Polymer dispersed light scattering polarizers

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Polymer Dispersed Light Scattering Polarizers

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Light Scattering Polarizers

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Summary

Polymeric sheet polarizers are nowadays widely used in liquid crystal display (LCD) applications. The commercial polarizers, produced from oriented polyvinylalcohol (PVAL) films containing dichroic dyes, have several disadvantages. They have a poor long term stability in humid environments and at elevated temperatures. This limits the applications of LCD's. Recently, polarizers based on polyolefins containing dichroic dyes have been produced, which have better properties according to these disadvantages.

All these dye containing polarizers absorb a part of the incident light. This causes the temperature of the polarizer to increase. If these polarizers are used in combination with high intensity light sources, the temperature of the LCD's will become too high.

Polarizers based on light scattering rather than absorbance will not have this drawback. These polarizers will also have the advantage of operating over the entire visible wavelength range, while absorbance based polarizers must contain several different dichroic dyes to achieve this effect, because each dye covers a relatively small wavelength range (100nm).

Recent research has shown that it is possible to produce such polarizers out of regular thermoplastic polymers on standard sheet extrusion equipment. The polarizers are produced by orienting a blend of two immiscible thermoplastic polymers. The blend becomes a polarizer when the ordinary or extraordinary refractive indices of the two polymers after orientation match each other. This thesis has been verified with a Polystyrene/Polybutadiene system. This system however is far from ideal, because the matching of refractive indices is very poor.

In this study a system made out of Polystyrene and Polycarbonate is explored, because it is expected that it is possible to get an exact matching with these materials. The Polystyrene rich blends however failed because of the appearance of voids during the orientation of the blend. The Polycarbonate blends failed because the refractive index of the used Polycarbonate differs from the index found in the literature, and the bad drawing properties of the blends.
Chapter 1

Introduction

1.1 Polymeric sheet polarizers

Polymeric sheet polarizers are widely used in liquid crystal display (LCD) applications. These LCD's are used in for example watches, dashboard display's, computer screens etc. Until now these polarizers are made of oriented polymer films containing dichroic dyes. In principle the polarizing effect is based on the absorbance of light by the oriented dichroic dye. The commercial polarizers are based on polyvinylalcohol (PVAL) as a host-polymer. PVAL however has a poor long-term stability in humid environments and at elevated temperatures. Research has shown that it is possible to make polarizers with polyolefins as a host-polymer. These polarizers show an enhanced durability in humid environments and at elevated temperatures. Still the polarizers based on light absorption have two big problems. First it is complicated to produce a polarizer which operates over the entire visible wavelength range. A dye molecule absorbs over a relatively small range of about 100 nm. Consequently to cover the entire visible wavelength range (400-700 nm) at least three different dyes are necessary. Secondly the absorbed light-energy is transformed into heat. This causes the temperature of the polarizer to go up. Therefore the polarizer cannot be used in combination with high-intensity lightsources, like for instance projection TV's.

1.2 Light scattering polarizers

Recently it has been shown that it is possible to make polarizers based on light scattering rather than absorbance. These
polarizers do not have the problems of operation over a selected bandwidth range and temperature increase. The light-scattering polarizers consist of a transparent matrix and a transparent dispersed phase. The oriented matrix is birefringent. This means that it has got a refractive index in the direction of orientation that differs from the index perpendicular to the direction of orientation. The refractive index of the dispersed phase should match the index of the matrix in one direction and mismatch the refractive index of the matrix in the other direction.

The development of light scattering polarizers has started with liquid crystal materials. The polarizers are manufactured by orienting a mixture of a reactive and a non-reactive liquid-crystalline material, after which the mixture is cured. After curing an oriented polymer network is formed in which the oriented non-reactive constituent is dispersed. These liquid crystal based polarizers have the following disadvantages:

- The compounds are expensive and not readily available.
- Only relatively small polarizers can be made and the technique is not suitable for industrial upscaling.

The next step was to make the polarizers out of convenient thermoplastic polymers, because they are commonly available cheap materials and can be processed on standard sheet extrusion equipment. Preliminary research on a Polystyrene (PS) / Polybutadiene (PB) system showed that it is possible to make such a thermoplastic polymer light scattering polarizer. This PS / PB system however has a poor polarizing quality. It is not possible to achieve a proper matching in the direction where matching is assumed. This limitation is a consequence of the materials selection.

The aim of this study is to investigate new blends which might have better polarizing qualities, while the advantages of a light scattering polarizer remain.
Chapter 2

Theory

2.1 Basic theory

Polymer dispersed light scattering polarizers are based on the principle of matching or mismatching of the refractive indices of the matrix and the dispersed phase. If there is matching in one direction, there should be mismatching perpendicular to this direction. If the direction of matching is in the direction perpendicular to orientation, we find: \( n_i^d = n_i^m \) and \( n_i^d \neq n_i^m \), as shown in Figure 2.1. In other words, the refractive indices perpendicular to the drawing direction match each other, while the indices parallel to the drawing direction do not match.

![Fig. 2.1: Operating principle of a light scattering polarizer](image)

As a result of this, the light perpendicular to the direction of orientation can travel without obstruction through the material. The light parallel to the direction of orientation however is scattered.
Theory

To get matching in one direction and mismatching in the direction perpendicular to this direction, at least one of the two materials must be birefringent. Birefringence occurs at molecular level if the molecules possess anisotropic binding forces, as in most polymer molecules. Because of these anisotropic binding forces there is anisotropic interaction with the electromagnetic field of the incident light wave.\textsuperscript{3,4} When the polymer molecules are oriented, the material becomes birefringent. The thermoplastic polymer based light scattering polarizers are oriented by drawing the blends. This causes the molecules to orientate in the direction of drawing.

The oriented polarizer functions as a polarizer for the incident light propagating in the direction perpendicular to the plane as depicted in Figure 2.2. Each natural light wave has an electromagnetic vector with a random direction in this plane. Each random oriented vector can be divided in a vector in the direction of orientation and a vector orthogonal to this vector (thus perpendicular to the direction of orientation),\textsuperscript{3} as shown in Figure 2.2.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{diagram.png}
\caption{Representation of incident light}
\end{figure}

Incident light with the electromagnetic vector perpendicular to the drawing direction will pass the polarizer without obstruction. Incident light with the electromagnetic vector parallel to the drawing direction will encounter a mis-match in refractive indices and will be scattered. After passing the
polarizer the light will be polarized with the electromagnetic
to in the direction perpendicular to the orientation
direction.
The polarizing quality improves when the difference \( n_i^d - n_i^m \) is
larger. The transparencies of the polarizer is optimal when the
difference \( n_i^d - n_i^m \) equals zero. The perfect polarizer should
scatter half the incident light and let through the other half
of the incident light. As a result of this the polarizer will
appear white/milky, because in the ideal situation still 50%
of the incident light will be scattered. The advantages of
such a polarizer are:

- The temperature does not increase as a result of the
  incident light, so it could also be used in combination
  with high intensity light sources
- Polarization is achieved over the entire visible wave-
  length, UV and infra-red range
- Long term stable in humid environments
- Producible on standard sheet extrusion equipment
- No requirement for the development of new dyes, which is
  a major drawback of the polyolefin/dye systems

2.2 Previous Research

Research has been done to see whether it is possible to produ-
ce such a polymer dispersed light scattering polarizer and to
explore possible new processes for the production of disper-
sive polarizers. The polarizer looked at consisted of a Polysty-
rene (PS) matrix and a Polybutadiene (PB) dispersed phase.\(^1\)
It was possible to obtain a birefringence value of -0.04 for the
PS after drawing. The absolute values for the refractive
indices were \( n_i = 1.56 \) and \( n_r = 1.60 \), whereas the refractive
index for isotropic PS is \( n_{iso} = 1.59 \).\(^1\)
A PS/PB (7.5% w/w) blend was compounded on a corotating twin-
screw extruder. The blend was compression moulded into thin
sheets. After drawing it could be observed that the PS/PB
films were dichroic. The intensity ratio was quantified as
Theory

the division of the absorbance perpendicular by the absorbance parallel to the drawing direction $A_\perp/A_\parallel$ (in fact the inverse of the dichroic ratio). In Figure 2.3, this intensity ratio is depicted as a function of the wavelength.

![Graph showing intensity ratio vs wavelength](image)

**Figure 2.3: Intensity ratio ($A_\perp/A_\parallel$) as a function of the wavelength for a drawn PS/PB blend.**

The polarizer covers the entire visible wavelength range, and is not restricted to the absorption peak of a dye, as in dye containing polarizers.

The research has shown that polarizers can be made out of regular thermoplastic materials. The choice for a PS/PB system however is not very good. For the ideal polarizer the intensity ratio should be nearly infinite or zero, while for the drawn PS/PB blend this ratio is about three. This can be explained by the differences in the refractive indices between the matrix and the dispersed phase:

$\Delta n_\perp = |n_{\perp}^{ps} - n_{\perp}^{pb}| = 0.04$

$\Delta n_\parallel = |n_{\parallel}^{ps} - n_{\parallel}^{pb}| = 0.08$

The mismatching is relatively large (0.08), but the matching is very poor (0.04). As a result of this the incident light with the electromagnetic vector parallel to the drawing direction will be partly scattered, even though scattering takes place to a much lesser extend than the light with the vector perpendicular to the drawing direction.
The aim of this study is therefore to investigate a polystyrene-based polarizer, containing an other dispersed phase, so there is nearly perfect matching. The dispersive phase should have a refractive index after drawing of 1.56 or 1.60, so there is matching in the direction parallel or perpendicular to drawing, respectively.

We choose Polycarbonate with n=1.60 as the dispersed phase. If Polycarbonate has good drawing capabilities, it could also function as a matrix with Polystyrene as the dispersed phase. This will also be investigated.
Chapter 3

Materials Selection

3.1 Introduction

The polymers to be used should meet several criteria:
- Immiscible
- The matrix should be highly birefringent after drawing
- The matrix should have good drawing properties
- After drawing there must be a direction in which the refractive indices of the matrix and the dispersed phase are (almost) the same
- $T_g$ between 100°C and 150°C, so the polarizer is suitable for use in applications with a temperature upto 100°C and can still be manufactured on regular sheet extrusion equipment.

We choose PS to be the matrix. We have seen that for the refractive indices of PS it can be found: $n_{iso} = 1.59$, $n_g = 1.56$ and $n_i = 1.60$. As dispersed material Polycarbonate (PC) complies with the demands mentioned above. The isotropic refractive index of PC is 1.60. There is a low compatibility at low PS contents. Still there are already two distinct phases at 1% PS. At low PC contents there is immediate phase separation. This means the materials are immiscible enough for application as a dispersed system.

As PC is positively birefringent, it can be expected that PC could also function as a matrix, with PS as the dispersed phase. Both systems (PS/PC as well as PC/PS) will be explored in this study.
3.2 Materials

PS/PC

PS has been used as a matrix before in the PS/PB system. Because the PS/PB blends had to be pre-oriented to prevent immediate failure, it can be expected that the PS-PC also has to be pre-oriented. We assume that the PC is not deformed after drawing. This can be checked after drawing with Scanning Electron Microscopy (SEM). If the PC particles are not deformed, the refractive index remains 1.60. This system should show matching perpendicular to the drawing direction, while the mis-matching in the direction parallel to drawing is 0.04.

![Figure 3.2: Principle of operation of polarizer manufactured from PS/PC. If PC is the matrix, PS could deform (dashed ellipsoid).](image)

PC/PS

As PC has a positive stress optical coefficient, PC is positively birefringent. This means that after uniaxial drawing of PC the refractive index in the drawing direction increases, while the refractive index perpendicular to this direction slightly decreases. If $n_{i}^{PC}$ decreases to the value of 1.59 and the refractive index of the dispersed PS does not change, there is matching perpendicular to the drawing direction.
To check which value $n_1^{PC}$ attains after drawing, first the drawing behavior and orientation of pure PC must be investigated. Next the drawing characteristics of the PC/PS blends will be explored.

If the PC/PS blend is drawn between 150 °C and 170 °C the dispersed PS should deform without orientation (as shown in Figure 3.2), because the drawing temperature $T_d$ is far above $T_g^{PS}$, as shown in Figure 3.3. As $T_g^{PC} = 148.5$ °C, the PC matrix will be oriented at this drawing temperature.\textsuperscript{8}
Chapter 4

Experimental

4.1 Blending

The blends were produced on a Haake kneader during 30 minutes at 200°C. The Polystyrene (DOW Styron 634, $M_w = 200$ Kg/mol) and Polycarbonate (Lexan 141, $M_w = 50$ Kg/mol, measured by GPC) were commercial materials. The PC was dried in a vacuum oven at 60°C. The blends were made in the compositions as mentioned in Table 4.1. All blends appeared transparent.

Table 4.1: Composition of the blends

<table>
<thead>
<tr>
<th>Material</th>
<th>%PS (w/w)</th>
<th>%PC (w/w)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PS/PC</td>
<td>95</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>80</td>
<td>20</td>
</tr>
<tr>
<td>PC/PS</td>
<td>20</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>95</td>
</tr>
<tr>
<td>PC</td>
<td>-</td>
<td>100</td>
</tr>
</tbody>
</table>

4.2 Compression Moulding

The blends were chopped into pieces with a maximum diameter of about 5mm. This granulate was dried again in a vacuum oven at 60°C. Thin sheets were compression moulded during 20 minutes at 200°C. The molten material was several times degassed by releasing the pressure. The sheets were quenched to room temperature.
Experimental

For the pure PC blends the aluminum foil was sprayed with a release agent, which was a teflon containing oil. Sheets were pressed with a thickness of 0.2 - 1 mm. The same was done for the PC rich blends. The blends with a PS matrix were pressed into the format of 150 x 150 x 3 mm.

4.3 Drawing

The drawing properties of the pure PC were investigated between 120 and 160 °C. In this temperature range the maximum draw ratio as well as the birefringence at \( \lambda = 2 \) as a function of the temperature was measured. Also the birefringence as a function of the draw ratio was determined. The samples were punched into a dumb-bell shaped specimens and drawn on a hot shoe. As a reference, the same was done with PC from DSM, which was delivered as a film, produced on a sheet extruder, with a thickness of 0.25 mm.

The PS rich sheets were cut into sections of 100 x 100 x 3 mm which were pre-drawn uniaxially constrained in an Iwamoto biaxially stretching frame at 120 °C, at DSM Geleen. From these pre-drawn sections dumb-bell shaped samples were punched. This was done in such a way that the pre- and post-drawing direction are the same. The samples were drawn on a tensile tester at a temperature of 100 °C, with a speed of 20 mm/s, in an oven that could reach temperatures up to 150 °C.

The PC rich sheets were drawn uniaxially constrained on the Iwamoto stretching frame. Again sections of 100 x 100 mm were cut out of the compression moulded sheets. The sections are drawn at temperature temperatures between 150 °C and 170 °C.

All draw ratios were measured as the displacement of ink marks printed onto the samples before drawing.
4.4 Characterisation

A Gel Permeation Chromatogram (GPC) before and after kneading an compression moulding of the lexan was taken, as well as from the extruded film from DSM. The refractive indices of the pure PC were measured before and after drawing with an Abbé refractometer. For the measurement of birefringence and trirefringence the refractive indices in the different directions were measured. The birefringence could be calculated as \(|n_\parallel - n_\perp|\). To measure the refractive indices in several directions a polarizer had to be added to the Abbé refractometer. The morphology of the blends before and after drawing as well as between pre-orienting and drawing was examined by SEM (Scanning Electron Microscopy) in a Cambridge Stereoscan 200 microscope at 20 kV accelerating voltage after gold sputter coating. The fractured surface of the blends before drawing were prepared by cryogenic fracturing. Samples of the drawn and pre-oriented blends were embedded in an epoxy resin which was cured to fixate the drawn samples. Thin sections were cut from the samples to obtain a smooth surface. The samples were cut in such a way that the surface is parallel to the drawing direction.
Chapter 5

Results and Discussion

5.1 Pure polycarbonate

Characterisation:
In Table 5.1 the GPC results of the PC samples are depicted. It can be observed that the PC retrieved from DSM has a higher molecular weight than the Lexan from DOW. The results for the Lexan 141 sheet are odd. As a result of degradation after mixing and compression moulding it is to be expected that the molecular weight should decrease instead of the found increase. This can be explained by the fact that for this experiment the Lexan is mixed in an old kneader which can not be properly cleaned. Probably the kneader is littered with heavy molecular weight molecules so the results for the Lexan 141 sheet are not reliable. It is however not likely that the Lexan has strongly degraded, for in that case $M_w$ would not have increased this much.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Lexan 141 granulate</th>
<th>Lexan 141 sheet</th>
<th>PC DSM film</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M_n$</td>
<td>22.3</td>
<td>24.5</td>
<td>33.8</td>
</tr>
<tr>
<td>$M_w$</td>
<td>49.2</td>
<td>64.4</td>
<td>65.5</td>
</tr>
<tr>
<td>D</td>
<td>2.21</td>
<td>2.63</td>
<td>1.94</td>
</tr>
</tbody>
</table>

It appeared that it is very important that the blends containing PC are properly dried after kneading. Otherwise the absorbed water will turn into steam during compression moulding. This causes gas bubbles in the sheets, which scatter the incident light.
Results and Discussion

Drawing properties:
In Figure 5.1 the maximum draw ratio is depicted as a function of the drawing temperature for Lexan and the PC from DSM. It can be observed that the maximal draw ratio untill failure of the sample for Lexan increases at temperatures above 140 °C, while this ratio for the PC from DSM increases above 160 °C. At 170 °C both materials are above $T_g$ and can be drawn to very high draw ratio's.

![Figure 5.1: Maximum draw ratio as a function of temperature](image)

The theoretical maximum draw ratio of PC is $2.1^\circ$. Lexan exceeds this value at temperatures over 140 °C, while the PC from DSM exceeds the maximum theoretical draw ratio at temperatures over 160 °C. This means the entanglements in Lexan show more slip than the entanglements of the PC from DSM at drawing temperatures between 150 °C and 170 °C. As a result of this the Lexan samples will be less oriented and so have a lower birefringent value than the DSM samples, at the same drawing temperature and draw ratio.

In figure 5.2 the birefringence is depicted as a function of the drawing temperature between 140 °C and 170 °C at a draw ratio of 2.
Results and Discussion

It can be concluded that the birefringent value of Lexan indeed strongly decreases at draw temperatures over 140 °C at the maximum theoretical draw temperature of 2 at drawing temperatures over 140 °C, while this decrease is much less strong for the PC from DSM under the same conditions.

![Graph showing birefringence as a function of drawing temperature at \( \lambda = 2 \)]

Figure 5.2: Birefringence as a function of drawing temperature at \( \lambda = 2 \)

At 140 °C both Lexan 141 and the PC from DSM have a maximal draw ratio of 2.4 and a birefringence of about 0.04 at \( \lambda = 2 \), as can be seen in Figure 5.1 and 5.2. In Figure 5.3 the refractive index in the drawing direction as well as the refractive index in the direction perpendicular to drawing are depicted as a function of the draw ratio. It was hard to get a wide draw ratio range for the Lexan, because the samples necked. At these spots the draw ratio increases almost immediately from 1 to 2. This phenomena appeared much less with the PC retrieved from DSM.

As Figure 5.3 shows the PC from DSM has a somewhat larger birefringent value (difference between \( n_l \) and \( n_s \)) than the Lexan PC at the same draw ratio. As we have only the Lexan 141 to our disposal in pellets form the blends will be made with this PC.
Results and Discussion

5.2 Polystyrene rich blends
drawing:
As all blends are transparent \( n_{\text{iso}}^\text{PC} \) must be almost the same as \( n_{\text{iso}}^\text{PS} \). We want matching in the direction perpendicular to the drawing direction. To achieve this, the refractive index of the matrix should remain \( n_{\text{iso}} \). This can be done by constrained drawing. In this case the displacement perpendicular to the drawing direction is constrained, so the refractive index in the direction perpendicular to drawing direction changes very little. This is the reason why the blends are drawn on a uniaxial constrained stretching frame. The tensile tester and hot shoe are only used to explore drawing properties. Because test samples failed immediately when drawn below \( T_g^\text{PS} \), the blends had to be pre-oriented above \( T_g^\text{PS} \). The uniaxial constrained pre-oriented samples are drawn to a draw ratio between 3.5 and 9. The pre-oriented samples are still transparent. This means that the concentration of dispersed particles is too low, or the mismatching of the refractive indices is too low. As even the blends with 20% PC (w/w) remains transparent, we assume that the mismatching of the refractive indices
Results and Discussion

is not enough to achieve a polarizing effect, which would cause the blends to appear white/milky.
To attain more orientation the pre-oriented samples must be drawn at temperatures below $T_g$. To explore the drawing properties of the pre-oriented PS-rich blends pre-oriented samples are uniaxially unconstrained drawn on a tensile tester. All samples drawn below 110 °C turn white at draw ratio's below 1.5 and no light can get through the samples. Still no polarizing effect can be observed.

Morphology:
In Figure 5.4 a, b and c SEM pictures of fracture surfaces of a PS/PC 90/10 w/w are shown before drawing, pre-drawn and after drawing, respectively. In Figure 5.4 a it can be seen that there is a clear phase separation. The maximal diameter of the dispersed PC increases from 1.6μm to 2.4μm for PC concentrations increasing from 5 w/w% to 20 w/w%. It seems that there is very little PS-PC interaction because some dispersed PC particles have been ripped out of the fractured surface without damaging the matrix.
Figure 5.4 b shows that in the pre-oriented samples the PC nodules are at some places detached from the matrix. After drawing at 100 °C the dispersed phase is a bit deformed and large voids appear, as can be seen in Fig 5.4 c.
Results and Discussion

Figure 5.4: Scanning Electron Micrographs obtained from PS/PC 90/10 blends
(a) before drawing (b) pre-oriented (c) after drawing

discussion:
The voids appear no matter what weight percentage PC. This explains why all drawn samples turn white before a draw ratio of 1.5 is achieved, when drawn at temperatures at or below $T_g$. The blends with high PC concentrations turn white at lower draw ratio's than the blends with less particles, because the concentration of voids is also high. The voids appear by drawing near or below $T_g$ because the dispersed phase deforms very little at the pre-drawing and drawing temperature and there is very little interaction between matrix and dispersed phase. These voids scatter the incident light, so the sample turns white and is no longer transparent. This means the PS/PC system can not function as a polarizer if produced in the described way.
5.3 Polycarbonate rich blends

drawing:
The PC rich blends are drawn uniaxial constrained for the same reason as the PS rich blends (the refractive index of the matrix and the dispersed phase are nearly the same). The sheets have to be pressed thinner than 3 mm, because otherwise the pneumatic clips of the stretching frame can not hold the samples. The thinner sheets however fail immediately at temperatures below 150 °C. The maximal draw ratio at 170 °C is 1.6.

morphology:
The PS particles have a maximum diameter of 1 μm for PS weight concentrations of 5% en 10%. The nodules in the blend with 20 w/w% PS have a maximum diameter of 1.7 μm. Figure 5.5 shows a SEM picture of cut surface of a drawn PC/PS blend. The PS particles in the drawn blends have indeed deformed into ellipsoids as predicted.

Figure 5.5: Scanning Electron Micrograph obtained from PC/PS 90/10 blend drawn at 168 °C, λ=1.4
Results and Discussion

discussion:
At temperatures above 150 °C and draw ratios below 1.5 the birefringent value is far too low to obtain a polarizing effect. This means a PC/PS polarizer can not be made on the used stretching frame. However the maximal birefringent value measured after unconstraint drawing for PC is 0.04. Even if it is possible to obtain this value on a constraint stretching frame, it is not likely that we have a good polarizer. This is because the refractive index of isotropic PC is not 1.60 as mentioned in the literature, but 1.584. As \( n_{iso}^{ps} = 1.59 \) and the refractive index of PC will slightly decrease (or remain the same if the drawing is ideal uniaxial constrained) in the direction perpendicular to drawing, the mismatch of the refractive indices in this direction will be at least 0.006. The maximal birefringent value of 0.04 we have achieved with unconstraint drawing will even be smaller with constrained drawing, because \( n_{l}(\lambda) \) increases in the same way as a function of \( \lambda \), while \( n_{s}(\lambda) \) remains almost \( n_{iso} \) instead of decreasing. If we assume \( \Delta n(max) \) to be 0.04, the maximal mismatch will be 0.034.
Results and Discussion

In the most fortunate case the matching and mismatching of the PC/PS system will be:

\[ \Delta n_1 (\text{max}) = |n_1^{\text{PS}} - n_1^{\text{PC}}| = 0.034 \]
\[ \Delta n_1 (\text{min}) = |n_1^{\text{PS}} - n_1^{\text{PC}}| = 0.006 \]

A schematic course of the refractive indices during the uni-axial constraint drawing is represented in Figure 5.6.

![Figure 5.6: Schematic representation of the refractive indices during drawing of the PC/PS system](image)

In the ideal case, the matching \( \Delta n_1 \) will do, but the mismatching is too small to have a good polarizer. The PC/PS system is, like the PS/PC not suitable to make a polarizer.
Conclusions and recommendations

Chapter 6

Conclusions and recommendations

From the results of this project it must be concluded that a blend made out of Polycarbonate and Polystyrene can not be fabricated into a polarizer with the used fabrication methods.

The blends with a PS matrix and PC as the dispersed phase failed as a result of voids which appear during drawing of the blend. As PC experiences very low shear as a result of the low interaction between PS and PC, and PC has a high elasticity coefficient at the drawing temperatures, there are tension concentrations at the nodules. As PS possesses a very poor thoughess, cracks develop and voids appear near the PC particles. These voids scatter the incident light, so the blend becomes white and can not function as a polarizer, even if the desired refractive index match/mismatch will be achieved.

The PC rich blends failed because the refractive index of Lexan 141 is lower than expected from the literature, the achieved maximal birefringent is relatively small, and the blends are hard to draw to a high draw ratio at a low drawing temperature.

Recommandations for systems to explore in the future are:
- Use a material which is easy to draw with a high maximal birefringent value as a matrix, so it is possible to achieve a proper matching and a severe mismatching (for instance PET).
- Use a material which is very easy to deform at the temperature at which the blend is drawn as the dispersed phase, so there is less concentration of tension at the nodules. This way it is less probable that voids appear.
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