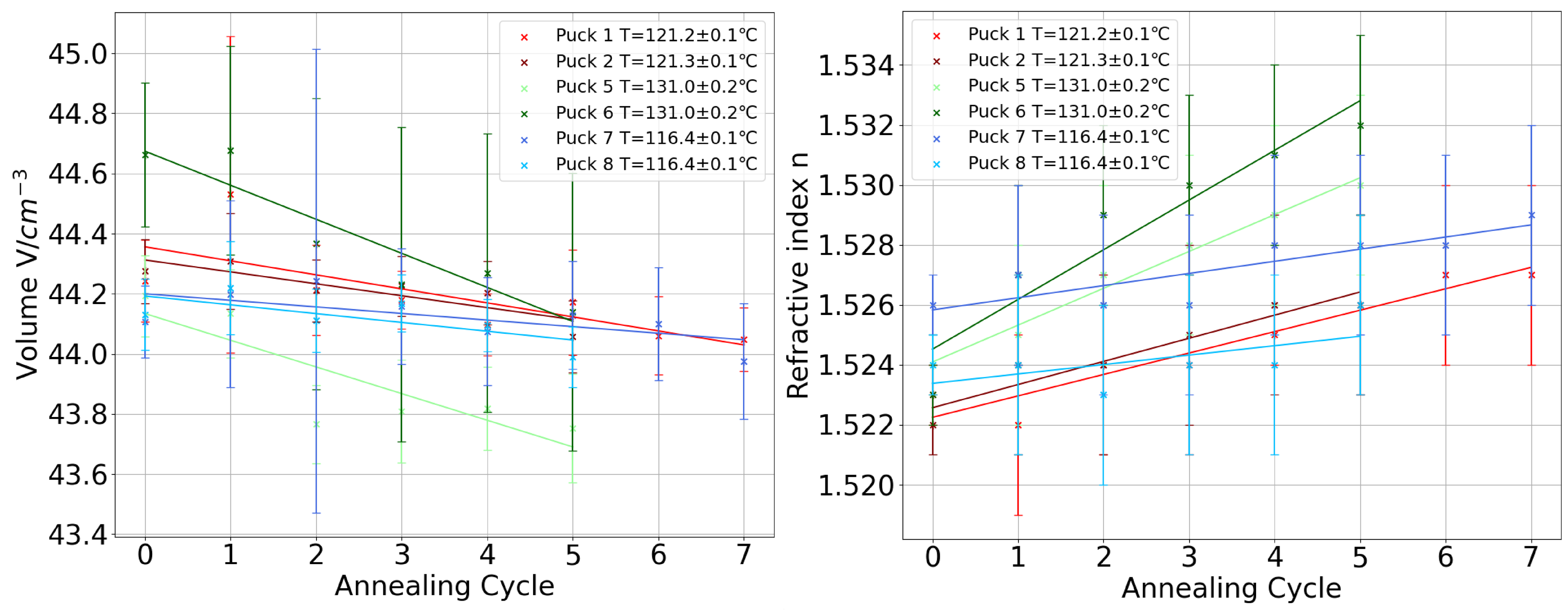

***FIG 2:* (1)** Volume & **(2)** Refractive Index Change with Cycle @ 115-130°C. A linear decrease in volume & linear increase in refractive index between cycle can be seen. The change in volume implies an increasing density. A more compact molecular structure results increasing refractive index.

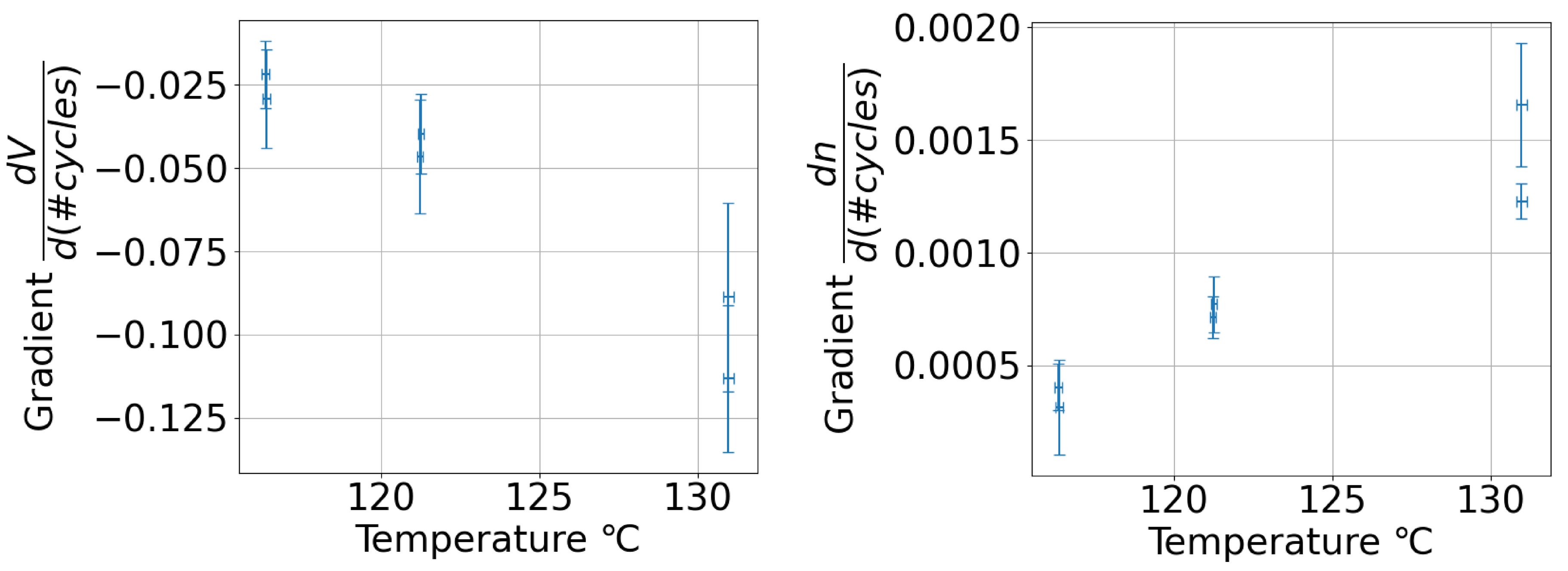

***FIG 3:* (1)** Volume change & **(2)** refractive index change per cycle vs annealing temperature. From this, the gradients at intermediate temperatures can be inferred, thus enabling a prediction of volume and refractive index change to be made.

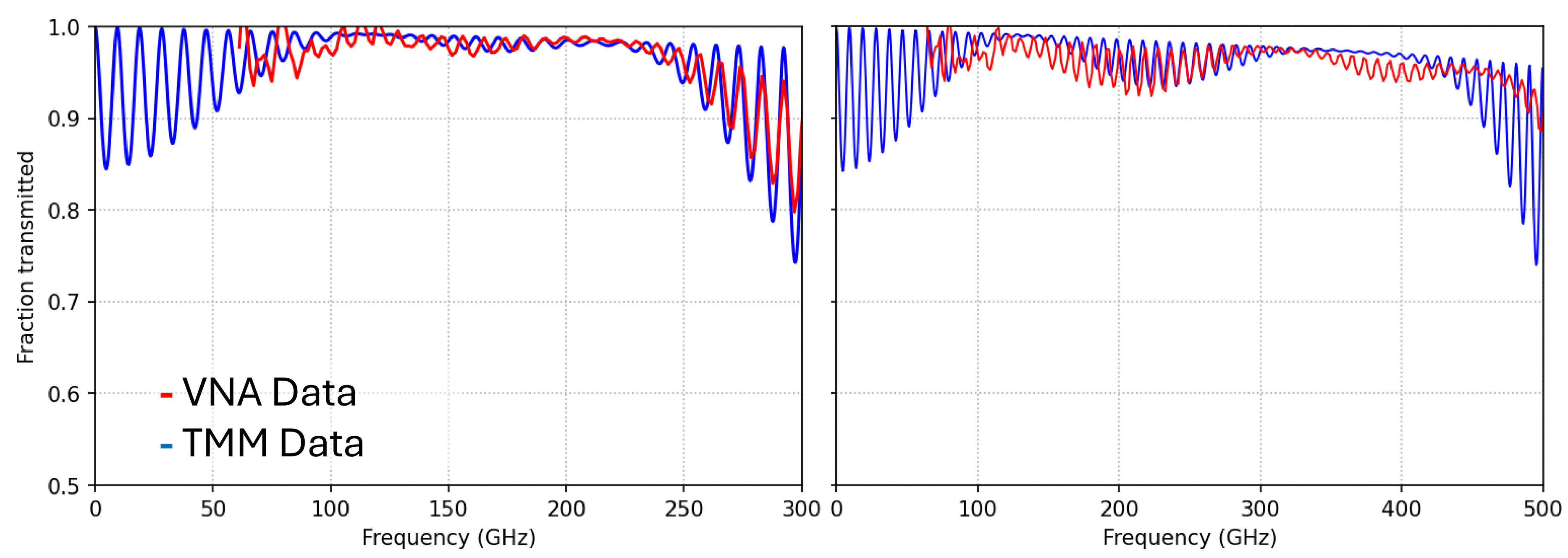

***FIG 4:* (1)** 3 Layer AR Coating **(2)** 5 Layer AR Coating showing agreement between the modelling and data collection.

Layer	Material	Ref. Index	µm
1	**pPTFE**	**1.15**	**415**
	LDPE	1.5141	6
2	**CPP**	**1.51**	**110**
	LDPE	1.5141	6
3	**pPTFE**	**1.15**	**127**
	LDPE	1.5141	6
Lens	UHMWPE	1.517	10020

Symmetric on the reverse side

Layer	Material	Ref. Index	µm
1	**pPTFE**	**1.15**	**250**
	LDPE	1.5141	6
2	**CPP**	**1.51**	**37**
	LDPE	1.5141	6
3	**pPTFE**	**1.15**	**127**
	LDPE	1.5141	6
4	**CPP**	**1.51**	**67**
	LDPE	1.5141	6
5	**pPTFE**	**1.15**	**55**
	LDPE	1.5141	6
Lens	UHMWPE	1.517	10020

Symmetric on the reverse side

TAB:* *(1) Test 3-layer ARC Puck ***(2)*** Test 5-layer ARC Puck. Both are symmetric on the reverse side of the lens.