1-1-2013

Compensation of blue phase I by blue phase II in optoeletronic device

Yi-Fen Lan
University of Central Florida

Cheng-Yeh Tsai

Jen-Kuei Lu

Norio Sugiura

Compensation of blue phase I by blue phase II in optoeletronic device

Yi-Fen Lan,[1,2,3,*] Cheng-Yeh Tsai,[1] Jen-Kuei Lu,[1] and Norio Sugiura[1]

[1]*Advanced Display Mode & Material Research Center, AU Optronics Corporation, Hsinchu 30078 Taiwan*
[2]*CREOL, College of Optics and Photonics, University of Central Florida, Orlando, Florida 32816 USA*
[3]*yi-fen.lan@ucf.edu*
**even.yf.lan@auo.com*

Abstract: Compensation effect of blue phase I (BP I) with blue phase II (BP II) liquid crystal was demonstrated. BP I and BP II were co-exist in the optoeletronic device by polymer stabilization. Consequently, disadvantages of BP I and BP II were greatly improved by compensation effect and resulted in high contrast ratio, low hysteresis and fast falling time. Mechanism of compensation effect was explained by relaxation ability of lattice structure under electrical field and compensation structure was well confirmed by Bragg's reflectance spectrum and Commission International de l'Éclairage chromaticity diagram.

OCIS codes: (160.3710) Liquid crystals; (160.5470) Polymers; (220.4000) Microstructure fabrication; (230.2090) Electro-optical devices.

References and links

1. H. Stegemeyer, T. H. Blumel, K. Hiltrop, H. Onusseit, and F. Porsch, "Thermodynamic, structural and morphological studies on liquid-crystalline blue phases," Liq. Cryst. **1**(1), 3–28 (1986).
2. P. P. Crooker, *Chirality in Liquid Crystals*, H. S. Kitzerow and C. Bahr, eds. (Springer, 2001).
3. H. Kikuchi, M. Yokota, Y. Hisakado, H. Yang, and T. Kajiyama, "Polymer-stabilized liquid crystal blue phases," Nat. Mater. **1**(1), 64–68 (2002).
4. E. Karatairi, B. Rozic, Z. Kutnjak, V. Tzitzios, G. Nounesis, G. Cordoyiannis, J. Thoen, C. Glorieux, and S. Kralj, "Nanoparticle-induced widening of the temperature range of liquid-crystalline blue phases," Phys. Rev. E Stat. Nonlin. Soft Matter Phys. **81**(4), 041703–041707 (2010).
5. H. Iwamochi, T. Hirose, Y. Kogawa, and A. Yoshizawa, "Chiral T-shaped semiflexible compound exhibiting a wide temperature range blue phase III," Chem. Lett. **39**(3), 170–171 (2010).
6. H. J. Coles and M. N. Pivnenko, "Liquid crystal 'blue phases' with a wide temperature range," Nature **436**(7053), 997–1000 (2005).
7. A. Yoshizawa, M. Sato, and J. Rokunohe, "A blue phase observed for a novel chiral compound possessing molecular biaxiality," J. Mater. Chem. **15**(32), 3285–3290 (2005).
8. M. Sato and A. Yoshizawa, "Electro-optical switching in a blue phase III exhibited by a chiral liquid crystal oligomer," Adv. Mater. (Deerfield Beach Fla.) **19**(23), 4145–4148 (2007).
9. C. V. Yelamaggad, I. S. Shashikala, G. Liao, D. S. Shankar Rao, S. K. Prasad, Q. Li, and A. Jakli, "Blue phase, smectic fluids, and unprecedented sequences in liquid crystal dimers," Chem. Mater. **18**(26), 6100–6102 (2006).
10. H. Kikuchi, H. Higuchi, Y. Haseba, and T. Iwata, "Fast electro-optical switching in polymer-stabilized liquid crystalline blue phases for display application," SID Sym. Digest Tech. Papers **38**(1), 1737–1740 (2007).
11. M. Lee, S. T. Hur, H. Higuchi, K. Song, S. W. Choi, and H. Kikuchi, "Liquid crystalline blue phase I observed for a bent-core molecule and its electro-optical performance," J. Mater. Chem. **20**(28), 5813–5816 (2010).
12. Y. Yoshizawa, Y. Kogawa, K. Kobayashi, Y. Takanishi, and J. Yamamoto, "A binaphthyl derivative with a wide temperature range of a blue phase," J. Mater. Chem. **19**(32), 5759–5764 (2009).
13. Y. Kogawa and A. Yoshizawa, "Chiral effects of blue phase stabilisation of a binaphthyl derivative," Liq. Cryst. **38**(3), 303–307 (2011).
14. B. Y. Zhang, F. B. Meng, and Y. H. Cong, "Optical characterization of polymer liquid crystal cell exhibiting polymer blue phases," Opt. Express **15**(16), 10175–10181 (2007).
15. H. Choi, H. Higuchi, and H. Kikuchi, "Electrooptic response of liquid crystalline blue phases with different chiral pitches," Soft Matter **7**(9), 4252–4256 (2011).
16. Y. F. Lan, C. Y. Tsai, L. Y. Wang, P. J. Ku, T. H. Huang, C. Y. Liu, and N. Sugiura, "Identification of polymer stabilized blue-phase liquid crystal display by chromaticity diagram," Appl. Phys. Lett. **100**(17), 171902 (2012).
17. C. Kittel, *Introduction to Solid State Physics* (Wiley-VCH, 1996).

#183885 - $15.00 USD Received 22 Jan 2013; revised 5 Feb 2013; accepted 8 Feb 2013; published 21 Feb 2013

18. K. M. Chen, S. Gauza, H. Xianyu, and S. T. Wu, "Hysteresis effects in blue-phase liquid crystals," J. Display Technol. **6**(8), 318–322 (2010).
19. A. Yoshizawa, "Molecular design for stabilizing a blue phase III and electro-optical switching in the blue phase," J. SID **16**(12), 1189–1194 (2008).
20. H. Choi, H. Higuchi, and H. Kikuchi, "Fast electro-optic switching in liquid crystal blue phase II," Appl. Phys. Lett. **98**(13), 131905 (2011).

1. Introduction

Blue phase liquid crystal (BPLC) was discovered by Reinitzer and described in 1888. Fundamental behaviors of BPLC were well studied in 1970s and BPLC generally was consisted of chiral dopant and cholesteric liquid crystal. However, BPLC appeared in narrow temperature range of 1 °C and hindered its further development and applications [1,2]. The problem of narrow stable temperature range has been overcome by using the polymeric stabilization [3], nanoparticles [4], and T-shaped compound [5]. Therefore, various innovational applications were proposed [3,6–9], and BPLC display is one of the most popular applications [10].

BPLC has three different types, BP I, BP II and BP III which can be characterized by polarized optical microscope (POM) [11], X-ray diffraction (XRD) [12], differential scanning calorimeter (DSC) [13,14], optical spectroscope [15], and Commission International de l'Éclairage (CIE) chromaticity [16]. The characterization revealed BP I has body-centered cubic, BP II has simple cubic and BP III has an arbitrary orientation (amorphous) [2,17]. Due to different lattice structures, BPLC showed different performance in opto-electrical devices. BP I has good contrast ratio and operation stability [15]. BP II exhibited a smaller hysteresis and faster response time than BP I [18]. BP III has the fastest response time in micro-second scale [19]. However, different type of BPLC revealed different disadvantages such as response time of BP I not satisfying to the field sequential color mode display, BP II has poor stability after polymerization, and PB III reveals high operation voltage [18,19]. Herein, this report studied compensation of BP I and BP II with each other in optoeletronic device. Electro-optical properties of BPLC device were greatly improved based on the compensation approach.

2. Experimental and compensation approach

BPLC was consisted of host liquid crystals (4-cyano-4'-pentyl biphenyl, 5CB, 43.74 mol. %; JC1041XX, 42.94 mol. %) and chiral dopant (ISO-SF, 4.82 mol. %). The BPLC was polymeric stabilized by monomer (ethyl hexyl acrylate, TMPTA, 3.81 mol. %), reactive mesogen (RM257, 2.45 mol. %), and photo initiator (DMPAP, 0.32 mol. %). Before polymerization, phase-transition sequence of the BPLC was N* (26.4 °C) BP I (31.3 °C) BP II (34.5 °C) ISO. Eutectic mixture of BPLC was filled into in-plane-switch (IPS) cell (line/space/gap = 10μm/10μm/10μm) and polymeric stabilized by ultraviolet (UV) cured process. In order to obtain compensation BPLC, as-prepared cell was cured from 29.8 °C to 33.3 °C (Fig. 1).

#183885 - $15.00 USD Received 22 Jan 2013; revised 5 Feb 2013; accepted 8 Feb 2013; published 21 Feb 2013

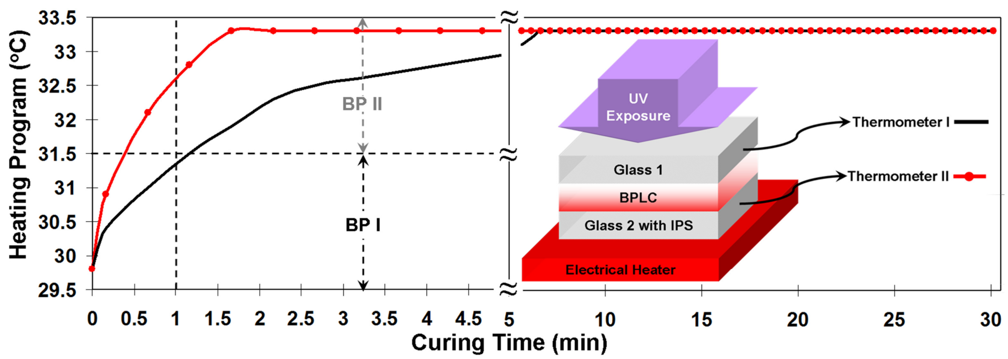

Fig. 1. Heating program of BPLC during UV curing process.

For references, polymer stabilized BP I and BP II were also prepared by polymer stabilized at 29.3 °C and 33.3 °C, respectively. After UV curing, as-prepared cells were analyzed by luminance colorimeter (Topcon, BM5A, CIE resolution: ± 0.03, Nit resolution: ± 4%). The luminance colorimeter was operated at room temperature with application of bias voltage. Response time was measured by opticscope (Eldim, OPTIScope, Aperture angle: ± 6.50°, Output signal sensitivity at 25 °C: 0.04 v/nm to 40 v/nm). In order to confirm compensation structure of BPLC in optoeletronic device, as-prepared cells were characterized by UV-visible spectroscope (Perkinelmer, Lambda 800) and CIE chromaticity diagram.

3. Results and discussions

In order to prepare compensation BPLC, BPLC was cured from 29.8 °C to 33.3 °C and detail heating program was showed in Fig. 1. Before 15 seconds of UV curing time, both glass 1 and glass 2 kept below BP I-BP II transition temperature of 31.3 °C and BP I was formed initially. After 15 seconds of UV curing time, glass 2 kept above 31.3 °C while glass 1 still maintained below 31.3 °C. Consequently, BP II formed near glass 2 and BP I formed near glass 1. Usually, the polymerization completed in 1 min of UV curing process. Therefore, both BP I and BP II co-existed in optoeletronic device.

As-prepared cells were analyzed by luminescence and voltage-transmittance (VT) curve was showed in Fig. 2(a). Compensation BPLC has threshold voltage at 1 V/μm and saturated at 6 V/μm. Reference of BP I has almost the same threshold and saturation voltage as compensation BPLC, but revealed difference in grey-to-grey level. Reference of BP II rendered larger threshold voltage at 2.25 V/μm and higher saturation at 7 V/μm. BP II revealed more poor VT curve than BP I and result was consisted with literature reports [18,20].

#183885 - $15.00 USD Received 22 Jan 2013; revised 5 Feb 2013; accepted 8 Feb 2013; published 21 Feb 2013

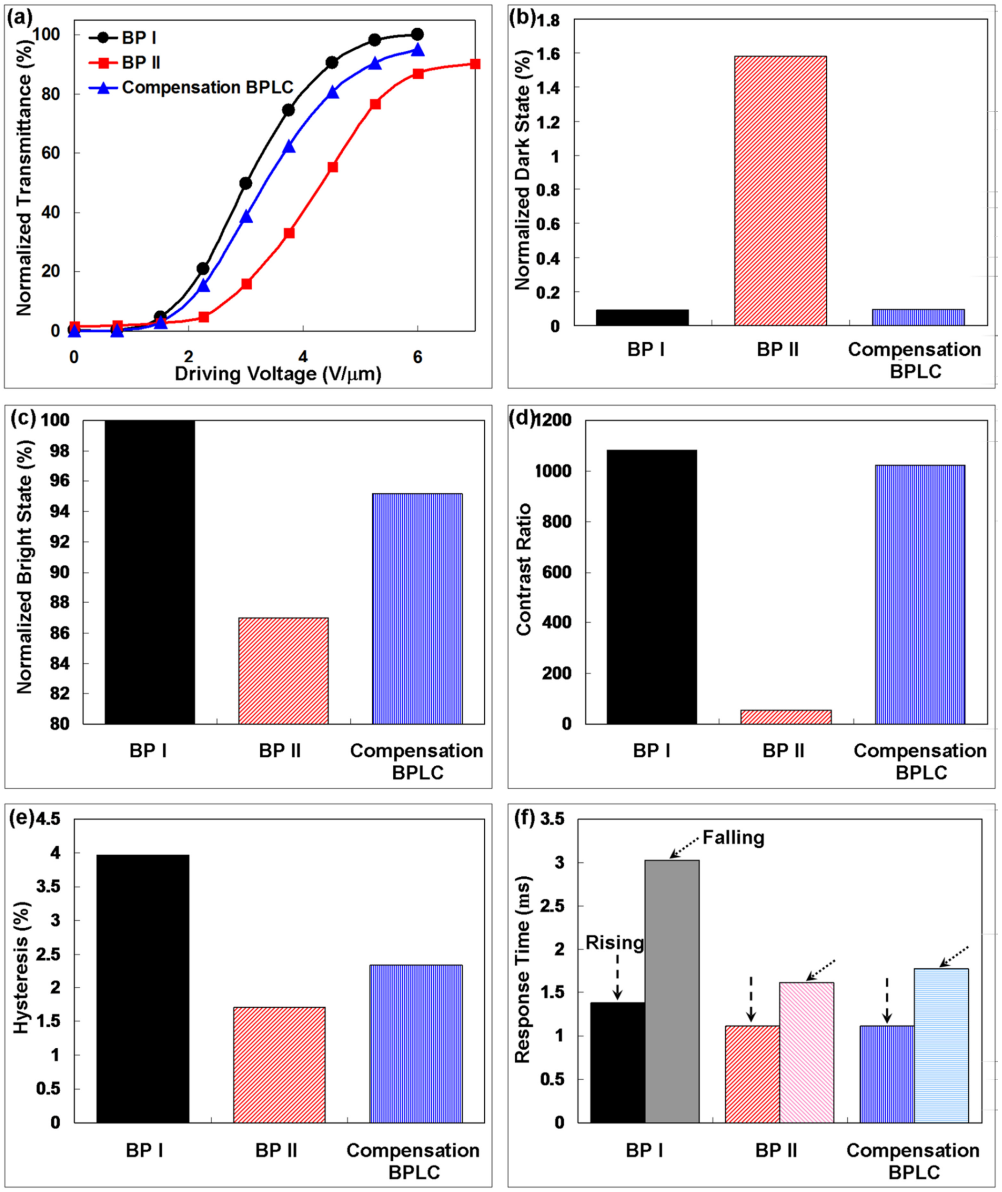

Fig. 2. Electro-optical properties of compensation BPLC and their references: (a) voltage-transmittance curve, (b) normalized dark state, (c) normalized bright state, (d) contrast ratio, (e) hysteresis and (f) response time.

Detail electro-optical (EO) properties were shown in Fig. 2(b)-2(e). BP I has good dark state (Fig. 2(b)), but BP II has poor one due to un-stabile polymerization [18]. Although compensation BPLC has BP II region, it still rendered good dark state. Normalized bright state was shown in Fig. 2(c), BP I was regarded as the standard and revealed in 100% transmittance. BP II has lowest bright state of 87% and compensation BPLC has almost the same bright state (95%) as BP I. Contrast ratio (CR) is the most important factor to evaluate the performance of liquid crystal display. As shown in Fig. 2(d), BP I has good CR, but BP II has poor one due to the poor dark state. Although compensation BPLC has BP II region, it still rendered good CR due to the good dark state.

#183885 - $15.00 USD Received 22 Jan 2013; revised 5 Feb 2013; accepted 8 Feb 2013; published 21 Feb 2013

Another serious issue of polymer stabilized BPLC is hysteresis. Poor hysteresis affect on performance of grey-to-grey level. BP I has poor hysteresis of 4.0% due to electrostriction (Fig. 2(e)) [8], but BP II has good hysteresis of 1.7%. Although compensation BPLC has BP I region, it still rendered good hysteresis of 2.3%. Rising and falling response time were also investigated and shown in Fig. 2(f). BP I, BP II and compensation rendered almost the same rising time around 1.11~1.38 ms. However, they showed large difference in falling time. Falling time of BP I is 3.03 ms (grey bar), but BP II is 1.62 ms (pink-right bar). Although compensation BPLC has BP I region, it still rendered fast falling time of 1.77 ms (cyan-horizontal bar).

Compared to references, compensation BPLC rendered better performance than BP I and BP II. Mechanism of compensation BPLC was further explained in Fig. 3. Mechanism of compensation BPLC in dark state and CR was showed in Fig. 3(a). In BP I cell, it revealed good dark state due to the stable optical isotropic, in opposite, BP II cell revealed poor dark state and light leakage due the un-stable optical isotropic. Un-stable optical isotropic was resulted from un-stable polymer network [18,20]. In compensation BPLC cell, BP II region may cause light leakage, however, exist of BP I effectively prevented light leakage of BP II and resulted in good dark state. In other word, light leakage from BP II was decreased by BP I due to stabile optical isoptropic. Consequently, better dark state resulted in better CR.

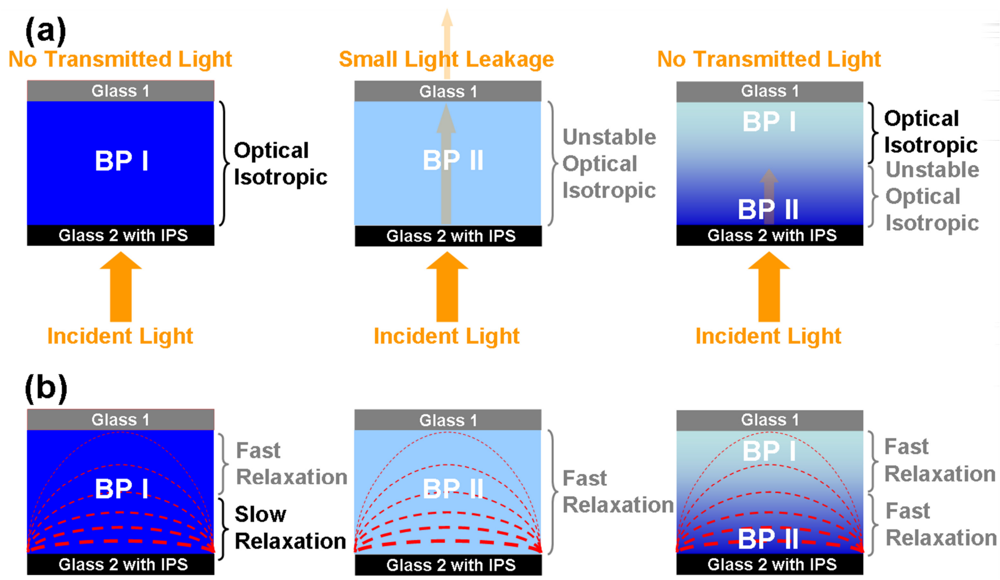

Fig. 3. Mechanism of compensation BPLC in (a) dark state and contrast ratio and (b) hysteresis and falling time.

Mechanism of compensation BPLC in hysteresis and falling time was described in Fig. 3(b). The phase retardation of backward driving is depended on the relaxation ability of BPLC. Generally, in the strong electric field, BP II has better relaxation ability than BP I due to BP II has simple cube lattice. For compensation BPLC, BP II located adjacent to glass 2 (IPS side) and was driven by strong electrical field (thick red dash), in opposite, BP I located adjacent to glass 1 and was driven by weak electrical field (thin red dash). Consequently, compensation structure revealed fast relaxation in whole heterogeneous electric field and rendered low hysteresis. Generally, BP II has sub micro-second response time and faster that BP I. In compensation BPLC, falling time of BP I was improved by BP II. Finally, BP I and BP II compensated with each other and revealed good dark state, low hysteresis and fast falling time in optoeletronic device.

#183885 - $15.00 USD Received 22 Jan 2013; revised 5 Feb 2013; accepted 8 Feb 2013; published 21 Feb 2013

In order to confirm both BP I and BP II co-exist in single optoeletronic device, compensation BPLC cell was characterized by Bragg reflectance[15] and CIE chromaticity diagram [16]. Figure 4(a) showed reflectance of BP I cell and both surface of glass 1 and glass 2 revealed the same peak wavelength of Bragg reflectance at 362 nm. The same Bragg reflectance indicated BP I homogeneously distributed in optoeletronic device. Compared to BP I cell (Fig. 4(b)), result of compensation BPLC cell rendered large difference. Bragg reflectance of glass 1 showed at 360 nm, however, result of glass 2 showed at 345 nm. Different Bragg reflectance peak indicated glass 1 has different BPLC lattice from glass 2, i.e. BPLC is heterogeneously distributed in optoeletronic device. Furthermore, heterogeneous BPLC cell was characterized by CIE chromaticity diagram (Fig. 4(c)) [16]. According to Lan's report, different type of BPLC has different CIE coordination diagram. CIE Result showed BP I distributed near glass 1 and BP II distributed near glass 2. Consequently, compensation BPLC has BP I adjacent to glass 1 and BP II adjacent to glass 2 in optoeletronic device.

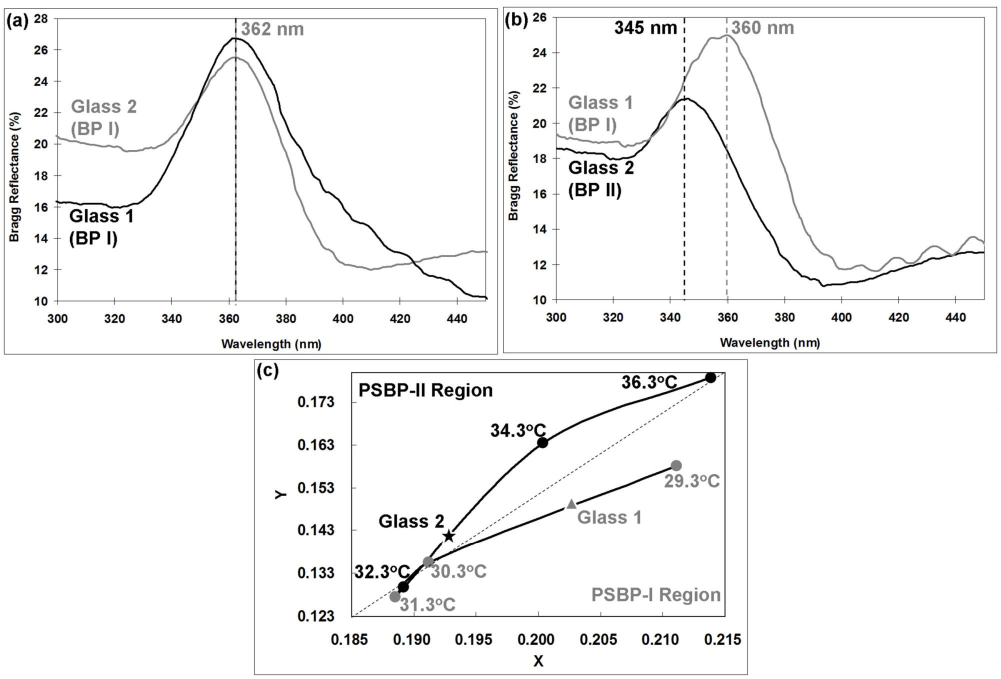

Fig. 4. Identification of compensation BPLC cell and its reference: Bragg Reflectance for BP I (a) and compensated BPLC (b), CIE chromaticity diagram for BPLC (c).

4. Conclusion

Compensation BPLC was prepared in optoeletronic device. Electro-optical properties showed both advantage of BP I and BP II and rendered high contrast ratio, low hysteresis and fast falling time. Consequently, heterogeneous BPLC was characterized by Bragg reflectance and CIE chromaticity diagram and result revealed both BP I and BP II distributed in opposite location in optoeletronic device. Concept of compensation BPLC will impact the development of polymer stabilized BPCL display.

#183885 - $15.00 USD Received 22 Jan 2013; revised 5 Feb 2013; accepted 8 Feb 2013; published 21 Feb 2013