A Rheological and SAXS Study of the Lamellar Order in a Side-on Liquid Crystalline Block Copolymer

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ABSTRACT: We study the structure and shear flow behavior of a side-on liquid crystalline triblock copolymer, named PBA-*b*-PA444-*b*-PBA (PBA is poly(butyl acrylate) and PA444 is a poly(acrylate) with a nematic liquid crystal side-on mesogen), in the self-assembled lamellar phase and in the disordered phase. Simultaneous oscillatory shear and small-angle X-ray scattering experiments show that shearing PBA-*b*-PA444-*b*-PBA at high frequency and strain amplitudes leads to the alignment of the lamellae with normals perpendicular to the shear direction and to the velocity gradient direction, i.e., in the perpendicular orientation. The order-to-disorder transition temperature (T_{ODT}) is independent of the applied strain, in contrast to results reported in the literature for coil-coil diblock copolymers, which show an increase in T_{ODT} with shear rate. It is possible that in our system, T_{ODT} does not depend on the applied strain because the fluctuations are weaker than those present in coil-coil diblock copolymer systems.

Introduction

Block copolymers composed of both liquid crystalline (LC) and isotropic blocks are attractive candidates for the development of new functional materials, such as smart or responsive materials and electrooptical systems, because the block copolymers tend to selfassemble into ordered micrometer or nanometer sized domains, while special functionalities can be introduced via the liquid crystalline parts into the micro- or nanostructures. In our previous work,¹ we have reported an artificial muscle made from an isotropic/nematic/ isotropic triblock copolymer, according to the model proposed by de Gennes. $^{2-4}$ The morphology of this material consists of a stack of side-on nematic polymer N and cross-linked elastomer R domains, i.e., a lamellar phase of the triblock copolymer. The elastomer block R was made by cross-linking the isotropic layer after obtaining an aligned lamellar phase (Scheme 1). The motor for the contraction/elongation is the reversible macromolecular shape change of the chain, from stretched to spherical, that occurs at the nematic to isotropic phase transition in side-on liquid crystalline polymers. Here, the alignment of the sample into a monodomain is an important issue, because only in this kind of monodomain sample are macroscopic contraction and elongation possible. The alignment includes that of the lamellar phase and of the nematic structure in the sublayer. In our previous studies,^{1,5} a magnetic field was used for the alignment of the triblock copolymer sample. The long axes of the rodlike mesogens aligned



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Scheme 1. Striated Artificial Muscle Based on a Side-on Liquid-crystalline Triblock Copolymer RNR in a Lamellar Phase, with a Suitable Cross-Linked Elastomer Block R,¹ Where H Indicates the Magnetic Field

H		H		H		H	
H		H		H		H	
Ŧ		+++		+++	22	41	
R	N	R	N	R	N	R	N
							→Ħ

parallel to the magnetic field because the aromatic units are diamagnetic. The lamellar phase was also aligned with layer normal parallel to the magnetic field (Scheme 1). The motivation of the present work was to explore the possibility to align the side-on liquid crystalline triblock copolymer using a shear field instead of a magnetic field. Oscillatory shear was applied to the triblock copolymer sample and small-angle X-ray scattering (SAXS) experiments were simultaneously carried out. It was shown that shearing the side-on nematic triblock copolymer at high frequency and strain amplitudes leads to alignment of the lamellae with normals along the neutral direction (so-called "perpendicular orientation", Scheme 2a). The nematic structure in the sublayer was partly oriented, as observed by a wideangle X-ray scattering (WAXS) experiment on a sample recovered following the shear experiments. The rheological response was also investigated in detail.

Experimental Section

1. Material. The side-on liquid-crystalline block copolymer, named PBA-*b*-PA444-*b*-PBA (Scheme 3), was synthesized and characterized according to methods described previously.⁵ The nematic block PA444 has $M_n = 17000$ (degree of polymerization = 27) and $M_w/M_n = 1.03$; the triblock copolymer PBA-*b*-PA444-*b*-PBA has $M_n = 33200$ (weight ratio of nematic block to isotropic block is 51/49) and $M_w/M_n = 1.37$. The homopoly-

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Scheme 2. Shear Alignment Geometries: (a) Perpendicular, (b) Parallel, and (c) Transverse







PBA-b-PA444-b-PBA



mer PA444 is a nematic polymer with a nematic-isotropic phase transition $T_{\rm N-I}$ at 115.5 °C upon heating and 113.5 °C upon cooling (these correspond to peak values in DSC thermograms recorded at 10 °C min⁻¹; DSC thermograms are given in the Supporting Information). Similar transitions, but at lower temperatures, were observed for the PA444 block in the triblock copolymer: 95.7 °C upon heating and 93.8 °C upon cooling. The small differences in transition temperatures on heating and cooling in DSC are due to thermal lag at the ramp rate employed. All transition temperatures are listed in Table 1. In the triblock copolymer sample, the nematic-to-isotropic transition ($T_{\rm N-I}$) of the LC block corresponds to the order-todisorder transition $T_{\rm ODT}$ of the self-assembled lamellar phase.⁵

2. SAXS and Oscillatory Shear Experiments. Experiments were performed on station 16.1 at the Synchrotron Radiation Source, Daresbury Lab, Daresbury, U.K. The wavelength was $\lambda = 1.41$ Å. Data were collected on a two-dimensional gas-filled area detector (RAPID). The wave vector scale q (= 4π (sin θ)/ λ , where 2θ is the scattering angle) was calibrated using a specimen of wet collagen (rat-tail tendon). Samples were studied under oscillatory strain using a modified Rheometrics solid analyzer RSA II system with shear sandwich geometry. This experimental setup is described in detail elsewhere.⁶ The shear sandwich cell comprises three brass plates, each with a central aperture to allow for X-rays transmission. The apertures are covered with Kapton and the two external plates are fixed, while the central piece oscillates

 Table 1. Transition Temperatures Obtained by DSC

 Analysis at 10 °C min⁻¹

polymer		$T_{\mathrm{Cr-N}^{a}}$ or T_{g} (°C) (LC polymer or block)	$T_{\mathrm{N-I}}{}^{a}$ (°C)
PA444	heating	52.7	115.5
ΡΒΔ_Α-ΡΔΛΛΛ_Α-ΡΒΔ	cooling	38.7 ⁶ 38.0	113.5 95.7 ^c
1 DA-0-1 A444-0-1 DA	cooling	28.0^{b}	93.8^{c}

 a $T_{\rm Cr-N}$ and $T_{\rm N-I}$ were taken as peak temperatures in DSC thermograms. $T_{\rm Cr-N}$ is the crystalline to nematic phase transition temperature. b $T_{\rm g}$ were measured upon cooling. No recrystallization was observed when cooling at 10 °C min^{-1}. c In the triblock copolymer, $T_{\rm N-I}$ of the LC block corresponds also to the $T_{\rm ODT}$ of the self-assembled lamellar phase.



vertically. The sample is loaded on both sides symmetrically about the insert piece. This shear geometry defines three perpendicular directions in space, i.e., the vectors \mathbf{v} , \mathbf{e} , and $\nabla \mathbf{v}$ which correspond to the shear direction, the neutral direction, and the velocity gradient direction respectively (see Scheme 4). The shear sandwich plates are perpendicular to the X-ray beam which is incident along $\nabla \mathbf{v}$, so that the (\mathbf{v} , \mathbf{e}) plane is accessed in SAXS experiments. Shear experiments were performed for temperatures between 33 and 113 °C.

The data from the two-dimensional area detector were finally converted into one-dimensional intensity profiles by radial integration, corresponding to the intensity $I_{\rm H}(q)$, or by azimuthal integration in a circular band enclosing only the first-order scattering peak, corresponding to the azimuthal intensity $I_{\rm A}(\phi)$ (ϕ = azimuthal angle).

3. WAXS Experiments. It was not possible to make WAXS experiments simultaneously while shearing the sample or insitu just after shearing the sample. A small sheet of sample (sheared at A = 70% and $\omega = 100$ rad s⁻¹) was recovered and measured by WAXS, at room temperature, several days after the shearing experiment, using Cu K α radiation ($\lambda = 1.54$ Å) from a classical rotating anode generator. The X-ray beam was incident along the initial $\nabla \mathbf{v}$ direction. The data from the two-dimensional imaging plate (\mathbf{v}, \mathbf{e}) were finally converted into one-dimensional intensity profiles by integration in a circular band enclosing the diffraction peak (azimuthal intensity $I_A(\phi)$).

Results

1. Oscillatory Shear Results at Low Amplitude and Low Frequency. Initial strain sweep experiments on PBA-*b*-PA444-*b*-PBA, performed at 70 °C for $\omega = 1$ rad s⁻¹, show that the linear viscoelastic regime extends up to a strain amplitude A = 2% (Figure 1). This is similar to the behavior of other types of polymers including side-chain LC polymers.⁷

To determine the order-disorder transition temperature of PBA-*b*-PA444-*b*-PBA via shear rheometry, the dynamic moduli were measured on heating from 34 to 131 °C, at a rate of 1 °C min⁻¹. The strain amplitude was A = 1%, and the frequency was $\omega = 1$ rad s⁻¹



Figure 1. Strain sweep experiments performed with $\omega = 1$ rad s⁻¹ at 70 °C (*G*' (\bullet); *G*'' (\bigcirc)).



Figure 2. Increasing temperature ramp for storage modulus $G''(\blacksquare)$ and loss modulus $G''(\Box)$ measured with $\omega = 1$ rad s⁻¹ and A = 1%. The arrow points the direction of the temperature ramp. The dotted lines mark the phase transition temperatures.

(Figure 2). Both dynamic moduli steadily decrease with increasing temperature over the range of temperatures accessed. The storage modulus G' is higher than the loss modulus G'' for temperatures in the range 34-58.5 °C. A crossover is observed at 58.5 °C. As the crossover will depend on ω , this is not an accurate measurement of the glass transition temperature $T_{\rm g}$. Between 58.5 and \sim 92 °C, we observe G'' > G', in good agreement with a liquid crystal phase. However, for temperatures higher than 92 °C, the data have poor statistics, probably due to the softening of the sample in the isotropic phase. Indeed, the data in Figure 2 suggest that the lamellar order–disorder transition temperature corresponds to $T_{\rm ODT} \sim$ 92 °C, in good agreement with DSC (Table 1).

Time-temperature superposition of the measured moduli was performed in the lamellar phase, between 70 and 90 °C (reference temperature $T_0 = 70$ °C), to facilitate comparison of the frequency response at different temperatures. Motivated by previous work,^{8,9} we attempted to perform time-temperature superposition of the storage and loss moduli for several temperatures in the lamellar phase region, by shifting only the ω -coordinate by a temperature-dependent shift factor¹⁰ $a_{\rm T}$ (Figure 3a). The results in Figure 3a show a breakdown in time-temperature superposition at low fre-



Figure 3. (a) Frequency superposition for PBA-*b*-PA444-*b*-PBA. Storage modulus *G'* measured at (●) 70, (■) 75, (▲) 80, (▼) 85, and (◆) 90 °C and loss modulus *G''* measured at (○) 70, (□) 75, (△) 80, (▽) 85, and (◇) 90 °C. The strain amplitude was fixed to *A* = 1%. The inset shows the temperature dependence of the frequency shift factor *a*_T. (b) Storage modulus *G'* (●) and loss modulus *G''* (○) as a function of frequency were measured at 75 °C. The full lines show the fitting according to *G'* ~ $\omega^{0.36}$ and *G''* ~ $\omega^{0.58}$.

quency, as previously reported for microstructural materials such as block copolymers¹¹ and side-chain LC polymers.⁷ A broad relaxation in *G*" is apparent at around $\omega = 1$ rad s⁻¹. This may be related to the chain dynamics in lamellar block copolymer structure since a similar relaxation was not observed for nematic side-chain LC homopolymers although it is observed in the lamellar phase,^{7–9} or it might be related to the "side-on" tethered nature of the mesogens.

The terminal behavior of the dynamic moduli shown in Figure 3a was fitted according to $G' \sim \omega^{\alpha}$ and $G'' \sim \omega^{\beta}$. Figure 3b shows a representative result obtained at 75 °C. The fits show that the coefficients α and β were nearly independent of the temperature and had average values $\alpha = (0.33 \pm 0.09)$ and $\beta = (0.56 \pm 0.07)$ respectively. It is interesting to note that the frequency sweeps in Figure 3a do not show the $G' \sim G'' \sim \omega^{0.5}$ scaling expected for a randomly oriented lamellar phase.^{11–13} Figure 3a also suggests that the highfrequency dynamic mechanical response is relatively insensitive to temperature in the lamellar phase. This is consistent with the fact that the high-frequency response arises from local chain dynamics.

2. Combined Oscillatory Shear and Simultaneous SAXS Investigations at High Frequency. To obtain additional information about orientation of the



Figure 4. Dependence of $I_{\rm H}(q)$ on temperature for a cooling ramp between 110 and 80 °C at 1 °C min⁻¹, using A = 0.2% and $\omega = 100$ rad s⁻¹.



Figure 5. Dependence of (a) the full width at half-height, Δq , and (b) the spacing, *d*, determined from the fitting of the first scattering peak in Figure 4 with a Lorentzian function. The arrows point the direction of the temperature ramp.

microstructure, simultaneous SAXS and shear flow experiments were performed. First, the location of $T_{\rm ODT}$ was confirmed. The memory of the sample orientation was erased by heating to 110 °C, in the disordered phase, with a strain amplitude A = 0.2% and a frequency $\omega = 100$ rad s⁻¹. Figure 4 shows a series of SAXS $I_{\rm H}(q)$ profiles for an un-oriented sample during a cooling ramp (with no shear alignment, A = 0.2%) from 110 to 80 °C at 1 °C min⁻¹. The first-order scattering peak shown in Figure 4 was fitted using a Lorentzian function, with a full width at half-height Δq and peak position q^* . Δq and the spacing $d = 2\pi/q^*$ are shown in Figure 5, parts a and b, respectively, as a function of the temperature. The transition temperature, $T_{\rm ODT}$ was



Figure 6. Dependence of $I_{\rm H}(q)$ on temperature for a cooling ramp between 110 and 80 °C at 1 °C min⁻¹, using A = 30% and $\omega = 100$ rad s⁻¹.



Figure 7. Dependence of $I_{\rm A}(\phi)$ on temperature for a cooling ramp between 110 and 80 °C at 1 °C min⁻¹, using A = 30% and $\omega = 100$ rad s⁻¹ (same series of data as in Figure 6).

determined through a pronounced sharpening of the first scattering peak at q^* (i.e., a large increase of correlation length) with the simultaneous appearance of a second-order scattering peak at $2q^*$. Figure 5a shows that Δq has a sudden decrease at $T_{\rm ODT} = 94.5$ °C which is in good agreement with the value measured by DSC, while a second-order scattering peak was detected in the SAXS curves in Figure 4 for T < 94.5 °C. Surprisingly, d exhibits a maximum at $T \sim 94.5$ °C continuously decreases down to 92 °C and increases again for lower temperatures (Figure 5b).

In previous work, it has been shown that $T_{\rm ODT}$ of conventional (i.e., without mesogenic moieties) block copolymers shifts under the application of large-amplitude oscillatory shear (LAOS).¹⁴ To study the dependence of $T_{\rm ODT}$ on applied strain, a series of cooling ramps from 110 to 80 °C at 1 °C min⁻¹ were made while LAOS was applied with a fixed $\omega = 100$ rad s⁻¹ and A = 10, 30, 60, and 70%. Figures 6–9 show representative SAXS data obtained for A = 30%. Figures 6 and 7 show the intensity profiles corresponding to $I_{\rm H}(q)$ and $I_{\rm A}(\phi)$, respectively. A typical two-dimensional SAXS diffraction pattern is shown in Figure 8.

The temperature dependence of the full width at halfheight, $\Delta \phi$, and the maximum position, ϕ^* , obtained by fitting with a Lorentzian function the central scattering peak in $I_A(\phi)$ (Figure 7), are shown in Figure 9, parts a and b, respectively. Figure 9c shows the variation with temperature of the spacing *d*, obtained from the fitting



Figure 8. Data obtained during shear of PBA-*b*-PA444-*b*-PBA at 84 °C, using a frequency $\omega = 100 \text{ s}^{-1}$, and associated strain amplitude A = 30%. SAXS pattern in the (**v**, **e**) plane (same data as for Figures 6 and 7).

of the first scattering peak in Figure 6, with temperature.

According to Figure 7, as denoted by the appearance of a scattering peak in the SAXS profile, a strain A = 30% is enough to orient the layers in the lamellar phase under shear. Therefore, in this experiment, $T_{\rm ODT}$ was defined as the highest temperature at which there is a preferential alignment of the lamellar layers under shear. According to Figures 6 and 7 $T_{\rm ODT} = 94.5$ °C.

Figure 8 shows the SAXS diffraction pattern in the lamellar phase: two scattering peaks symmetrically positioned along the equatorial direction \mathbf{e} , indicate that the lamellae adopt the "perpendicular orientation" (Scheme 2a), since they are oriented perpendicularly to the (\mathbf{v}, \mathbf{e}) plane, with their normals along the \mathbf{e} direction.

Figure 9a shows that the mosaic spread of the lamellar order decreases with decreasing temperature, reflecting an improvement of the alignment in the system. Figure 9b shows that the layer normals in the (\mathbf{v}, \mathbf{e}) plane are tilted at $\sim 6^{\circ}$ with respect to the \mathbf{e} direction at low temperatures in the lamellar phase, probably because the shearing direction is not perfectly parallel to the meridian of the X-ray detector.

Finally, similar to the results in Figure 5b (obtained during cooling without LAOS), d exhibits a maximum at $T_{\text{ODT}} \sim 94.5$ °C, continuously decreases down to 92.5 °C, and increases again for lower temperatures (Figure 9c).

Figure 10 shows the dependence of the dynamic moduli with the temperature measured during a cooling ramp from 110 to 80 °C at 1 °C min⁻¹, for a fixed $\omega = 100$ rad s⁻¹ and A = 10 and 30%. It is noteworthy that the temperature dependence of G' and G'' is similar to that exhibited by d (Figure 9c), but shifted by ~2.0 °C; i.e., the viscoelastic data presents a maximum at 96.5 °C and continuously decreases down to ~95 °C, increasing again for lower temperatures. It should be considered however that T_{ODT} located by shear rheometry can depend on frequency. T_{ODT} determined by SAXS is based on disordering of the structure and is more accurate.



Figure 9. Dependence with temperature of (a) $\Delta \phi$ and (b) ϕ^* , obtained from the fitting of $I_A(\phi)$ in Figure 7 with a Lorentzian function and (c) dependence with temperature of the spacing *d* determined from the fitting with a Lorentzian function of the first-order scattering peak in Figure 6. The arrows point in the direction of the temperature ramp.



Figure 10. Temperature dependence of the elastic moduli measured for a fixed $\omega = 100 \text{ rad s}^{-1} \text{ and } A = 10\% (G'(\blacksquare), G''(\bullet))$ or A = 30% (G'(□), G''(○)). The arrow points in the direction of the temperature ramp.

Figures 9 and 10 provide information on the alignment of the lamellae under shear. Although the sample forms lamellae for temperatures immediately below T_{ODT} , the mosaic spread is still relatively high (Figure 9a) and the orientation of the lamellar planes is very



Figure 11. Dependence of T_{ODT} with the applied strain at a fixed frequency $\omega = 100$ rad s⁻¹.

different from the equilibrium configuration under shear (Figure 9b). To evolve toward its equilibrium configuration under shear, the system needs to adopt an initial configuration associated with the lowest energy process of alignment under flow. This configuration apparently corresponds to a "thinning" of the lamellae (decrease in d for $T < T_{\text{ODT}}$, Figure 9c) with an associated softening of the sample (reduction of the dynamic moduli for $T < T_{\text{ODT}}$, Figure 10) and eases the orientation of the sample under shear toward an equilibrium configuration (i.e., perpendicular lamellae).

Results similar to those presented in Figures 6–9 were also found for a fixed $\omega = 100$ rad s⁻¹ and A = 10, 60, and 70% (Figure 11), leading to the conclusion that $T_{\text{ODT}} \sim 94.5$ °C is independent of the applied strain for a cooling ramp within the range of strains investigated in this work. This is in contrast with previous reports for coil block copolymers,^{14,15} where an increase in T_{ODT} with shear rate (not strain) is ascribed to the suppression of composition fluctuations under shear. It is apparent that this does not occur in our system, probably because the fluctuations are weaker than those present in coil-coil diblocks.

At this stage, it might be useful to compare the information given by Figures 2 and Figure 10. It appears that the order-disorder transition temperature can be identified more easily from the temperature ramp of the "dynamic moduli" measured in the non-linear regime (Figure 10) than from the temperature ramp of the dynamic moduli measured in the linear regime (Figure 2). This is probably due to the alignment of the lamellar phase under shear at A = 30% and $\omega = 100$ rad s⁻¹. It has been shown elsewhere that the dynamic moduli are more strongly (frequency, temperature) dependent for shear-aligned lamellar or cylindrical samples.^{16,17}

It is also possible at this stage to use our results in the evaluation of the potential application of PBA-*b*-PA444-*b*-PBA to construct an artificial muscle. The "perpendicular orientation" (Scheme 2a) obtained under shear is essential to prepare an artificial muscle. In the "perpendicular orientation" the layer normal is parallel to the large surfaces of the sample sheet, similarly to the case of the alignment by magnetic field (Scheme 1).¹ In addition, the degree of alignment of the layer normal relative to the **e** direction obtained by shear field, $\Delta \phi =$



Figure 12. Azimuthal intensity profile of WAXS in the (\mathbf{v}, \mathbf{e}) plane for a sample recovered from oscillatory shearing.

12° at T = 85 °C (Figure 9a), is close to the degree of alignment obtained by magnetic field, $\Delta \phi = 10^{\circ}$ at room temperature.⁵

Our previous studies⁵ and the results in this study (Figure 5b and Figure 9c) have shown that the lamellar spacing decreases with increasing temperature especially around T_{ODT} . That result suggests that with suitable cross-linking, a significant contraction might be observed along the **e** direction in a sample sheet with a "perpendicular orientation", when the sample is heated into the disordered phase.

From the two paragraphs above we can conclude that a shear field can be used to align the triblock copolymer PBA-*b*-PA444-*b*-PBA with the aim of preparing artificial muscles. The advantage of using a shear field instead of a magnetic field to align a sample sheet in the "perpendicular orientation" is that the sample sheet size used in the shear flow experiment can be made larger than that used in the magnetic field experiment, because it will not be constrained by the distance between the poles of the electromagnet used for the magnetic field experiment.

3. WAXS Results with Recovered Sheared Sample. A broad circular pattern was obtained by WAXS. The lateral distance between mesogens in the nematic sublayer gives rise to a broad scattering ring corresponding to a range d = 4-5 Å with average $\bar{d} =$ 4.4 Å. There is a slight anisotropy of the broad ring, with its maximum along the v direction. The analysis of the angular profile of the broad ring (Figure 12) shows that the LC sublayer is partly aligned. Some mesogens are aligned along the e direction (as the supramolecular layer normal) with a nematic order parameter $S\sim 0.3$ (according to the approach described in ref 18),¹⁸ while the remaining part is not aligned. Note that WAXS experiment is not made in situ. The rather poor alignment may possibly be due to the deterioration of the orientational order resulting from the recovery process and the time delay between the oscillatory shearing/ SAXS experiment and the WAXS measurement.

Summary

Time-temperature superposition of the measured moduli in the lamellar phase, although being acceptable at high frequency, breaks down at low frequency, as previously reported for microstructured materials such as block copolymers¹¹ and side-chain LC polymers.⁷

The temperature dependence of the shear moduli provided $T_{\rm ODT} \sim 92$ °C, in good agreement with DSC results. In addition, the study of the SAXS pattern characteristics for a sample under shear flow submitted to a cooling ramp indicated $T_{\rm ODT} \sim 94.5$ °C. The value of $T_{\rm ODT}$ determined from simultaneous shear/SAXS experiments remained constant independent of the strain applied, in contrast with previous reports for coil-coil block copolymers.

It was observed that during a cooling ramp, the spacing *d* exhibits a maximum at T_{ODT} , continuously decreases for the next ~3 °C and increases again for lower temperatures. This behavior was explained in terms of an initial configuration of the system during the shear flow alignment process in the lamellar phase.

From simultaneous oscillatory shear and SAXS experiments, we showed that shearing PBA-*b*-PA444-*b*-PBA at high frequency and strain amplitudes (i.e., $\omega = 100 \text{ rad s}^{-1}$ and A = (10-70%)) leads to a perpendicular orientation of lamellae (Scheme 2a). It should be noted that there is the possibility that a fraction of the lamellae is aligned in the "parallel orientation" (Scheme 2b). This cannot be resolved without data from diffraction planes other than (\mathbf{v}, \mathbf{e}) which were inaccessible in our experiment. Nevertheless, the "transverse orientation" (Scheme 2c) is excluded based on the SAXS pattern in the (\mathbf{v}, \mathbf{e}) plane (see Figure 8).

Our results confirm that the shear field can be used to align the triblock copolymer PBA-*b*-PA444-*b*-PBA with the aim of preparing artificial muscles. Therefore, efforts will be made to improve and characterize the nematic alignment in the LC sublayer.

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