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Self-Assembled Monolayer Coatings as a New Tool for the Resolution of Racemates

Ruth Binnes, Aharon Gedanken* and Shlomo Margel*
Bar-Ilan University, Dept. of Chemistry, Ramat-Gan 52900, Israel

Abstract: Chiral voids were created in self-assembled monolayer coatings on various polar surfaces. The chiral voids were utilized for resolving a racemic mixture of a long chain oxirane. An enantiomeric excess of 18% was observed.

Previous studies have demonstrated that coatings prepared by the self-assembly technique from trichloroalkylsilane molecules, i.e. $SiCl_3(CH_2)_nCH_3$, n>8, onto polar solid substrates (such as glass, silicon crystals, silica microspheres, etc.) have formed fully extended close-packed monolayer coatings.[1-4] These self-assembled coatings are based on the covalent bonds formed between the silane molecules and the polar substrates. Pinhole formations in these structures were first reported by Sagiv *et al*[5] and subsequently by others.[6-8] These pinholed-monolayer structures were composed of self assembled coatings of mixed monolayers, i.e. trichloroalkylsilane molecules covalently bonded to the solid substrates and various guest molecules, such as long chain fatty acids[9] or long chain cyanine dyes, which physically adsorbed to the substrates. These physically adsorbed molecules could be extracted readily with the appropriate solvent. The cavities which are left on the substrates surface after the removal of the physically adsorbed molecules can then be refilled with either the same molecules or molecules with a similar molecular shape.[6-8] Recently, several researchers have reported success in employing these pinhole-monolayer structures for selective molecular recognition. For example, molecules such as vitamin K_1, vitamin A and cholesterol were selectively incorporated into these films and quantified.[7-8, 10-12]

We would like to report on our initial results in utilizing the aforementioned idea to prepare chiral voids which may be useful for optical resolution of racemates. The enantiomeric excess that has been achieved for the probed system demonstrates the chiral recognition of the cavities. In these studies, self-assembled monolayers have been prepared on substrates such as silica microspheres, glass slides and silicon crystals. The mixture implanted on the various substrates contained a solution of dodecyltrichlorosilane (DTS, Aldrich 99%) and R-(+)-1,2 Epoxydodecane (EDC, Nippon Mining Co., 97% $[\alpha]_D^{25}$=+10.2) in bicyclohexyl (BCH, Aldrich 99%). For glass slides (8 x 8 x 1 mm), the typical volume ratios of the three components used in the coating process varied from DTS:EDC:BCH=1:5:1995 to 1:50:1990. For silicon crystals (45°, 25 x 10 x 2 mm) the typical volume ratios were DTS:EDC:BCH=1:1:1000. For the silica microspheres (0.2 μ average diameter), we have used 200 mg of particles per 20 ml solution whose volume ratio was DTS:EDC:BCH=1:1:10,000. The latter concentration ratio is required for the formation of sufficient voids which have been formed by the removal of EDC from the coatings. Increasing concentration of the physically adsorbed molecules (EDC) resulted in the formation of too bulky voids which were not suitable for the enantiomeric enrichment. Extraction of the optically active EDC monolayers was performed by immersing the coated substrates in chloroform. For example, the extraction of EDC from the monolayer coated silica microspheres was accomplished by rinsing the particles six times with chloroform and then once with a 1:1 (v:v) ethanol:chloroform solution. The whole process took place at room temperature and the particles were separated by centrifugation. For the glass slides and the silicon crystals, the extraction of EDC was carried out by soxhleting in chloroform for 6 h. The kinetics of the extraction process was followed by advancing water contact angle measurements and by ATR (Attenuated Total Reflection)-FTIR measurements. For the glass slides coated with the 1:5 DTS:EDC concentration ratio, the advancing contact angle of the fully coated slides was 107°±2° and for the slides with voids 103°±2°. For the 1:50 DTS:EDC coated glass slides, the fully coated slides showed advancing water contact angles of 97°±2° and the presence of the voids changed it to 91°±2°. These measurements were carried out with at least 10 different glass slides. Each measurement is an average of 3 readings taken at different locations on each slide. These consistent differences in the advancing water contact angles between the fully coated slides and the coatings after extraction of the EDC may indicate the higher homogeneity of the former coatings. Also, the absorption peak intensity of the methylene vibration band at ca. 2920 cm^{-1} of the fully coated silicon crystals was approximately 5-10% higher than that obtained after generating the voids. Refilling the voids in the coatings was accomplished by immersing the substrates in ethanol solution containing the dl-(±)-1,2 epoxydodecane (Aldrich, 97%) in 1:2000 volume ratio. The water advancing contact angles and the IR absorption peak at ca. 2920 cm^{-1} of the refilled coatings were similar to their values before the removal of EDC. The significant differences observed in the IR spectra of coatings onto a Si ATR crystal prepared from different DTS:EDC concentrations' ratio after generating the voids in the coatings by EDC extraction is demonstrated in Fig. 1. For example, the peak absorbance intensities at ca. 2920 cm^{-1} for coatings prepared from 5:1 DTS:EDC, 1:1 DTS:EDS and 1:5 DTS:EDC were 0.0256, 0.0226 and 0.0189, respectively. The decrease in the peak intensity at ca. 2920 cm^{-1} shows that the higher the relative concentration of the EDC in the coating solutions, the lower the absorbance of the methylene moiety of the coatings. This may be explained by the successful removal of the EDC from the coatings by the extraction process. Both the contact angle results and the ATR-FTIR results hereby demonstrated may be interpreted as an indication for the creating of cavities in the homogeneous DTS coatings.

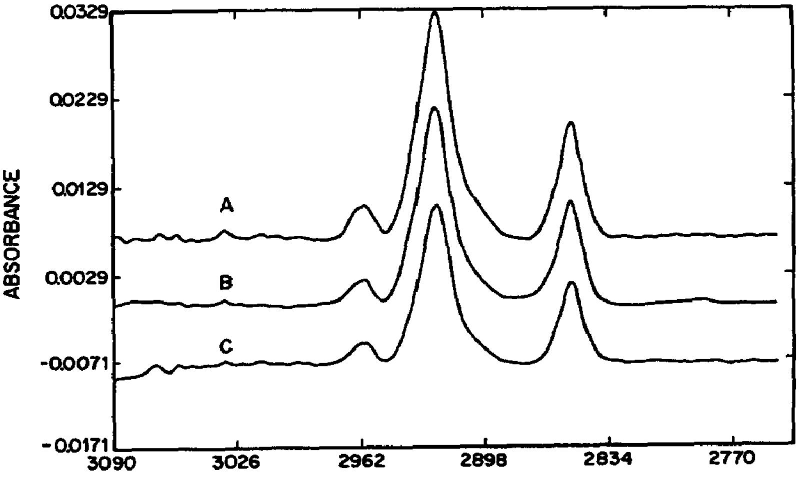

Fig 1 ATR-FTIR spectra of coatings prepared from 5:1 DTS:EDC(A), 1:1 DTS:EDC(B) and 1:5 DTS:EDC(C) onto a Si ATR crystal, after generating the voids in the coatings by EDC extraction

Quantitative experiments demonstrating the enantiomeric excess by gas chromatographic analysis could be accomplished only with silica microspheres (200 mg microspheres of 0.2 μ average diameter) due to their high surface area. In order to check whether the voids are chiral, silica microspheres were coated with the mixture of EDC (the R-(+) enantiomer only) and DTS according to the above mentioned concentration ratio. The optically active EDC was then washed out by soxhleting with chloroform After refilling the voids with racemates, the EDC was extracted using a chloroform solution. This process of refilling with racemate and rinsing with a chloroform solution was repeated 5-10 times. The rinses were collected after each stage of extraction. The analyte assembled was evaporated to ~10% of its original volume and examined by gas chromatography using a Chirasil-Nickel column. The observed results are presented in Fig. 2 and demonstrate an enantiomeric excess of 17%. The mixture was enriched in the R-(+) enantiomer which shows the chiral recognition of the voids.

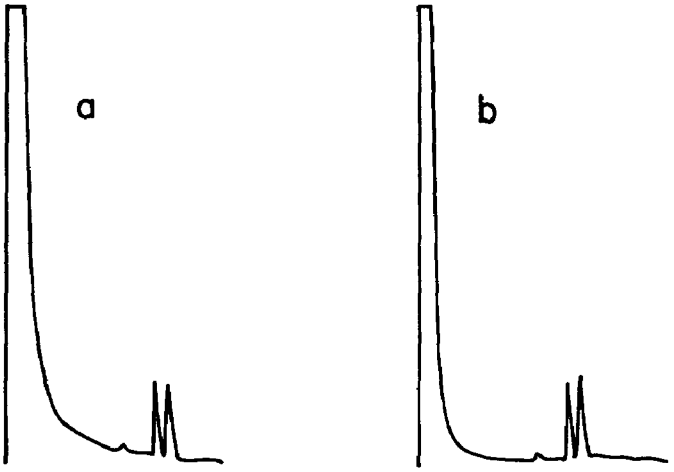

Fig. 2. The chromatogram of (a) a racemic solution 1,2 epoxydodecane; (b) an ethanol solution containing the 1,2 epoxydodecane extracted from the coated microspheres. The column used for the separation is fused silica capillary 5m x 250 μm, Chirasil-Nickel 0.2 μm. The temperature: 115°C carrier gas:He, 0,3 bar. The results shown that the R:S concentration ratio was changed from 1:1.05 for the racemate to 1:0.71 for the extracted solution, respectively.

This communication presents preliminary results. The described methods for preparation of chiral voids for racemate separation is analogous to the molecular imprinting technique[13-15] wherein polymerization is allowed to occur in the presence of a chiral substrate whose recognition is desired. Further studies in this area are ongoing in our laboratories.

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