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Optical cements for interferometric applications

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The wave front distortion introduced by optical cements is important in interferometric applications. We describe here tests performed to characterize two common cements, Epo-Tek 301 (Epoxy Technology, Inc.) and Norland Optical Adhesive 61 (Norland Products, Inc.).

The design of an all-glass interferometer intended for space flight called for the use of optical cements in the optical aperture.[1] Dissimilar glasses and unavoidable temperature cycling ruled out optical contacting, while positioning tolerances, vibration, and the possibility of dust entry made mechanical mounting of separate components impractical. In addition, an index-matching material at the glass interfaces was desirable to reduce stray light.

The choice of cements was limited to those permitting a room temperature cure and forming strong relaxation-free joints. A 25°C survival range and long life were also required. Epo-Tek 301, a two-part epoxy, and NOA 61, a UV cure cement, were selected on the basis of previous experience, availability, and compliance with the above criteria.

A prototype instrument had been marred by a prominent wave front defect associated with the cement and cementing technique used (Fig. 1). The cement joint had been formed by pouring a puddle of fresh Epo-Tek 301 onto a dielectric coating consisting of cryolite and ZnS layers deposited on a glass substrate, waiting ~1 min, and then applying another clean glass piece on top to produce a cement line ~15 μm thick. It was not known whether the puddle effect was attributable to coating, glass, or cement alteration. However, evidence of refractive-index variations was detected on two subsequent glass/glass joints: the region of the initial cement puddle displayed a different critical angle for total internal reflection, thus suggesting that the coating was not necessarily implicated.

Cement manufacturers' information on wave front distortion proved sparse. Previous publications have typically dealt with performance at noninterferometric tolerances[2,3] or with long-term effects.[4]

Prior to assembling a second instrument, it was decided to study the mechanical stresses and optical distortions introduced by the cements during their curing processes.

Mechanical strain was characterized by measuring the surface flatness of a pair of thin and thick plates before and after cementing; the stress introduced by the cement would tend to amplify the distortion with respect to two plates of equal thickness. Pairs of Pyrex flats 15 cm in diameter and 0.63 and 2.5 cm thick, respectively, were used. Surface flatness for the exposed surface of the dry-contacted thin flats was $\lambda/10$.

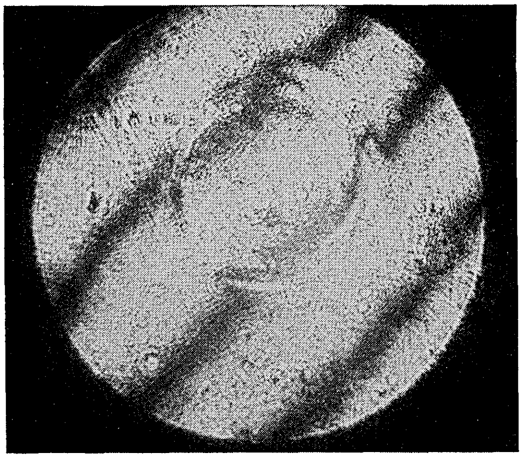

Fig. 1. Wave front distortion of a glass interferometer cemented using Epo-Tek 301. The circular discontinuity corresponds to the initial cement puddle.

Wave front distortion was determined using pairs of 10-cm diam quartz flats polished to $\lambda/20$ fine-scale flatness (and up to $\lambda/4$ spherical power) and coated with a 96% reflective dielectric coating on the contacting surfaces. Glass pairs were initially airspaced using 10-μm thick Mylar tabs and operated as fixed Fabry-Perot interferometers to note the initial fringe quality. Pairs were subsequently bonded with the candidate cement. Cement thickness was typically ~20 μm.

Epo-Tek 301 test pieces were bonded by applying a 2-cm diam puddle to one glass piece, waiting 1 min, and then squeezing the cement between the glass pairs. The pieces were left horizontal without external constraint to cure overnight.

NOA 61 cement was applied similarly but was cured using various configurations of UV lamps to study the relationship between UV illumination uniformity and curing irregularities. The lamps employed were two Spectrasil fluorescent tubes at 25-cm distance from the glass test pieces. Initially, glass pairs were UV cured with one-half of the surface shielded for 10 min and then completely uncovered for 30 min [Fig. 2(A)]. The initially exposed area thus cured almost completely before the second half had begun to cure. As a more subtle test of the effect of curing uniformity, a second series of test pairs was exposed to the UV radiation with areas masked to 90 and 81% transmittance (measured at 360 nm, the mean curing wavelength). Stacks of glass slides covering one-half and one-quarter of the plate area, respectively, were employed. The test pieces were exposed for 1 h. During this time, the 546-nm mercury line emitted by the lamps allowed Fabry-Perot fringes to be viewed by reflection.

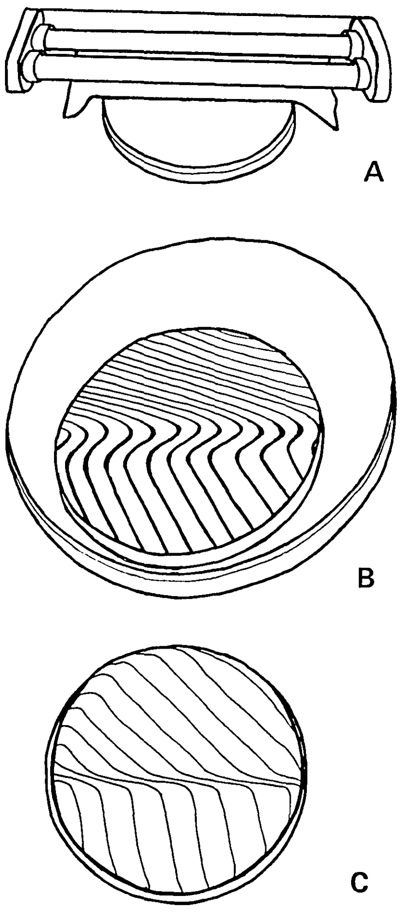

Fig. 2. Curing test of NOA 61: (A) setup: UV lamps illuminate the test piece half covered by an opaque mask; (B) mechanical stress: Newton's rings fringes obtained by comparing the thin-plate surface to a test flat; (C) wave front distortion: Fabry-Perot fringes viewed in transmission. See text for details.

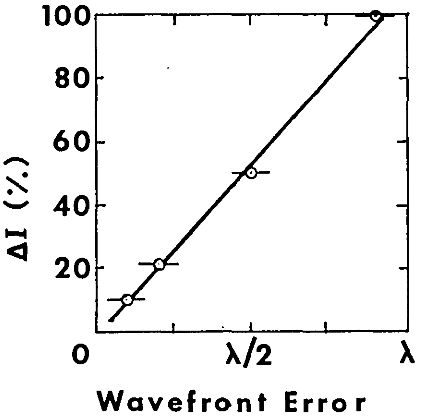

Fig. 3. Wave front distortion (P–P) across a 25-μm thickness NOA 61 cement layer for various spatial gradients in UV curing intensity ΔI. 100% variation corresponds to a cement layer cured in two separate exposures as in Fig. 2(A).

The Epo-Tek 301 proved to introduce slight mechanical stress: the thin-plate surface was strained into a gentle curve of λ/8 rms and λ/4 worst-case deviation from its initial λ/10 flatness. Wave front distortion was also slightly worsened from the initial λ/15 P–P value to λ/10 P–P (~λ/25–λ/20 rms, respectively). More important, the edges of the initial puddle spot were apparent as a localized λ/4 distortion. No other fine-scale distortion was detected. As a final test to locate the puddle distortion produced by Epo-Tek 301 cement, uncoated 2.5-cm diam flats were contacted as described above. Upon stressing the uncured cement by squeezing the flats, the region around the initial cement puddle became visible via higher reflectance at glancing incidence. The effect disappeared when the pieces were allowed to relax. The pieces were separated, cleaned of cement, and reexamined. No trace of the puddle was observed on the glass surfaces, suggesting that the cement itself caused the effect. When this test was repeated with only 5 sec between pouring the cement puddle and squeezing the cement, no evidence of cement irregularity was seen.

The effect is tentatively explained as resulting from the alteration of the surface of the cement puddle after long (more than several seconds) exposure to air and to a consequent change in its glass-contacting properties. The stress introduced by external force or by shrinkage during the initial curing appears to modify the refractive index of the cement at the puddle–air interface.

The NOA 61 test pieces that had been cured with one-half of the surface initially shielded showed a significant buckling of the thin plate on the later-cured side [Fig. 2(B)].

Similarly, the wave front was strongly distorted within ~0.5 cm of the masked edge but remained very smooth on either side. Shadowing of the UV light at the ground edges of the plate caused curvature of about one fringe within 1 cm of the edge [Fig. 2(C)]. The partially transmitting masked pieces showed wave front distortions almost proportional to the decrease in UV intensity. The distortion appeared gradually during the UV exposure becoming constant after ~30 min. Figure 3 plots the peak fringe curvature observed for various intensity gradients. As had been observed for the Epo-Tek cement, the Norland bonds were completely free of blemishes and fine scale wave front distortions.

The refractive index of NOA 61 cement thus appears to be influenced by the spatial uniformity of the UV curing radiation. This is presumably related to stresses throughout the cement line produced by shrinkage during the curing process.

Five glass interfaces, representing parts of two interferometers, were subsequently bonded with NOA 61. The spatial variation in UV curing illumination was <10% in all cases. Twyman-Green fringes were observed with the pieces contacted using oil, fluid cement, and at various stages of curing. No change in fringe quality was observed. However, a tilting of the wave front of up to three fringes was observed for those pieces that had not been allowed to rest in an unconstrained aligned position for at least 45 min prior to curing.

In summary: both Epo-Tek 301 and Norland Optical Adhesive 61 cements can introduce wave front distortion of the order of one fringe. Epo-Tek distorts wave fronts passing through areas where the cement has been initially deposited. The Norland cement alters the wave front in proportion to the gradient in UV curing intensity.

Both cements can be used to construct interferometric optics if precautions are taken: Epo-Tek 301 must be exposed to air for no more than several seconds before being spread between the glass pieces to be bonded; NOA 61 cement lines must be cured by UV light having a spatial variation of intensity of somewhat <10% for λ/10 (P–P) wave front distortion.

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References

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17–20 April 1984 OSA SPRING CONFERENCE ON APPLIED OPTICS, Monterey Information: Meetings Department at OSA

17–18 April 1984 SCIENCE OF POLISHING TOPICAL MEETING, Monterey Information: Meetings Department at OSA

17–19 April 1984 OPTICAL INTERFERENCE COATINGS TOPICAL MEETING, Monterey Information: Meetings Department at OSA

18–20 April 1984 WORKSHOP ON OPTICAL FABRICATION AND TESTING, Monterey Information: Meetings Department at OSA

18–20 April 1984 OPTICAL DATA STORAGE TOPICAL MEETING, Monterey Information: Meetings Department at OSA

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24–26 April 1984 INTEGRATED AND GUIDED-WAVE OPTICS, Orlando Information: Meetings Department at OSA

12–15 June 1984 ULTRAFAST PHENOMENA TOPICAL MEETING, Monterey Information: Meetings Department at OSA

18–21 June 1984 QUANTUM ELECTRONICS, OSA/IEEE/APS THIRTEENTH INTERNATIONAL CONFERENCE, Anaheim Information: Meetings Department at OSA

19–22 June 1984 CLEO 84, CONFERENCE ON LASERS AND ELECTROOPTICS, Anaheim Information: Meetings Department at OSA

13–14 August 1984 INDUSTRIAL APPLICATIONS OF COMPUTER TOMOGRAPHY AND NMR IMAGING, Manitoba Information: Meetings Department at OSA

Meetings Schedule

OPTICAL SOCIETY OF AMERICA
1816 Jefferson Place N.W.
Washington, D.C. 20036

29 October–2 November 1984 ANNUAL MEETING OPTICAL SOCIETY OF AMERICA, San Diego Information: Meetings Department at OSA

15–18 January 1985 OPTICAL REMOTE SENSING OF THE ATMOSPHERE TOPICAL MEETING, Lake Tahoe Information: Meetings Department at OSA

4–6 February 1985 MICROPHYSICS OF SURFACES, BEAMS, AND ADSORBATES TOPICAL MEETING, Santa Fe Information: Meetings Department at OSA

11–13 February 1985 OFC 85, OSA/IEEE CONFERENCE ON OPTICAL FIBER COMMUNICATION, San Diego Information: Meetings Department at OSA

18–20 March 1985 WINTER 85, Lake Tahoe Information: Meetings Department at OSA

18–20 March 1985 MACHINE VISION TOPICAL MEETING, Lake Tahoe Information: Meetings Department at OSA

18–20 March 1985 OPTICAL COMPUTING TOPICAL MEETING, Lake Tahoe Information: Meetings Department at OSA

19–20 March 1985 NONINVASIVE ASSESSMENT OF VISUAL FUNCTION, Lake Tahoe Information: Meetings Department at OSA

21–24 May 1985 CLEO 85, OSA/IEEE CONFERENCE ON LASERS AND ELECTROOPTICS, Baltimore Information: Meetings Department at OSA

15–18 October 1985 ANNUAL MEETING OPTICAL SOCIETY OF AMERICA, Washington D.C. Information: Meetings Department at OSA