Melt-Processed, Electrically Conductive Ternary Polymer Blends Containing Polyaniline

M. ZILBERMAN, A. SIEGMANN & M. NARKIS


To link to this article: http://dx.doi.org/10.1081/MB-100100389

Published online: 16 Aug 2006.
Melt-Processed, Electrically Conductive Ternary Polymer Blends Containing Polyaniline

M. ZILBERMAN, A. SIEGMANN, \(^1\) and M. NARKIS\(^2,\) *

\(^1\) Department of Materials Engineering and
\(^2\) Department of Chemical Engineering
Technion—Israel Institute of Technology
Haifa 32000, Israel

ABSTRACT

Conductive binary and ternary blends containing polyaniline (PANI) were developed through melt blending. The investigation of the binary blends focused on their morphology in light of the interactions between their components and on the resulting electrical conductivity. Similar solubility parameters of PANI and a constituting polymer lead to a fine PANI particle segregated dispersion within that polymer and to the formation of conducting paths at low PANI contents. In ternary blends consisting of PANI and two immiscible polymers, the PANI preferentially locates in one of the phases due to increased interactions between PANI and the preferred polymer. This concentration magnification effect leads to increased electrical conductivity at lower PANI nominal contents. The electrical conductivity of a ternary blend is mainly determined by the effective PANI content in the preferred phase, by the level of PANI fracturing in this phase, and by the details of the conductive network structure created in the co-continuous structure blend.

Key Words. Melt processing, Polyaniline blends, Ternary polymer blends.

INTRODUCTION

Research studies dealing with polyaniline (PANI) have recently focused on electrically conductive blends consisting of various types of doped PANI dispersed in polymer matrices. In most studies of electrically conductive blends containing PANI, blending
was performed in a solution. Only a few studies concerning melt processing have been reported [1–8]. Shacklette et al. [1] reported that Versicon™ (Allied-Signal, Inc. USA), a conductive PANI, is dispersible in polar polymers such as polycaprolactone and poly-(ethylene glycol-terephthalate). The conductivity percolation threshold in these blends was observed in the range 6–10% vol/vol of Versicon. Ikkala et al. [2] reported concerning the electrical and mechanical properties of conductive polymer blends prepared by conventional melt blending of a variety of thermoplastic polymers with a Neste PANI complex (Neste Oy, Finland). According to Passiniemi et al. [3], certain blends with PANI can be processed by ordinary methods such as injection molding, film blowing, and fiber spinning. They suggested that the key factor in their processing studies is a plasticizer technology developed by Neste Oy.

In our recent studies, various doped PANI complexes were melt blended with thermoplastic polymers, and the resulting binary PANI-polymer blends were investigated [4–7]. It was found that the combined characteristics of the matrix polymer and the doped PANI (dopant type) determine the resulting morphology and electrical conductivity of the blends. The interaction level between a doped PANI and a matrix polymer determines the level of fracturing of the PANI particles during melt mixing and thus the dispersion mode within the matrix polymer. It was suggested that the conductive network consists of two structural levels: a primary structure of the fractured PANI particles interconnected by a secondary very fine PANI fibrillar structure. The secondary structure was described as created on melt cooling through precipitation of a soluble short-chain PANI fraction in the melt. Specific interactions between the matrix polymer and the PANI, such as polar groups and hydrogen bonding, enhance the fracturing process and the solubility effects, thus improving the primary and secondary PANI structures in the solid state, and the resulting electrical conductivity. The conductive PANI network in semicrystalline blends is located in the amorphous regions, which results in lower percolation thresholds compared to amorphous matrices.

PANI was also melt blended with two immiscible thermoplastic polymers, forming ternary systems showing unique structures [8]. The conductivity and structure of the ternary blends were compared with the PANI-polymer binary reference blends. In the present study, ternary blends based on immiscible binary polymers and PANI were studied. This study was an extension of a previous study [8] in which different polymers in combination with PANI were used.

**EXPERIMENTAL**

**Materials**

The polyaniline used was Versicon (Zipperling Kessler and Co., Germany), polyaniline doped with p-toluene sulfonic acid (PANI-pTSA), which has a conductivity of 6 S/cm. The matrix polymers were as follows: polystyrene (PS), Galirene HH-102-E (Carmel Olefins, Israel); PS plasticized with dioctyl phthalate (PS/DOP), PS:DOP 85:15; copolyamide 6/6.9 (CoPA), a random copolymer of 51% [HN–(CH₂)₅–CO] and 49% [HN–(CH₂)₆–NH–CO–(CH₂)₇–CO] (EMS, Switzerland); and linear low-density polyethylene (LLDPE), Dowlex NG 5056 (Dow Chemicals, Midland, TX).

**Blend Preparation**

Binary and ternary blends were prepared by melt mixing in a Brabender plastograph at 50 rpm for 12 min. The blending temperature varied with the matrix polymer.
as follows: binary blends containing PS or LLDPE were blended at 180°C, plasticized PS at 155°C, and CoPA at 165°C. The ternary CoPA/LLDPE/PANI and (PS/DOP)/LLDPE/PANI blends were blended at 165°C and 180°C, respectively. Flat plaques, 3 mm thick, were prepared for conductivity measurements by compression molding.

**Conductivity Measurements**

Electrical conductivity measurements were performed using the four-probe technique (ASTM D 991-89) for samples \((12 \times 1.2 \times 0.3 \text{ cm}^3)\) with conductivity levels greater than \(10^{-4} \text{ S/cm}\) and the two-electrode technique (DIN-53596) for the less conductive blends. Samples for the latter technique were coated with a silver paint to reduce the sample-electrode contact resistance.

**Morphological Characterization**

High-resolution scanning electron microscopy (HRSEM) of cryogenically fractured surfaces was performed using a Leo Gemini-982 (Germany) at an accelerating voltage of 1 kV.

**Glass Transition Temperature**

The glass transition temperatures \(T_g\) of the studied polymers were obtained through dynamic mechanical thermal analysis (DMTA) using a Rheometrics MKIII machine (U.K.) in the flexure mode (single cantilever) at a frequency of 1 Hz. Samples of \(2 \times 0.5 \times 0.3 \text{ cm}^3\) were heated at a rate of 3°C/min.

**Molecular Simulation**

Solubility parameters of the polymers were calculated by molecular simulation, using the quantitative structure-property relationship (QSPR) method, based on semiempirical software [9]. The software principles are described elsewhere [10]. The interaction parameters of the matrix polymer with PANI were calculated as well.

**RESULTS AND DISCUSSION**

**Binary Blends**

Binary blends containing PANI and a thermoplastic matrix polymer were investigated. The electrical conductivity as a function of PANI content in blends with CoPA, LLDPE, PS/DOP, and PS is presented in Fig. 1. A percolation threshold of about 10–15 wt% PANI was observed for the CoPA and PS/DOP blend series. The PS/DOP blend series exhibited a conductivity "jump" of more than nine orders of magnitude within the percolation region; the CoPA blend series showed a more gradual increase in conductivity. Beyond percolation, the conductivity level of these blend series slowly increased with the PANI content due to improving quality of the conductive networks. The maximal conductivity level, 0.3 S/cm, observed for the (PS/DOP)/PANI 70/30 blend, is similar to that of the neat compression-molded PANI after exposure to 155°C. The electrical conductivity of this PANI (as received) is 6 S/cm, but after exposure to 155°C for 30 min (as in blending and compression-molding processes), it decreased to 0.4 S/cm due to changes in the structure of the polymer [5]. Interestingly, the LLDPE/PANI and PS/
PANI blends were insulating even at a PANI content as high as 20 wt% (as shown by a single data point for PS; Fig. 1), becoming conductive only at a PANI content of 30 wt%, as shown for the LLDPE/PANI blends.

The morphology of the binary blends was studied to elucidate the electrical conductivity-structure relationships. HRSEM fractographs of cryogenically fractured surfaces of LLDPE, PS, CoPA, and PS/DOP blends with 20 wt% PANI are presented in Fig. 2. Large PANI agglomerates (5–50 µm) are observed within LLDPE and PS, indicating the absence of a continuous network of PANI and thus the insulating behavior of the LLDPE/PANI and PS/PANI blends, even at 20 wt% PANI. In contrast, the blends of CoPA or PS/DOP with PANI exhibited dispersed small PANI particles consisting of primary particles (0.1–0.5 µm) and small aggregates (2–5 µm). The PANI particles in the PS/DOP matrix are smaller than those observed in the CoPA matrix. The high conductivity at relatively low PANI contents in PS/DOP and CoPA thus is related to the high fracturing levels and structuring of the PANI particles within the matrix polymer.

As previously reported [4–7], to create conducting blends at low PANI contents, the PANI phase should be segregated as finely dispersed tiny particles in the polymer matrix. During melt blending, the matrix polymer-PANI interaction level influences the level of PANI fracturing and dispersion. High interaction levels lead to a higher level of PANI fracturing due to better interphase shear stress transferability. This is expected in systems comprised of components of similar solubility parameters (i.e., low interaction parameters, which also result in enhanced solubility). The level of interaction between PANI and the matrix polymers was evaluated two different ways:

1. Molecular simulations were performed to calculate solubility parameters of the studied polymers and their interaction parameter with PANI. The results are presented in Table 1.
FIG. 2. HRSEM fractographs of various polymer/PANI 80/20 binary blends.

2. The $T_g$ values of the neat matrix polymers and in the binary 80/20 blends with PANI were determined by DMTA. The change in $T_g$ of the matrix polymer, resulting from blending with PANI, is related to the level of interaction between the two polymers. Tan $\delta$ curves of CoPA/PANI and LLDPE/PANI blends and their neat polymers are presented in Fig. 3. The $T_g$ values, taken as the temperatures at the peak tan $\delta$, are indicated.

The solubility parameters of PANI (Versicon includes p-TSA as a dopant) and CoPA are similar; therefore, the interaction parameter of the CoPA/PANI system is low (0.006). Addition of 20 wt% PANI to CoPA increases its $T_g$ by 4°C (Fig. 3a), suggesting

TABLE 1

<table>
<thead>
<tr>
<th>Polymer</th>
<th>Solubility parameter, ($J/cm^3)^{0.5}$</th>
<th>Interaction parameter with PANI</th>
</tr>
</thead>
<tbody>
<tr>
<td>PANI</td>
<td>23.9</td>
<td>—</td>
</tr>
<tr>
<td>CoPA</td>
<td>24.2</td>
<td>0.006</td>
</tr>
<tr>
<td>LLDPE</td>
<td>16.8</td>
<td>0.510</td>
</tr>
<tr>
<td>PS</td>
<td>19.5</td>
<td>0.790</td>
</tr>
<tr>
<td>DOP</td>
<td>20.9</td>
<td>—</td>
</tr>
</tbody>
</table>
FIG. 3. DMTA thermograms of polymer/PANI 80/20 binary blends and the neat polymers heated at 3°C/min.

specific interactions in the CoPA/PANI system. Such interactions may include hydrogen bonds between hydrogens of the undoped imine nitrogens in the PANI and the amide oxygens in CoPA. Hydrogen bonding was described also in other polymer blends containing intrinsically conductive polymers (ICPs), such as polycaprolactone/PANI [5] and polycarbonate/polypyrrole [11]. Hence, hydrogen bonding, existing even at the elevated processing temperatures [12], enhances the interaction level between CoPA and PANI and leads to increased PANI fracturing. As a result, segregated fine continuous PANI paths are formed already at relatively low PANI contents.

In contrast, the solubility parameter of LLDPE is well below that of the PANI, and therefore the interaction parameter of the LLDPE/PANI system is relatively high (0.51). Thus, the addition of 20 wt% PANI to LLDPE does not practically affect its $T_g$ (Fig. 3b). Therefore, in the LLDPE/PANI system, only poor PANI dispersion in the molten LLDPE is obtained, and a high PANI content is needed to form a PANI network that generates a conductive blend (Fig. 1).

As previously mentioned, while the PS/PANI blends are insulating, due to the poor dispersion of PANI, the studied (PS/DOP)/PANI blends exhibit a percolation behavior...
(Fig. 1) due to the high level of PANI dispersion and segregation (Fig. 2). The solubility parameter of PS is well below that of PANI (Table 1), and its \( T_g \) like that of LLDPE, is practically not affected by the presence of PANI [8]. In contrast, addition of 20 wt% PANI to PS/DOP increases the PS \( T_g \) by 5°C [8]. The effect of DOP content on the electrical conductivity of (PS/DOP)/PANI 80/20 blends and on the \( T_g \) of PS was studied further. Interestingly, the conductivity sharply increased with DOP content, up to 10 wt% DOP, and then leveled off (Fig. 4). Molecular simulations were performed to find the optimal structure for the (PS/DOP)/PANI blends. It was suggested [8] that part of the DOP locates at the interphase between PS and PANI. Hence, DOP, in addition to plasticizing the PS, seems also to act as a PS/PANI compatibilizer, which improves the PS-PANI interaction and results in (PS/DOP)/PANI blends that conduct at relatively low PANI contents.

**Ternary Blends**

In addition to the binary polymer/PANI blends, ternary blends consisting of two immiscible thermoplastic polymers and PANI were investigated. Our recent study [8] focused on the (PS/DOP)/CoPA/PANI system consisting of two polymers, each compatible with PANI-pTSA. The present systems investigated, CoPA/LLDPE/PANI and (PS/DOP)/LLDPE/PANI blends, contained a matrix polymer compatible with the PANI (CoPA and PS/DOP), while the other matrix polymer (LLDPE) is incompatible with the PANI. Surprisingly, the electrical conductivity behavior of these two systems is different.

**Copolyamide 6 or 6.9/Linear Low-Density Polyethylene/Polyaniline Blends**

The electrical conductivity as a function of LLDPE content for blends containing 10 and 20 wt% PANI is presented in Fig. 5. The conductivity level of the ternary blends
containing 20 wt% PANI (upper curve) slightly increased with increasing LLDPE content (also decreasing CoPA content). This behavior was more significant in the blends containing 10 wt% PANI. It can also be noticed that the addition of 30 wt% CoPA (sufficient to form a continuous structure within the LLDPE) to the insulating LLDPE/PANI 80/20 binary blend increased its conductivity by nine orders of magnitude to become a conductive ternary blend.

HRSEM fractographs of cryogenically fractured surfaces of ternary blends containing 20 wt% PANI are presented in Fig. 6 compared with the morphology of the corresponding binary blends. The PANI phase (in white) is preferentially located in the CoPA phase (Figs. 6a, 6e), and its mode of dispersion resembles the one observed in the CoPA/PANI binary blend (Fig. 2). Thus, the effective PANI content in the CoPA phase is higher than its nominal content in the blend. The double-percolation phenomenon (both PANI located in the CoPA phase and CoPA are continuous phases), for example, in the ternary blends containing 10 wt% PANI (Fig. 5), resulted in high conductivity for the blend based on CoPA/LLDPE 30/70. At this 10 wt% PANI content, the individual binary blends based on CoPA and LLDPE are insulating (Fig. 5). Focusing on the LLDPE domains indicates a relatively high PANI quantity on their surfaces (Fig. 6c) and just a few PANI particles in their interiors (Fig. 6d). During blending, most of the PANI particles become included in the CoPA phase. The solubility parameter of PANI [23.9 (J/cm^3)^0.5] is similar to that of CoPA [24.2 (J/cm^3)^0.5] and is much higher than that of LLDPE [16.8 (J/cm^3)^0.5], and therefore only part of the PANI particles remains at the CoPA/LLDPE interface. These PANI particles probably do not contribute to the conductivity of the ternary blends. One would expect that, if most of the PANI particles were located at the CoPA/LLDPE interface, a very low percolation threshold would be observed.

Energy dispersive spectroscopy (EDS) sulfur mapping of the fracture surfaces of the blends was used to estimate the PANI distribution quantitatively within the two
polymers. Since the dopant (p-TSA) of the PANI contains sulfur, the mapping enabled evaluation of the PANI concentration within each matrix. It was found that about 90% of the PANI was located within the CoPA phase, and only about 10% was located within the LLDPE phase and at the CoPA/LLDPE interphase. Thus, the conductivity of the CoPA/LLDPE/PANI was determined mainly by the PANI content within the preferred (CoPA) phase, its mode of dispersion, and the conducting network structure created.

To study the effect of blending sequence on the morphology and conductivity of the blends, ternary blends containing 20 wt% PANI were prepared in three different ways: (1) all together (i.e., by simultaneously mixing the three components), (2) (CoPA + PANI) + LLDPE (i.e., by hot mixing CoPA with PANI and then adding LLDPE), (3)
(LLDPE + PANI) + CoPA (i.e., by hot mixing LLDPE with PANI and then adding CoPA). The three blend series studied showed similar conductivity levels (Fig. 7) and morphology. Hence, the PANI has a high tendency to locate within CoPA rather than in LLDPE, and the transfer of the PANI particles from the LLDPE phase to the CoPA phase is an efficient process.

**(PS/DOP)/LLDPE/PANI Blends**

Like CoPA/LLDPE/PANI blends, the (PS/DOP)/LLDPE/PANI blends also consist of polymers that are compatible (PS/DOP) and incompatible (LLDPE) with PANI. Hence, one could expect a similar behavior of the two systems; however, a different behavior was found for the electrical conductivity. As shown in Fig. 8, the conductivity level of blends containing 20 wt% PANI slightly decreased with increasing LLDPE content (decreasing CoPA content), whereas the blends containing 10 wt% PANI were all insulating, like the corresponding binary blends.

HRSEM fractographs of cryogenically fractured surfaces of the (PS/DOP)/LLDPE/PANI blends containing 20 wt% PANI are presented in Fig. 9 compared with the morphology of the corresponding binary blends. It is almost impossible to distinguish between the two polymers (PS/DOP and LLDPE) comprising the ternary blends, while the PANI particles are clearly observable. Most of the fracture surface of the (PS/DOP)-rich, (PS/DOP)/LLDPE 70/30 blend contained PANI particles (Fig. 9a), while only part of the fracture surface in the LLDPE-rich blend based on (PS/DOP)/LLDPE 30/70 contained PANI particles (Fig. 9c). Thus, PANI was located mainly within the (PS/DOP) phase, and only a small quantity was located within the LLDPE. This behavior was expected from the calculated interaction parameters shown in Table 1, that is, PANI...
FIG. 8. Electrical conductivity versus LLDPE content for (PS/DOP)/LLDPE/PANI blends containing 10 and 20 wt% PANI.

FIG. 9. HRSEM fractographs: (a) [(PS/DOP)/LLDPE 70/30]/PANI (80/20) blend; (b) (PS/DOP)/LLDPE 70/30 blend; (c) [(PS/DOP)/LLDPE 30/70]/PANI (80/20) blend; (d) (PS/DOP)/LLDPE 30/70 blend.
tends to locate within the more compatible matrix polymer. Interestingly, in this case, the high effective PANI content in the (PS/DOP) phase did not generate electrical conductivity at relatively low PANI contents. This phenomenon can be explained by some migration of DOP from PS, leaving the PS less plasticized and less compatible with PANI. As a result, the PANI fracturing level in this phase is less effective, leaving larger aggregated particles than those obtained in the (PS/DOP)/PANI binary blend (Fig. 2). It is assumed that some DOP in the ternary blends leaves the PS phase due to the demanded higher mixing temperature of 180°C, compared with 155°C for the (PS/DOP)/PANI binary blends. In addition, in contrast to CoPA/LLDPE/PANI blends, the larger PANI particles in the (PS/DOP)/LLDPE/PANI blends are located within the PS/DOP phase rather than at the interphase between the two polymers. Therefore, a larger PANI content within the PS/DOP phase is needed to obtain electrical conductivity. It is suggested that the DOP migration from the PS phase is the main reason for the insulating (PS/DOP)/LLDPE/PANI blends containing 10 wt% PANI.

To verify the possibility of DOP migration, the $T_g$ of the plasticized PS in the ternary and corresponding binary blends was determined by DMTA (Fig. 10). In both cases, the $T_g$ of PS increased with increasing LLDPE content in the blends. Some of the DOP in the ternary blends (containing PANI) may locate at the interface between PS and PANI, acting as a compatibilizer [8]. As a result, the $T_g$ values of the ternary blends are slightly higher than those of the corresponding binary blends. The DOP content in the PS phase can be estimated by using the Fox equation and the $T_g$ values of (PS/DOP)/PANI 80/20 blends containing various DOP contents (Fig. 4). The results for the two blend series are presented in Table 2. The DOP tendency to leave the PS phase during hot mixing was more significant for the binary blends (Table 2). A possible reason for this may be that the part of the DOP that locates at the interphase between PS and PANI (in the ternary blends) had a lower tendency to leave the blend.

![FIG. 10. The $T_g$ values of PS versus LLDPE content for ○, (PS/DOP)/LLDPE blends and ●, [(PS/DOP)/LLDPE]/PANI 80/20 blends.](image)
A schematic description of high-quality and low-quality double-percolation blends is depicted in Figs. 11a and 11b, respectively. In CoPA/LLDPE/PANI blends, the PANI preferentially locates in the CoPA phase. This concentration effect leads to high electrical conductivity at low PANI contents. A schematic description of these blends is presented in Fig. 11a. Similarly, the PANI phase in the (PS/DOP)/LLDPE/PANI blends is located mainly in the plasticized PS phase. Some of the DOP leaves the PS due to the high mixing temperature. Therefore, this PS is less compatible with PANI, and the PANI structure within this PS is coarser, leading to low electrical conductivity. A schematic description of these blends is presented in Fig. 11b.

**SUMMARY AND CONCLUSIONS**

- Binary and ternary blends of conductive PANI with CoPA, PS, DOP-plasticized PS, and LLDPE were prepared by melt processing. The investigation focused on the morphology, interactions between the components, and the resulting electrical conductivity of the blends.
- Similar solubility parameters of the matrix polymer and PANI led to the formation of high-quality conductive networks. Thus, CoPA/PANI binary blends became conductive at low PANI contents, while binary blends of PANI with LLDPE or PS remained insulating even at relatively high PANI contents. DOP, in addition to plasticizing the PS phase and reducing the processing temperature, seems to act as a PS/PANI compatibilizer since (PS/DOP)/LLDPE/PANI blends were conductive at relatively low PANI contents.
- In ternary blends consisting of PANI and two immiscible polymers, the PANI preferentially located in one of the constituting polymers, resulting in a PANI effective content higher in that polymer than in the nominal one. This concentration magnification effect led to high electrical conductivity levels at low PANI contents.
- The electrical conductivity of a ternary blend was determined by the effective PANI content in the “preferred” phase, its continuity (the first percolation), the level of PANI fracturing in this phase, and the detailed conductive network structure formed within the preferred phase.
In CoPA/LLDPE/PANI ternary blends, CoPA rather than LLDPE was the preferred phase for PANI location due to specific interactions (hydrogen bonds) between CoPA and PANI. The PANI mode of dispersion within CoPA, the particle size, and the conducting network structure created resemble those in the corresponding binary CoPA/PANI blends.

In (PS/DOP)/LLDPE/PANI blends, although PS/DOP is the preferred phase for PANI location, the concentration magnification effect did not improve the electrical conductivity, apparently due to partial migration of DOP from the PS.

The electrical conductivity of the ternary blends was practically independent of the blending sequence of the components in accordance with the stronger tendency of PANI toward CoPA or PS/DOP than to LLDPE.

Proper selection of matrix polymers with a given doped PANI helps to create designed structuring in potentially useful ternary blends.

**FIG. 11.** Schematic description of doped PANI dispersion in a host matrix containing two co-continuous immiscible thermoplastic polymer phases: (a) high-quality conducting PANI network in a CoPA/LLDPE/PANI blend; (b) poor-quality PANI network in a (PS/DOP)/LLDPE/PANI blend.
TERNARY BLENDS WITH POLYANILINE

ACKNOWLEDGMENT

We are grateful to the Israel Ministry of Science for partial support of this research and to Dr. D. Alperstein for the molecular simulations.

REFERENCES


Received June 18, 1999
Revised July 14, 1999
Accepted July 29, 1999
Request Permission or Order Reprints Instantly!

Interested in copying and sharing this article? In most cases, U.S. Copyright Law requires that you get permission from the article’s rightsholder before using copyrighted content.

All information and materials found in this article, including but not limited to text, trademarks, patents, logos, graphics and images (the "Materials"), are the copyrighted works and other forms of intellectual property of Marcel Dekker, Inc., or its licensors. All rights not expressly granted are reserved.

Get permission to lawfully reproduce and distribute the Materials or order reprints quickly and painlessly. Simply click on the "Request Permission/Reprints Here" link below and follow the instructions. Visit the U.S. Copyright Office for information on Fair Use limitations of U.S. copyright law. Please refer to The Association of American Publishers’ (AAP) website for guidelines on Fair Use in the Classroom.

The Materials are for your personal use only and cannot be reformatted, reposted, resold or distributed by electronic means or otherwise without permission from Marcel Dekker, Inc. Marcel Dekker, Inc. grants you the limited right to display the Materials only on your personal computer or personal wireless device, and to copy and download single copies of such Materials provided that any copyright, trademark or other notice appearing on such Materials is also retained by, displayed, copied or downloaded as part of the Materials and is not removed or obscured, and provided you do not edit, modify, alter or enhance the Materials. Please refer to our Website User Agreement for more details.

Order now!

Reprints of this article can also be ordered at http://www.dekker.com/servlet/product/DOI/101081MB100100389