

# Photoinduced Antimicrobial Polymer Blends with Benzophenone as a Functional Additive

Kyung Hwa Hong, Gang Sun

*Division of Textiles and Clothing, University of California, Davis, California 95616*

Received 22 July 2008; accepted 17 November 2008

DOI 10.1002/app.29697

Published online 12 February 2009 in Wiley InterScience (www.interscience.wiley.com).

**ABSTRACT:** Benzophenone (BP)-incorporated polymer films including polystyrene (PS), polyethylene (PE), polypropylene (PP), and polyvinyl alcohol (PVA) films were prepared, and the structural and photoactivated properties were investigated by SEM, XRD, DSC, antimicrobial, and hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>) production tests. When the amount of incorporated BP concentration was 0.5 wt %, the polymer films were successfully prepared without significant changes in physical properties. Also, all the BP-incorporated polymer films showed antimicrobial abilities

under UVA (365 nm) irradiation, and the effectiveness increased as the amounts of BP in the polymers are increased. On the other hand, it was observed that photo-irradiated PVA/BP composite films created H<sub>2</sub>O<sub>2</sub> under the atmospheric dark condition. © 2009 Wiley Periodicals, Inc. *J Appl Polym Sci* 112: 2019–2026, 2009

**Key words:** benzophenone; polystyrene; polyethylene; polypropylene; polyvinyl alcohol; antimicrobial ability; hydrogen peroxide

## INTRODUCTION

Personal protective products including gloves, masks, and gowns are widely used in hospitals, which can reduce transmissions.<sup>1,2</sup> However, researchers have found that microorganisms can survive on most polymeric and textile materials for days and even months, indicating that the personal protective gears could be sources of infectious diseases.<sup>3</sup> Thus, development of antibacterial polymers and textiles that can be microorganism free has been the interests of research. Antibacterial polymers and textiles can be produced by chemical or physical incorporation of different biocides into polymers, with examples of addition of silver ions, quaternary ammonium salts, and halamine structures.<sup>4,5</sup> These approaches are effective at certain level, but also bear some shortfalls, such as high cost, impaired user performance because of the weight and bulkiness, and environmental concerns.<sup>6,7</sup> Therefore, there is an urgent need to develop systems that are more powerful in neutralizing biological agents and chemical pollutants and toxins while being environmentally friendly.<sup>8</sup>

More recently, we have found that chemically incorporate photosensitizers such as benzophenone (BP) structures to polymers and textiles could result

photoactivated antimicrobial materials.<sup>9–11</sup> According to the results of antimicrobial polymers, antimicrobial agents can be applied to matrix polymers by physical mixing such as dissolution or dispersion. Because unbound antimicrobial agents can continuously diffuse to the polymer surface to react with microbes in contact with the surface, such an approach could produce durable functional materials.<sup>12</sup>

BP, an aromatic ketone (diphenyl ketone), is an important compound in organic photochemistry and perfumery as well as in organic synthesis. Therefore, it has been used as a constituent of synthetic perfumes and as a precursor compound for making dyes, pesticides, and drugs (especially anxiolytic and hypnotic drugs).<sup>13</sup> So far, there has been no report about the significant toxicity of the BP for human being. Also, BP has been used as a photoinitiator, which break down into free radicals upon exposure to ultraviolet radiation.<sup>13,14</sup> The BP chromophoric group-incorporated cellulose could be easily activated into radicals under not only UVA (365 nm) light but also fluorescent light irradiation, and the photoactivated BP groups on matrix polymers showed ability to decompose certain chemical compounds as well as the excellent antimicrobial activities.<sup>9–11</sup> Such results motivated us to explore the polymers containing BP chromophoric groups as a potential photoactivated self-decontamination polymer material applicable to hygiene gloves, protective masks, and surgical gowns. In this study, we prepared photoinduced antimicrobial polymers by incorporating the BP with conventional polymers, such as polystyrene (PS), polyethylene (PE),

Correspondence to: G. Sun (gysun@ucdavis.edu).

Contract grant sponsor: National Science Foundation; contract grant number: CTS-0424716.

polypropylene (PP), polyvinyl alcohol (PVA), and investigated the radical properties as well as structural properties.

## EXPERIMENTAL

### Materials

PS (atactic; average  $M_n$  140,000; average  $M_w$  230,000), PE (medium density), PP (isotactic; average  $M_w$  190,000; average  $M_n$  50,000), and PVA (atactic; 87–89% hydrolyzed; average  $M_w$  85,000–124,000) were purchased from Aldrich, MO. BP (99% pure) was purchased from Acros, NJ. Xylene and acetone, solvents for mixing BP with different polymers, were purchased from Acros, NJ. All the reagents were used as received without any further purification.

### Preparation

PS, PE, and PP were, respectively, dissolved in xylene (initial concentration 10 wt %) by heating up to around 100°C, and BP was dissolved in xylene at room temperature. When the polymers were completely dissolved in xylene, the BP/xylene solution was added to the polymer/xylene solutions, respectively. Then, the mixed solutions were stirred by a magnetic stirrer for 30 min. After thorough mixing, the solvent was completely removed in vacuum oven at room temperature.

PVA was dissolved in distilled water by heating up to around 80°C, and a BP/acetone solution was prepared at room temperature. The BP/acetone solution was added into the PVA/water solution, and then the mixture solution was stirred by magnetic stirrer for 30 min. Pristine polymer films of PS, PE, PP, and PVA were prepared as references.

On the other hand, PE and PP could not be casted into proper films from the polymer/xylene solutions, which seemed that the differences of dielectric constants between the polymers (PE pellet: 1.5; PP pellet: 1.5–1.8) and solvent (xylene: 2.2–2.6) are each bigger than that of difference of dielectric constant between PS (2.4–2.6) and solvent (xylene: 2.2–2.6).<sup>15</sup> Therefore, all polymers prepared were each melted on slide glasses and cast into the films. In addition, according to the previous report,<sup>16</sup> the postheat treatment would make the PVA and PVA/BP films insoluble in water.

To photoactivate the radicals in the BP-incorporated polymers, UVA light (bandwidth: 365 nm; five 8 W lamps (12''); sample to bulb distance: 15.8 cm) was used.

### Characterization

Fourier transform infrared (FTIR) spectroscopy was performed with a Nicolet 6700 FTIR spectrometer

(Thermo Scientific, USA) with a resolution of 4 cm<sup>-1</sup>, and the measurements were carried out with a KBr support. Thermal behaviors of the polymers were characterized using a differential scanning calorimeter (DSC), Shimadzu DSC-60 (Shimadzu, USA), under nitrogen atmosphere with programmed heating of 10°C/min. X-ray diffraction (XRD) measurements were performed at room temperature with Cu K $\alpha$  X-rays ( $\alpha = 1.5418 \text{ \AA}$ ) with a D8 Advance (Bruker, Germany). Theta-theta wide angle goniometer was used and the ultimate peak resolution was  $2\theta = 0.025^\circ$ . Data were recorded from 10 to 30° in steps of 0.02°. A field emission scanning electron microscope (FE-SEM) (Philips XL30, USA) was used for high-magnification observation of the polymer film surfaces. Hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>) production analyses were conducted as follows: we irradiated the polymer films by UVA light for 1 h and then dripped one drop of distilled water (0.1 mL) on the polymer film surfaces, and left them in dark chamber for 1 h. Subsequently, we detected H<sub>2</sub>O<sub>2</sub> created in the water drops by the peroxide test strip (Code 2984LR, LaMotte, MD). Antimicrobial activity of the polymer films was tested against *Staphylococcus aureus* (*S. aureus*) (ATCC 12600) and *Escherichia coli* (*E. coli*) (K-12) according to the modified testing method for antibacterial activity of film (DOW 0923). The antimicrobial test was conducted by following procedures: 0.1 mL of diluted microbial aqueous solution was dropped on the polymer films to cover the same area on the films. Following the inoculation, UVA light was irradiated on the polymer films covered by microbial solution for 1 h. After then, the film was immersed in quenching solution (distilled water) in a sterilized container, and the container was placed in a shaker for 5 min. And then, 0.1 mL of microbial suspension was taken from the container and placed onto agar plate, and incubated at 37°C for 18 h. The reduction of bacteria was calculated according to the following eq. (1).

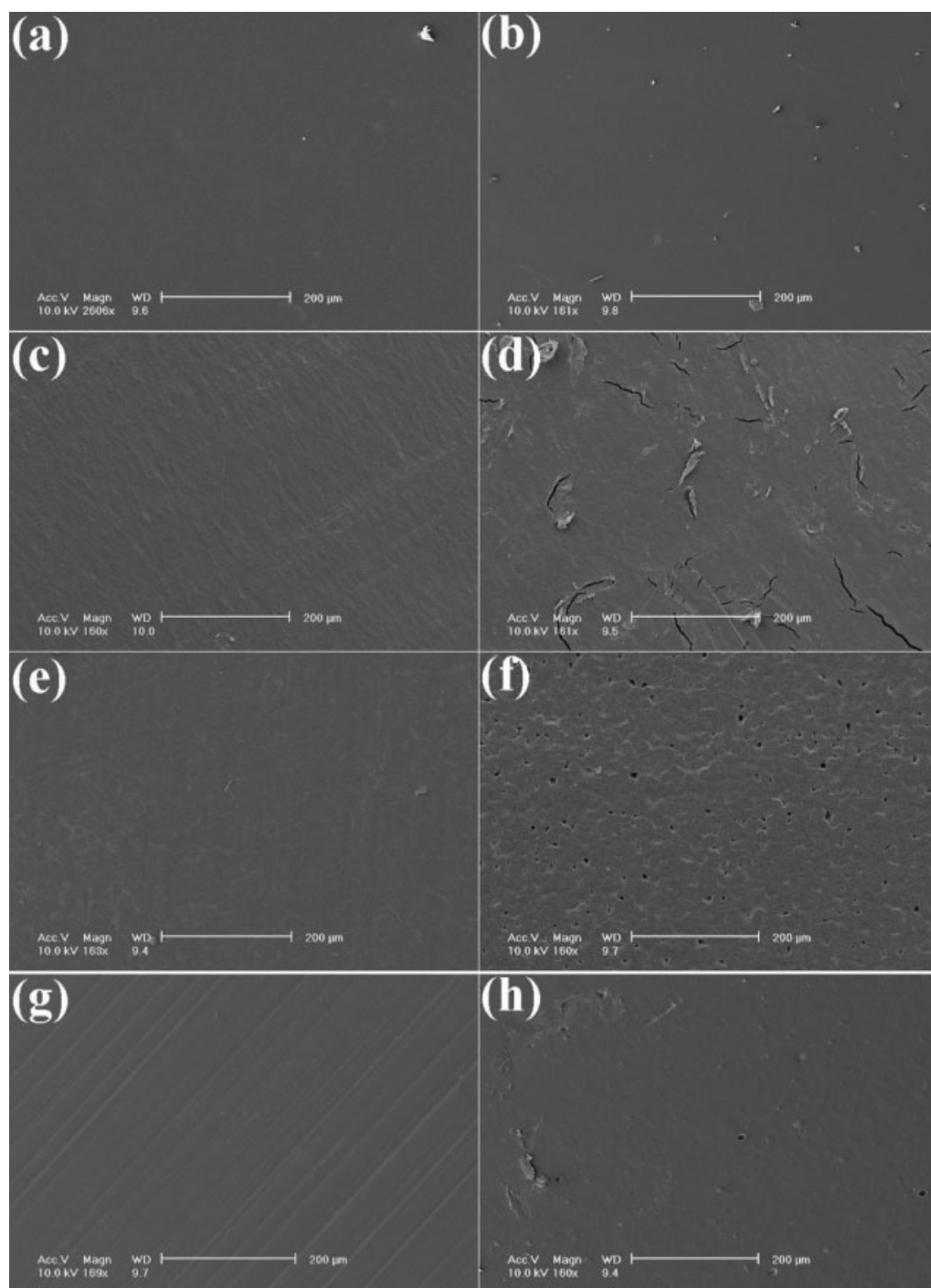
$$\text{Reduction of bacteria (\%)} = \frac{(B - A)}{B} \times 100 \quad (1)$$

where  $A$  and  $B$  are the surviving cells (colony forming unit mL<sup>-1</sup>) on the agar plates corresponding to the test polymer sample and the control, respectively. All the antimicrobial tests were conducted with at least triplicates of samples ( $n = 3$ ), respectively.

## RESULTS AND DISCUSSION

### Preparation and structures

BP (0.5 wt %, based on the weight of polymer powder)-incorporated polymer films, PS/BP, PE/BP, PP/BP, and PVA/BP, as well as pristine polymer

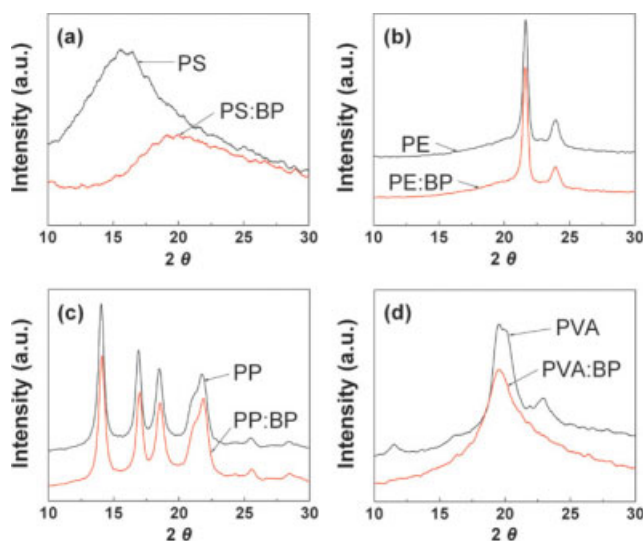


**Figure 1** SEM images of pristine polymer film and BP-incorporated polymer films; (a) PS, (b) PS/BP, (c) PE, (d) PE/BP, (e) PP, (f) PP/BP, (g) PVA, and (h) PVA/BP.

films, PS, PE, PP, and PVA, were prepared, respectively. Figure 1 shows the SEM of the polymer films and most of them are in proper surface morphologies, smooth surfaces. However, tiny cracks or pores were observed on the surfaces of the PE/BP [Fig. 1(d)] and the PP/BP film [Fig. 1(f)]. Addition of BP affected the solid arrangements of polymer chains in PE and PP, respectively, which have relatively higher crystalline than PS and PVA. Thus, in

the PE/BP and PP/BP blend films, the intermolecular interactions of the polymer chains might be interfered and reduced, which lead to formation of cracks.

XRD patterns of the polymer films are shown in Figure 2. The XRD patterns of PE/BP and PP/BP films each showed the characteristic crystalline peaks of pristine PE and PP films; PE/BP displayed typical diffracting peaks at  $21.6^\circ$  and  $23.8^\circ$ ,



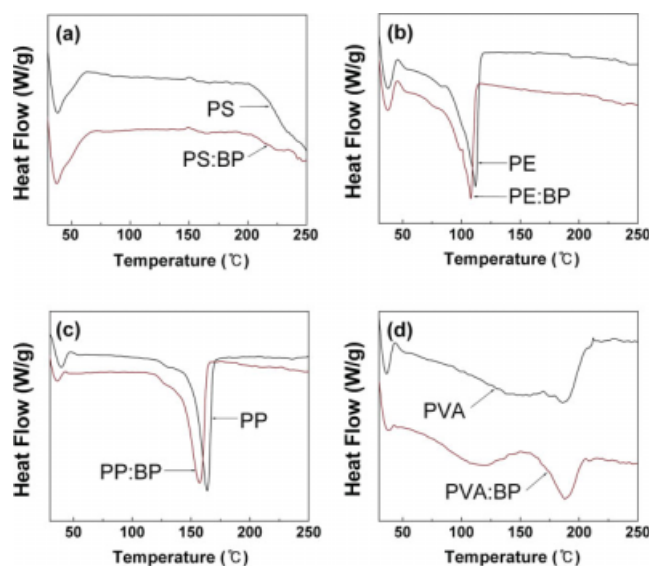
**Figure 2** XRD patterns of pristine polymer film and BP-incorporated polymer films; (a) PS and PS/BP, (b) PE and PE/BP, (c) PP and PP/BP, and (d) PVA and PVA/BP. [Color figure can be viewed in the online issue, which is available at [www.interscience.wiley.com](http://www.interscience.wiley.com).]

corresponding to the (110) and (200) crystalline plane of PE,<sup>17</sup> and PP/BP showed characteristic diffracting peaks at  $2\theta = 14.0^\circ$ ,  $16.9^\circ$ ,  $18.5^\circ$ ,  $21.2^\circ$ , and  $21.8^\circ$ , corresponding to the respective (1 1 0), (0 4 0), (1 3 0), (1 1 1), and (0 4 1) planes of the  $\alpha$ -phase crystal of PP.<sup>18</sup> Meanwhile, PS/BP and PVA/BP films, respectively, showed only broad amorphous peak<sup>19</sup> and semicrystalline peaks<sup>20</sup> in the XRD patterns. Therefore, the incorporated BP did not significantly affect the interstructural phase of the polymer matrices. However, all polymers showed slight decreases in peak intensities after incorporating BP in the polymer systems, as shown in Table I. Therefore, it was possible that the mechanical properties like modulus of the polymers could be affected by the addition of BP. On the other hand, it was observed that the long-range order peak (around  $2\theta = 12^\circ$ ) and higher order peak (around  $2\theta = 23.8^\circ$ ) created by heat treat-

**TABLE I**  
Crystallinity Values of Pristine Polymer Films and BP-Incorporated Polymer Films

Pristine polymers	Crystallinity (%)	BP-incorporated polymer	Crystallinity (%)
PS <sup>a</sup>	–	PS/BP	–
PE	31.86	PE/BP	29.08
PP	55.90	PP/BP	50.58
PVA <sup>a</sup>	–	PVA/BP	–

<sup>a</sup> PS and PVA have no crystalline peaks in their XRD spectra.

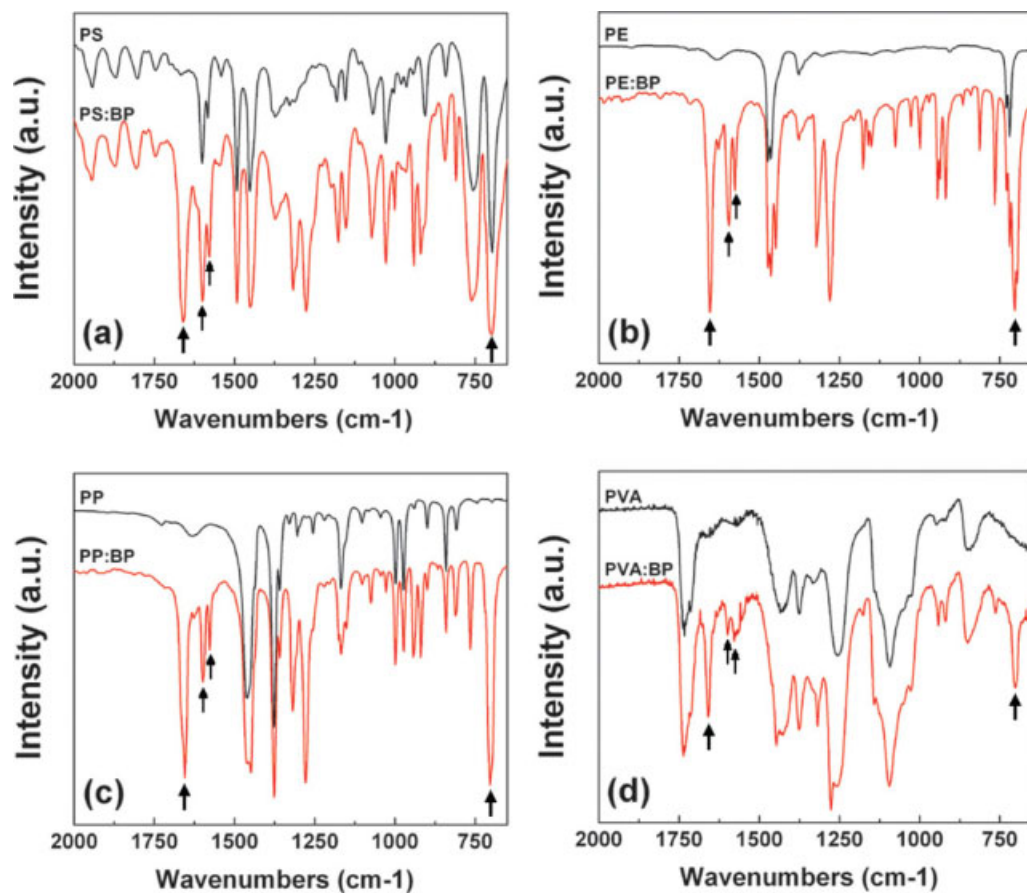


**Figure 3** DSC thermograms of pristine polymer film and BP-incorporated polymer films; (a) PS and PS/BP, (b) PE and PE/BP, (c) PP and PP/BP, and (d) PVA and PVA/BP. [Color figure can be viewed in the online issue, which is available at [www.interscience.wiley.com](http://www.interscience.wiley.com).]

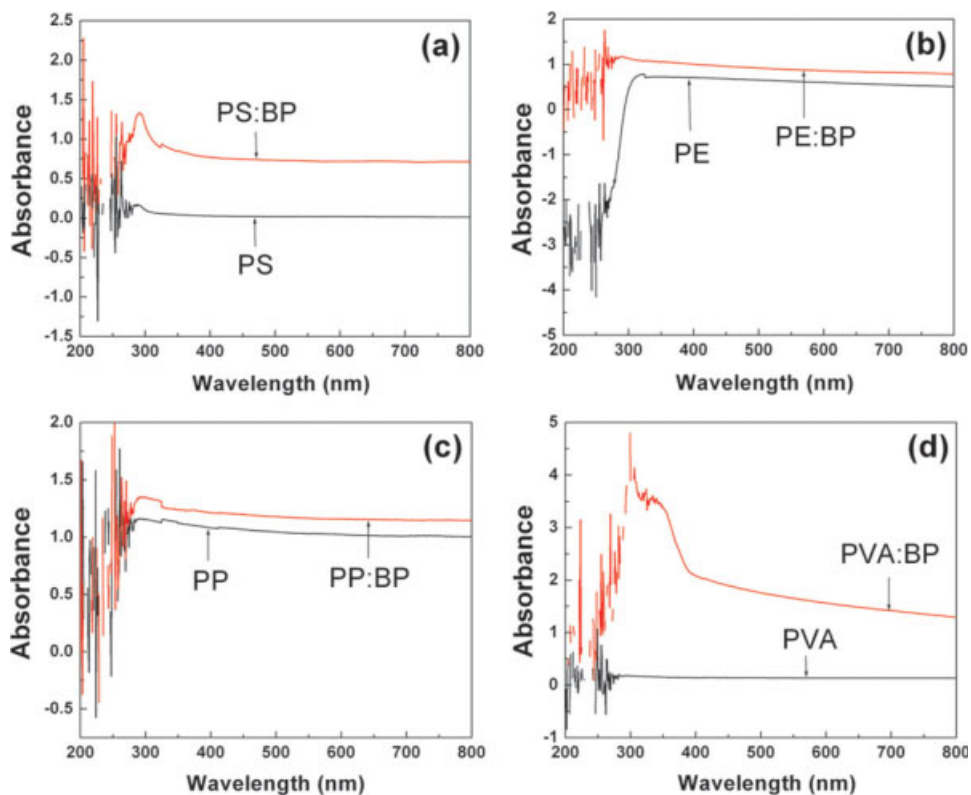
ment<sup>16</sup> in the curve of pristine PVA film disappeared in the curve of heat-treated PVA/BP film. Hence, it was presumed that the insolubilization of PVA/BP film in water was not achieved by heat treatment, different from the pristine PVA film.

Thermal properties of the pristine polymer films and the BP-incorporated polymer films were analyzed and compared by DSC analysis, as shown in Figure 3. Overall, the endothermic peaks of the pristine polymers in DSC curves decreased with addition of BP into the polymers, an indication of decrease in crystallinity of the polymers. And, this result is consistent to the previous XRD result. Hence, it was thought that although the addition of BP into the polymers did not significantly affect the polymer structures, it would slightly widen the space between the adjacent main polymer chains and reduce Van der Waals' forces between the adjacent polymer chains. On the other hand, no significant phase separation occurred in the composite system because no  $T_m$  peak of BP ( $T_m$  of BP:  $47.9^\circ\text{C}$ ) was observed in the DSC curves. Therefore, it was thought that the polymer composite systems were homogeneously formed.

Figure 4 shows the FTIR-ATR spectra of pristine polymer films and BP-incorporated polymer films. In the BP-incorporated polymers, the BP characteristic peaks can be observed. The peak at  $1651\text{ cm}^{-1}$  is the vibration of carbonyl C=O double bond, and the peaks at around  $1580\text{ cm}^{-1}$  are the aromatic C=C double bond stretch, and the peak at  $700\text{ cm}^{-1}$  is assigned to the out of plan C–H vibration of the



**Figure 4** FTIR spectra of pristine polymer film and BP-incorporated polymer films; (a) PS and PS/BP, (b) PE and PE/BP, (c) PP and PP/BP, and (d) PVA and PVA/BP. [Color figure can be viewed in the online issue, which is available at [www.interscience.wiley.com](http://www.interscience.wiley.com).]



**Figure 5** UV-vis spectra of pristine polymer film and BP-incorporated polymer films; (a) PS and PS/BP, (b) PE and PE/BP, (c) PP and PP/BP, and (d) PVA and PVA/BP. [Color figure can be viewed in the online issue, which is available at [www.interscience.wiley.com](http://www.interscience.wiley.com).]

**TABLE II**  
Antimicrobial Abilities of Pristine Polymer Films and BP-Incorporated Polymer Films Against *S. aureus*

	Colony numbers on agar plates after incubation	Bacteria reduction % from blank	Bacteria reduction % from pristine polymer
Blank	131	–	–
Pristine PS	16	87.79	–
PS/BP (0.25 wt %)	4	96.95	75.00
PS/BP (0.5 wt %)	1	99.24	93.75
PS/BP (1.0 wt %)	0	100	100
Pristine PE	27	79.39	–
PE/BP (0.25 wt %)	20	84.73	25.93
PE/BP (0.5 wt %)	3	97.71	88.89
PE/BP (1.0 wt %)	0	100	100
Pristine PP	24	81.68	–
PP/BP (0.25 wt %)	16	87.79	33.33
PP/BP (0.5 wt %)	12	90.84	50.00
PP/BP (1.0 wt %)	5	96.18	79.17
Pristine PVA	1	99.24	–
PVA/BP (0.25 wt %)	0	100	100
PVA/BP (0.5 wt %)	0	100	100
PVA/BP (1.0 wt %)	0	100	100

**TABLE III**  
Antimicrobial Abilities of Pristine Polymer Films and BP-Incorporated Polymer Films Against *E. coli*

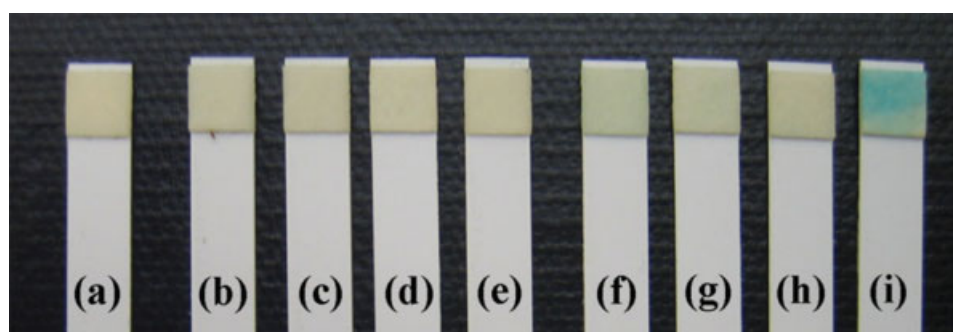
	Colony numbers on agar plates after incubation	Bacteria reduction % from blank	Bacteria reduction % from pristine polymer
Blank	178	–	–
Pristine PS	13	87.08	–
PS/BP (0.25 wt %)	1	94.38	92.31
PS/BP (0.5 wt %)	1	94.94	92.31
PS/BP (1.0 wt %)	0	98.31	100
Pristine PE	35	80.34	–
PE/BP (0.25 wt %)	24	86.52	31.43
PE/BP (0.5 wt %)	1	99.44	97.14
PE/BP (1.0 wt %)	0	100	100
Pristine PP	25	85.96	–
PP/BP (0.25 wt %)	18	89.89	28
PP/BP (0.5 wt %)	11	93.82	56
PP/BP (1.0 wt %)	8	95.51	68
Pristine PVA	6	97.74	–
PVA/BP (0.25 wt %)	0	100	100
PVA/BP (0.5 wt %)	0	100	100
PVA/BP (1.0 wt %)	0	100	100

monosubstituted benzene ring.<sup>9–11,21</sup> Therefore, it was verified that BP exists on the surface of the composite films, and so it seemed the BP would reveal its functionality on the surface of the composite films.

Figure 5 shows the UV–vis spectra of pristine polymer film and BP-incorporated polymer films. Overall, the BP-incorporated polymer films absorbed more photons than pristine polymer films, and in particular, the absorbance peak intensities around 300 nm tend to be dominant. Therefore, the incorporated BP in the composite polymers shows its own chemical and photoreactive functionalities.

### Antimicrobial ability

Antimicrobial functions of the BP-incorporated polymer films in different BP concentrations were investigated against *S. aureus* and *E. coli* under UVA irradiation, the results are shown in Tables II and III. All BP-incorporated polymer films show certain photoinduced antimicrobial activities, and the effectiveness tends to increase as the BP concentration increased. And it was observed that the PVA/BP film demonstrated the best antimicrobial functions, and the PP/BP film showed the worst antimicrobial effectiveness in the BP-incorporated polymer films. PVA films are quite hydrophilic and thus were observed to absorb bacteria aqueous solution and



**Figure 6** Peroxide test strip result for water drop on pristine polymer film and BP-incorporated polymer films after fifth repeat cycles; (a) distilled water, (b) PS, (c) PS/BP, (d) PE, (e) PE/BP, (f) PP, (g) PP/BP, (h) PVA, and (i) PVA/BP. [Color figure can be viewed in the online issue, which is available at [www.interscience.wiley.com](http://www.interscience.wiley.com).]

**TABLE IV**  
**Hydrogen Peroxide Extracted from Pristine Polymer**  
**Films and BP-Incorporated Polymer Films**

	Hydrogen peroxide yield (ppm)	
	After first cycle	After fifth repeat cycles
Distilled water	0	0
Pristine PS	0	0
PS/BP (0.5 wt %)	<1	<1
Pristine PE	0	0
PE/BP (0.5 wt %)	<1	<1
Pristine PP	0	0
PP/BP (0.5 wt %)	<1	<1
Pristine PVA	0	0
PVA/BP (0.5 wt %)	3–10	3–10

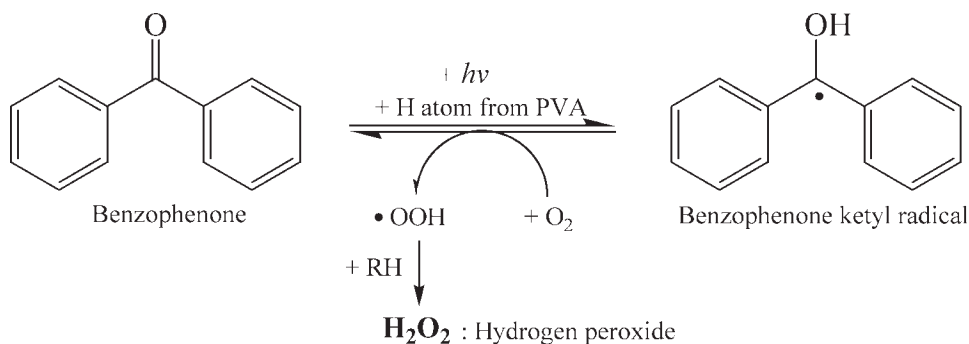
became swollen during the antimicrobial tests. Therefore, the PVA matrix could absorb and capture bacteria from the bacteria solution, which lead to difficulty of bacterial removal from the films. This is a reason that the pristine PVA film even revealed some antimicrobial ability as shown in Tables II and III. However, the antibacterial functions of PVA/BP films are due to formation of triplet radicals and potential production of  $H_2O_2$ . Photoirradiated BP is well known to attract H atoms from suitable hydrogen donors such as amines or alcohol (i.e., PVA) and form corresponding benzophenone ketyl (BPK) radicals.<sup>22</sup> And when exposed to oxygen, the BPK radicals rapidly reoxidize to form BP with an accompanying formation of  $H_2O_2$ .<sup>22,23</sup> This is consistent with the UV spectrum of PVA/BP, which has a very high UV absorbance. On the other hand, in case of PP/BP film, the PP is the most water-repellent in the polymers we prepared,<sup>24</sup> so bacterial solution seemed not to contact sufficiently with the polymer surface. And also, PP is instinctively oxidized easily by daylight (UV),<sup>25</sup> so it was thought that the electron-deficient PP polymer backbone might reduce the radical activity of BP in the PP/BP films.

### Hydrogen peroxide production

Figure 6 and Table IV show the formation of  $H_2O_2$  from the surfaces of the polymer films we prepared and tested. The PVA/BP film demonstrated significant positive response to  $H_2O_2$  test strip, and the positive response repeatedly continued over five test cycles, as shown in Figure 5. Therefore, the anticipated scheme of producing  $H_2O_2$  from the PVA/BP film could be depicted, as shown in Scheme 1. Consequently, we knew that the 100% antimicrobial efficacy of the PVA/BP films (see Tables II and III) could be attributed to  $H_2O_2$  as well as photoactivated BP moieties. Thus, the PVA/BP film is able to reveal antimicrobial ability even in the dark condition if they were exposed to light.

### CONCLUSIONS

BP-incorporated polymer films, PS/BP, PE/BP, PP/BP, and PVA/BP film were prepared, and the structural and photoactivated properties were investigated. Polymer blend films were successfully prepared with addition of BP at 0.5 wt % in the composite system. However, through DSC and XRD investigation, it was revealed that the structural and mechanical properties of all the polymer films were slightly damaged by the addition of BP. In particular, it seemed that the addition of BP could result in more damages to mechanical properties of PE and PP according to SEM observation. On the other hand, all the BP-incorporated films showed antimicrobial abilities under UVA (365 nm) irradiation, and the effectiveness increased as the incorporated BP concentration increased. And, PVA/BP composite films showed the best antimicrobial effectiveness, and PP/BP composite films showed the most inferior antimicrobial effectiveness in the BP-incorporated polymers. On the other hand, photoirradiated PVA/BP composite films created  $H_2O_2$  in atmospheric dark chamber.



**Scheme 1** Schematic reaction of producing hydrogen peroxide in PVA/BP film.

## References

1. Holzmann, R. D.; Liang, M.; Nadiminti, H.; McCarthy, J.; Gharia, M.; Jones, J.; Neel, V.; Schanbacher, C. F. *J Am Acad Dermatol* 2008, 58, 817.
2. Ganczak, M.; Szych, Z. *J Hosp Infect* 2007, 66, 346.
3. Carleton, F. J.; Agalloco, J. P. *Validation of Pharmaceutical Processes: Sterile Products*; Informa Health Care: New York, 1999; p 358.
4. Tan, K.; Obendorf, S. K. *J Membr Sci* 2007, 305, 287.
5. Sun, Y.; Sun, G. *Ind Eng Chem Res* 2004, 43, 5015.
6. Schreuder-Gibson, H. L.; Truong, Q.; Walker, J. E.; Owens, J. R.; Wander, J. D.; Jones, W. E., Jr. *MRS Bull* 2003, 28, 574.
7. Horrocks, A. R.; Anand, S. C., Eds. *Handbook of Technical Textiles*; Woodhead Publishing Limited: Cambridge, UK, 2000; p 38.
8. Singh, A.; Lee, Y.; Dressick, W. J. *Adv Mater* 2004, 16, 2112.
9. Hong, K. H.; Sun, G. *J Appl Polym Sci* 2007, 106, 2661.
10. Hong, K. H.; Sun, G. *Carbohydr Polym* 2008, 71, 598.
11. Hong, K. H.; Sun, G. *Polym Eng Sci* 2007, 47, 1750.
12. Bilyk, A.; Li, S.; Murphy, J.; Petinakis, S.; Zerdin, K.; Scully, A. *Prog Org Coat* 2008, 62, 40.
13. Chemicalsearching website hosted and developed by Arokor Holdings Inc. Available at: <http://chemicalland21.com/specialtychem/finechem/BENZOPHENONE.htm>, Accessed January, 2008.
14. Jeon, H. K.; Sarma, S. N.; Kim, Y. J.; Ryu, J. H. *Toxicology* 2008, 248, 89.
15. López, D.; Reinecke, H.; Mijangos, C. *Macromol Symp* 2001, 166, 25.
16. Hong, K. H. *Polym Eng Sci* 2007, 47, 43.
17. Krimm, S.; Tobolsky, A. V. *J Polym Sci* 1951, 7, 57.
18. Bao, S. P.; Tjong, S. C. *Mater Sci Eng A* 2008, 485, 508.
19. Chen, H.; Xu, H.; Cebe, P. *Polymer* 2007, 48, 6404.
20. Koji, N.; Tomonori, Y.; Kenji, I.; Fumio, S. *J Appl Polym Sci* 1999, 74, 133.
21. FTIR information of benzophenone (purified by sublimation,  $\geq 99\%$ ) product in Aldrich home page. Available at: <http://www.sigmaaldrich.com/spectra/ftir/FTIR007399.PDF>, Accessed January, 2008.
22. Korchev, A. S.; Konovalova, T.; Cammarata, V.; Kispert, L.; Slaten, L.; Mills, G. *Langmuir* 2006, 22, 375.
23. Görner, H. *Photochem Photobiol* 2003, 77, 171.
24. Butt, H. J.; Graf, K.; Kappl, M. *Physics and Chemistry of Interfaces*; Wiley-VCH: Germany, 2006; p 127.
25. Polypropylene information in Wikipedia website. Available at: <http://en.wikipedia.org/wiki/Polypropylene>, Accessed May, 2008.