The effect of surface morphology on the peel performance of UV-induced adhesion-reducing adhesives

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Abstract
In this paper, end-hydroxy fumaryl chloride-diol copolyesters (EHFDCP) with different double bond contents were prepared by the reaction of fumaryl chloride and diols. The molecular weight of the target hydroxy polyster was controlled to be essentially the same, EHFDCP prepared from 1,8-octanediol, 1,5-pentanediol and ethylene glycol named EHFDCP-1, EHFDCP-2 and EHFDCP-3, respectively. The UV-induced adhesion-reducing adhesives (ARA) were prepared with EHFDCP, isophorone diisocyanate (IPDI), chain extender and photoinitiator. The ARA-1, ARA-2 and ARA-3 were produced by EHFDCP-1, EHFDCP-2 and EHFDCP-3, respectively. After UV curing, all the surfaces of ARA-1, ARA-2, and ARA-3 had a high number of concave and convex areas, which helped to reduce the contact area between the adhesive and the substrate surface. The surface roughness of ARA-2 is the highest and the adhesion reduction effect is the most significant. The higher surface roughness of ARA-2 came from moderate double bond content and crosslinking density. With the increasing photoinitiator content, the 180° peel strength after UV curing decreased. The 180° peel strength of ARA-2 was reduced to 0.16 N/25 mm at 4 wt% of photoinitiator content, and it also had a high initial 180° peel strength of 18.55 N/25 mm due to the absence of small molecule polyfunctional monomers.

1. Introduction
Semiconductor chips are indispensable basic materials in large-scale integrated circuits and electronic devices [1, 2]. The processing of semiconductor chip involves grinding and cutting of wafers, which is thin, brittle, and easy to break and fly apart during processing, so a peelable special tape is needed to bond and fix the wafers [3–5]. The tape has a high adhesive strength, which allows it to hold silicon wafers during processing [6]. After processing, the tape loses its adhesive properties and the wafers can be easily picked up [7, 8]. Some adhesion-reducing adhesives have been reported in recent years, and they can be divided into three types: degradation-induced debonding, and light/heat and UV induced crosslinking debonding [9–12].

The adhesives of degradation-induced debonding compose of degradable polymers [13]. The adhesive broke down into small molecules, and the peel strength reduced considerably when it was exposed to light or heat [14]. Sugita et al [15] used decomposable multi-acrylate oligomers to prepare an adhesion-reducing adhesive, after post-exposure-bake, the adhesive decomposed into olefin and carboxylic acid derivatives, and debonded from glass panels. Sasaki et al [16] prepared a novel photo-separable adhesive base on poly (olefin sulfone), which showed high adhesive strength on quartz plates. When the adhesive was exposed to UV light and heated to 100 °C, the poly (olefin sulfone) depolymerized and released gaseous material resulting in a drastic decreasing in bond strength. However, the degradation of polymers to small molecules usually takes a long time and produces volatile gases. Furthermore, the residues of adhesive are difficult to remove completely.

The adhesives of light/heat induced dual curing debonding are generally prepared from various acrylate polymers, reactive diluents, photoinitiators, and heat curing agents [17–19]. Zhu et al [20] prepared a polyacrylate pressure-sensitive adhesive by light/heat double curing. The tack force and peel strength of the
adhesive decreased with the increase content of the thermal cross-linker KL-1202. However, this curing process has high energy consumption, low efficiency, high cost, and poor debonding ability.

Another candidate strategy is the adhesives with UV-induced crosslinking debonding [21–23]. After UV irradiation, the adhesive shrinks greatly in volume through the polymerization of multifunctional oligomers, resulting in a significant reduction in peel strength [24, 25]. This method has outstanding advantages such as fast reaction rate, high efficiency, and low energy consumption [26–30]. Hao et al. [31] used polyethylene glycol-modified isophorone disiocyanate oligomer (PEG-IPDI) and acrylic acid copolymer to prepare adhesion-reducing adhesives. The peel strength significantly reduced and the residual adhesive was very low after UV irradiation due to the formation of an IPN structure. Han et al. [32] used 2-isocyanatoethyl methacrylate to modify a hydroxyl-containing acrylate copolymer, and further mixed with a photoinitiator and aziridine crosslinker to prepare the adhesive. The adhesive exhibited good debonding ability after 40 s of UV irradiation and was suitable for wafer cutting and grinding processes. However, the addition of multifunctional oligomers may weaken the cohesive force of the adhesive and reduce the initial peel strength [33–35]. In addition, unreacted oligomers can easily transfer to the wafer surface and cause contamination [36].

In this paper, end-hydroxy fumaryl chloride-diol copolyester (EHFDPC) was designed and synthesized. A series of UV-induced adhesion-reducing adhesives were prepared by reacting the hydroxyl group of EHFDCP with the isocyanate group of IPDI, and adding chain extender and photoinitiator. The initial 180° peel strength was high due to the absence of small molecule polyfunctional monomers, and the 180° peel strength after UV irradiation decreased significantly due to the crosslinking of the adhesive to form a concave convex surface structure. This paper reveals the effect of surface morphology on the peel performance of UV-induced adhesion-reducing adhesives.

2. Experimental

2.1. Materials

Fumaryl chloride (GC), 1,5-pentanediol (AR), ethylene glycol (AR), 1,8-octanediol (AR), dibutyltin dilaurate (AR), triethylamine (GC), 1-hydroxycyclohexyl phenyl ketone (AR), 4-tert-butylpyrocatechol (AR), tetrahydrofuran (THF, AR), and ethyl acetate (GC) were purchased from Aladdin Co., Ltd. Isophorone disiocyanate (IPDI, AR) and 1,4-butanediol (AR) were provided by Macklin Co., Ltd. All materials were used as received except THF, which was treated with metallic sodium to remove water before using.

2.2. Preparation of EHFDCP

1,8-octanediol (15.18 g), triethylamine (16.16 g) and 4-tert-butylpyrocatechol (0.03 g) were dissolved in 50 mL dry THF. The mixture was added to a 250 mL three-necked flask equipped with a mechanical stirrer, constant pressure funnel, and nitrogen inlet. Under the protection of nitrogen, 40 mL THF containing 12.24 g fumaryl chloride was added dropwise through the constant pressure funnel at 5 °C, and the reaction was carried out for 1 h. Then the reaction solution was warmed up to 30 °C and reacted for 2.5 h. Triethylamine hydrochloride byproduct was removed by centrifugation, and the product was obtained by precipitation using deionized water, then washed with deionized water several times. Finally, the polymer product was dried under high vacuum at 50 °C for at least 8 h to obtain EHFDCP-1 [37].

The synthesis step of EHFDCP-2 and EHFDCP-3 was the same as that of EHFDCP-1 by using 1,5-pentanediol and ethylene glycol instead of 1,8-octanediol, respectively. The synthesis route was shown in scheme 1.

2.3. Preparation of UV-induced adhesion-reducing adhesive (ARA)

EHFDCP-1 (5 g), IPDI (2.250 g), and dibutyltin dilaurate (0.015 g) were dissolved in 15 mL ethyl acetate. The molar ratio of NCO/OH was fixed at 1.2. The mixture was added to a 100 mL three-necked flask equipped with a
mechanical stirrer, reflux condenser, and nitrogen inlet. Under the protection of the nitrogen, the mixture reacted at 60 °C for 3 h. Then, the chain extender 1,4-butanediol (0.5 g) was added into the flask, and the reaction continued for 1 h. Finally, 1-hydroxycyclohexyl phenyl ketone (0.233 g) was added to the solution and the mixture was stirred at room temperature for about 1 h to obtain the isocyanate-terminated ARA-1.

In a similar manner, ARA-2 and ARA-3 were prepared from the EHFDCP-2 and EHFDCP-3, respectively. The synthesis route was shown in scheme 2.

2.4. Preparation of the ARA tape
The ARA was coated onto the polyolefin film treated by corona with a thickness of 50 μm using wet film applicator and then aged at room temperature for 24 h.

2.5. Characterization
2.5.1. Hydroxyl value
The hydroxyl value was measured according to the method described in ISO 2554-1974.

2.5.2. Fourier transform infrared (FTIR) spectroscopy
The FTIR spectra were measured on a Nicolet iS50 (Nicolet, USA) FT-IR Spectrometer by coating samples on KBr chips. The wavenumber range was 400–4000 cm⁻¹, and the resolution was 2 cm⁻¹.

2.5.3. ¹H NMR spectroscopy
The ¹H NMR spectra were recorded using a VNMRS 600 spectrometer (Agilent, USA). All samples were analyzed using CDCl₃ as solvent and tetramethylsilane (TMS) as internal reference.

2.5.4. Gel permeation chromatography
Average molecular weight and molecular weight distribution were determined by a GPC instrument (Waters 1525, USA). Polystyrene standards were used for calibration and THF was used as carrier solvent.

2.5.5. 180° peel strength
The silicon wafers cutted into 25 mm wide were glued to the stainless-steel plate, the tape was attached to the wafers and a 2 kg rubber roller was rolled over them twice. The samples were allowed to place at room
temperature for 24 h to measure the 180° peel strength of before and after UV irradiation. The sample was cured by using a 1KW UV lamp (the wavelength of UV lamp is 365 nm) to irradiate 60 s. The 180° peel strength of the tape was measured using a universal testing machine CMT4304 (Shenzhen Sans, China) according to ISO 29862: 2007. The peeling speed was 300 mm min⁻¹.

2.5.6. SEM
The surface morphology of the samples was observed by a field-emission scanning electron microscope Gemini 500 (ZEISS, Germany). All samples were sprayed with a thin layer of gold before SEM observation.

2.5.7. Laser confocal 3D measurement microscope
3D surface morphology observation of the samples was carried out with a laser confocal 3D measurement microscope VK-X250 (KEYENCE, Japan). The resulted pictures were further analyzed and processed with MultiFileAnalyzer software. The surface roughness parameters including the arithmetic average height (Sa), root mean square height (Sq), maximum peak height (Sp), maximum valley height (Sv) and the maximum height (Sz) were obtained.

2.5.8. The crosslinking density (Ve)
The Ve of the samples was determined by swelling experiments [38].

3. Results and discussion

3.1. Synthesis and characterization of EHFDCP
Diols containing methylene groups of varying lengths (1,8-octanediol, 1,5-pentanediol, and ethylene glycol) were used to react with fumaryl chloride for synthesizing polyesters with hydroxyl groups as end groups. The molecular weight of the target hydroxy polyesters was controlled to be essentially the same, and the content of carbon-carbon double bond in the main chain gradually increased from EHFDCP-1 to EHFDCP-3. The molar ratios of diols to chloride in the feedstock were listed in table 1. As shown in figure 1, the number-average molecular weights (Mn) of EHFDCP-1, EHFDCP-2 and EHFDCP-3 were 1282, 1482 and 1404 g mol⁻¹.
respectively, and the hydroxyl value of EHFDCP-1, EHFDCP-2 and EHFDCP-3 were 64.83, 69.91 and 74.05 mg KOH/g, respectively.

$^1$H NMR spectra of EHFDCP-1, EHFDCP-2 and EHFDCP-3 were shown in figure 2. In the spectrum of EHFDCP-1 (figure 2(a)), the peak at 6.84 ppm was attributed to the protons of $\text{–CH} = \text{CH}$–, the peak at 3.63 ppm was assigned to the protons of C–OH, and the peaks at 4.18 and 1.33–1.67 ppm corresponded to the protons of $\text{–CH}_2$–$\text{CH}_2$–$\text{CH}_2$–$\text{CH}_2$–$\text{CH}_2$–$\text{CH}_2$–$\text{CH}_2$–$\text{CH}_2$–. Similar results were presented in the spectra of EHFDCP-2 and EHFDCP-3 [39]. As shown in figure 2(b), the peak at 6.82 ppm was assigned to the hydrogen protons of $\text{–CH} = \text{CH}$–, the proton peaks of the long chain $\text{–CH}_2$–$\text{CH}_2$–$\text{CH}_2$–$\text{CH}_2$–$\text{CH}_2$–$\text{CH}_2$–$\text{CH}_2$–$\text{CH}_2$–$\text{CH}_2$– were found at 4.19 and 1.44–1.72 ppm, the peak of C–OH group was seen at 3.63 ppm. In the spectrum of EHFDCP-3 (figure 2(c)), the proton peak of $\text{–CH} = \text{CH}$–, C–OH, and $\text{–CH}_2$–$\text{CH}_2$– was at 6.89 ppm, 3.89 ppm, and 4.34–4.66 ppm, respectively. The solvent peak of the deuterated chloroform (CDCl$_3$) was at 7.26 ppm.
The FT-IR spectra of EHFDCP-1, EHFDCP-2, and EHFDCP-3 were shown in figure 3. The stretching vibration peak of C=O appeared at 1644 cm\(^{-1}\), and became weaker as the increasing length of –CH\(_2\)–. The absorption peak at 3446 cm\(^{-1}\) was attributed to the stretching vibration of hydroxy, the peak at 2858–2929 cm\(^{-1}\) represented the stretching vibration of C–H, and the absorption peaks at 1720 cm\(^{-1}\), 1160 cm\(^{-1}\) were ascribed to C=O stretch and C–O stretch patterns, which confirmed the formation of ester bond in synthesis of EHFDCP [40].

3.2. Adhesion reduction and surface morphology
The 180° peel strength of initial and after UV irradiation of ARA-1, ARA-2 and ARA-3 were measured and shown in figure 4. Before UV irradiation, the 180° peel strength of ARA-1, ARA-2 and ARA-3 were 16.5, 18.2 and 17.4 N/25 mm, respectively. All samples showed high initial 180° peel strength. The reason may be that there were no small molecule multifunctional monomers in the binder, and cohesion hardly reduced by plasticizing. In addition, the hydrogen bonding in carbamate (NHCOO), carbonyl group (C=O) and silicon wafer surface might further strengthen the initial bond strength [41, 42]. After UV irradiation, the 180° peel
strength of ARA-1, ARA-2 and ARA-3 decreased to 3.68, 0.46, 2.14 N/25 mm, respectively. The decrease of the 180° peel strength may be due to the adhesive shrank during the UV curing process. The most significant adhesion-reducing effect was obtained for ARA-2. It is likely that a special morphology formed by ARA-2 of moderate double bond content is benefit to reduce the adhesion during UV curing process.

Figure 5 shows the surface morphology of ARA-1 to ARA-3 after UV irradiation. The surfaces of ARA-1, ARA-2 and ARA-3 all showed a large number of concave and convex areas, which were due to the volume shrinkage caused by crosslinking of the adhesion-reducing adhesive under UV irradiation. The generation of the bumpy structure reduced the contact area between the adhesive and the surface of the substrate, resulting in reduced cohesion. In this study, ARA-2 showed the best adhesion reduction effect because it possessed the most obvious concave and convex structure and the maximum number of concave and convex areas in the same unit area compared with the other two samples.

Laser confocal 3D measurement microscope was used to observe the surface and 3D height images of ARA-1, ARA-2 and ARA-3 before and after UV curing, and the results were shown in figure 6. Before UV irradiation, the surface of ARA-1, ARA-2 and ARA-3 was very flat, which could facilitate the wetting and adsorption of ARA on the wafer surface, resulting in a high initial 180° peel strength. After UV curing, at the same scale, all three samples showed concave and convex structures on the surface, which reduced the contact area between the adhesive and the surface of the substrate, resulting in the decrease of 180° peel strength, but compared to ARA-1 and ARA-3, the concave and convex structures of ARA-2 were more obvious. This phenomenon was also confirmed by the 3D height images, where the Z-axis value of ARA-2 (11.94 μm) is much larger than that of ARA-1 (3.85 μm) and ARA-3 (6.77 μm). The surface roughness was usually used to characterize the concave and convex structure [43, 44]. The values of a series of roughness parameters, including Sa and Sq, were shown in table 2. It can be clearly seen that the Sa values of ARA-1, ARA-2 and ARA-3 were 0.34, 1.01 and 0.50 μm, respectively, and the Sq values were 0.44, 1.28 and 0.64 μm, respectively. The other three roughness parameters including Sp, Sv and Sz also revealed that the corresponding value of ARA-2 was the highest. Sdr indicates how much the unfolded area of the defined region increases compared with the area of the defined region. The Sdr of

![Image](image-url)
**Figure 7.** Effect of photoinitiator on the ARA-2 180° peel strength.

**Figure 8.** Laser confocal 3D measurement microscope images of ARA-2 with different photoinitiator contents after UV curing: (a) 1 wt%, (b) 2 wt%, (c) 3 wt%, (d) 4 wt% and (e) 5 wt%. 
Three kinds of EHFDCP with different double bond contents were synthesized and cured by varying the photoinitiator content. The roughness data showed that ARA-2 has the highest surface roughness. ARA-1, ARA-2, and ARA-3 were 0.06, 1.02, and 0.38, respectively. The above roughness data showed that ARA-2 has the highest surface roughness.

The crosslinking density has a great influence on the surface roughness of polymer [45]. Under UV irradiation, the crosslinking of adhesion-reducing adhesive increased the intermolecular forces and caused uneven stresses during UV curing, resulting in volume shrinkage and uneven surface. The Ve value after UV curing of ARA-1, ARA-2, and ARA-3 were $5.55 \times 10^{-3}$, $13.32 \times 10^{-3}$, and $31.21 \times 10^{-3}$ mol cm$^{-3}$, respectively. As the double bond content increased, the crosslinking density of ARA increased. At the proper crosslink density, the surface was the roughest, the concave and convex structure of the surface was more obvious, and the adhesion reduction effect was better. Yong et al. investigated the effect of crosslinker content on the surface microstructure of acrylic resin film. The results showed that when the crosslinker content increased from 0 to 0.2 wt%, the surface of the film became rough and presented a bumpy structure, and when the crosslinker content was further increased to 0.4 wt%, the surface of the film did not change much. The surface roughness is maximized under the appropriate crosslinking degree [46].

### 3.3. Effect of photoinitiator content on surface morphology

Table 3. Surface roughness parameters of ARA-2 with different photoinitiator contents after UV curing.

| Photoinitiator content (wt%) | Sa (μm) | Sz (μm) | Sp (μm) | Sq (μm) | Sv (μm) | Sdr |
|-----------------------------|---------|---------|---------|---------|---------|-----|
| 1                           | 0.88    | 9.04    | 4.25    | 1.11    | 4.79    | 0.68|
| 2                           | 0.96    | 8.48    | 3.10    | 1.20    | 5.38    | 0.81|
| 3                           | 1.01    | 11.94   | 6.08    | 1.28    | 5.86    | 1.02|
| 4                           | 1.19    | 13.37   | 5.22    | 1.49    | 8.15    | 1.37|
| 5                           | 1.14    | 12.75   | 5.10    | 1.45    | 7.64    | 1.28|

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### 3.3. Effect of photoinitiator content on surface morphology

Figure 7 shows the effect of the amount of photoinitiator on the 180° peel strength of ARA-2 before and after UV irradiation. Before UV irradiation, the initial 180° peel strength did not change much due to the addition of a small amount of photoinitiator, while after UV irradiation, the 180° peel strength decreased with the increase of photoinitiator content, and the 180° peel strength did not change much when the photoinitiator content was higher than 4 wt%. With the increase of photoinitiator concentration, the concentration of free radicals increased and the crosslinking reaction accelerated, which resulted in an increase of crosslinking density and a decrease of 180° peel strength. At 4 wt% photoinitiator content, the 180° peel strength was 18.55 N/25 mm before UV irradiation and reduced to 0.16 N/25 mm after UV curing. The 180° peel strength of tape produced by LINTEC Corporation was about 11.38 N/25 mm before UV irradiation and 0.56 N/25 mm after UV irradiation [31].

Figure 8 shows the surface and three-dimensional height images of ARA-2 after UV curing with different photoinitiators contents. The concave and convex microstructure is thought to help reduce the contact area between the adhesive and the substrate, thus achieving the adhesion reduction effect. As shown in Figure 8, when the photoinitiator content increased from 1 wt% to 4 wt%, the surface roughness became more obvious and the 180° peel strength decreased from 1.52 N/25 mm to 0.16 N/25 mm after UV irradiation, which was mainly because the increasing photoinitiator content increased the concentration of free radicals and accelerated the crosslinking reaction. When the photoinitiator content was increased to 5 wt%, the surface bumpy structure changed very little and the 180° peel strength after UV curing hardly changed.

The roughness data of ARA-2 with different photoinitiator contents were given in Table 3. With the increase of photoinitiator content, Sa increased from 0.88 μm to 1.19 μm, Sdr increased from 0.68 to 1.37, and reached the maximum when the content of photoinitiator was 4 wt%. The other roughness parameters including Sz, Sp, Sq and Sv also followed this trend. When the photoinitiator content increased to 5 wt%, the roughness parameters were roughly the same as that of 4 wt% photoinitiator.

### 4. Conclusion

Three kinds of EHFDCP with different double bond contents were synthesized and confirmed by FT-IR and 1H NMR, and three UV-induced adhesion-reducing adhesives were successfully prepared. All samples had high initial 180° peel strength due to the absence of small molecule multifunctional monomers. After UV curing, the different crosslinking density caused a difference in the surface morphology of the adhesive, which further resulted in the variable adhesion reduction effect. Compared with ARA-1 and ARA-3, the surface concave and convex structure of ARA-2 was the most obvious, which resulted in the best adhesion reduction, and the 180° peel strength decreased from 18.21 N/25 mm to 0.46 N/25 mm. The 180° peel strength of ARA-2 after UV irradiation was further reduced to 0.16 N/25 mm at 4 wt% photoinitiator content.
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Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

Conflicts of interest

The authors of this paper have no conflict of interest.

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References

[1] Dong Z. H and Lin Y. W 2020 Ultra-thin wafer technology and applications: a review Mat. Sci. Semicon. Proc. 105 104681
[2] Lee S. W, Lee T. H, Park J. W, Park C. H, Kim H. J, Song J. Y and Lee J. H 2014 Curing behaviors of UV-curable temporary adhesives for a 3D multichip package process J. Electron. Mater. 43 4246–54
[3] Saiki N, Yamazaki O and Ebe K 2008 UV/Heat dual-curable adhesive tapes for fabricating stacked packages of semiconductors J. Appl. Polym. Sci. 108 1178–83
[4] Ozawa T, Ishiwata S, Kano Y and Kasemura T 2000 Acrylate copolymer/ultraviolet curable oligomer blends as pressure-sensitive adhesives J. Adhesion. 72 1–16
[5] Lee S. W, Lee T. H, Park J. W, Park C. H, Kim H. J, Kim S. M, Lee S. H, Song J. Y and Lee J. H 2015 The effect of laser irradiation on peel strength of temporary adhesives for wafer bonding Int. J. Adhes. Adhes. 57 9–12
[6] Montméat P, Enot T, Pellat M and Fournel F 2017 Study of a silicon/glass bonded structure with a UV-curable adhesive for temporary bonding applications Microelectron. Eng. 173 13–21
[7] Gatty H. K, Niklaus F, Stemme G and Roehd N 2014 Temporary wafer bonding and debonding for 3D integration using an electrochemically active polymer adhesive ECS. J. Solid. State. Sci. 3 115–21
[8] Lee S. W, Park J. W, Kim H. J, Kim H. K and Ryu J. K 2012 Adhesion performance and microscope morphology of UV-curable semi-interpenetrated dicuring acrylic PSAs in Si-wafer manufacture process for MCP J. Adhes. Sci. Technol. 26 317–29
[9] Inui T, Sato E and Matsumoto A 2012 Pressure-sensitive adhesion system using acrylate block copolymers in response to photoirradiation and postbaking as the dual external stimuli for on-demand dismantling. ACS. Appl. Mater. Inter. 4 3214–32
[10] Lee S. H, You R, Yoon Y. J and Park W. H 2017 Preparation and characterization of acrylate pressure-sensitive adhesives based on UV and heat curing systems Int. J. Adhes. Adhes. 75 190–5
[11] Ryu C. M, Pang B. L, Kim H. I, Kim H. J, Park J. W, Lee S. W and Kim K. M 2013 Wettability and adhesion characteristics of photo-crosslinkable adhesives for thin silicon wafer Int. J. Adhes. Adhes. 40 197–201
[12] Do H. S, Park Y. J and Kim H. J 2006 Preparation and adhesion performance of UV-crosslinkable acrylic pressure sensitive adhesives J. Adhes. Sc. Technol. 20 1259–45
[13] Fritz N, Dao H, Allen S. A. B. and Kohl P A 2012 Polycarbonates as temporary adhesives Int. J. Adhes. Adhes. 38 45–9
[14] Yamanishi K, Sato E and Matsumoto A 2013 Precise synthesis of acrylic block copolymers and application to on-demand dismantlable adhesion systems in response to photoirradiation and postbaking J. Polymol. Sci. Tec. 26 239–44
[15] Sugita H, Itoh K, Itoh Y, Wada N, Kurita T. U, Hirose Y, Hatase K, Matsumoto H and Ichinohe D 2021 Multi-acrylate-based UV-curable dismantlable adhesives Int. J. Adhes. Adhes. 104 102758
[16] Sasaki T, Hashimoto S, Nogami N, Sugiyama Y, Mori M, Naka Y and Le K. V 2016 Dismantlable thermosetting adhesives composed of a cross-linkable poly (olefin sulfone) with a photobase generator ACS. Appl. Mater. Inter. 8 5880–5
[17] Zhan X. Y, Ye J. M, Yue L. P, Bai Y. P and Liu H H 2019 Heat resistance of acrylic pressure-sensitive adhesives based on commercial curing agents and UV/heat curing systems J. Appl. Polym. Sci. 136 67310
[18] Park Y. J, Lim D. H, Kim H. J, Park D. S and Sung K K 2009 UV- and thermal-curing behaviors of dual-curable adhesives based on epoxy acrylate oligomers Int. J. Adhes. Adhes. 29 710–7
[19] Kim Y. B, Park S. C, Kim H K and Hong J W 2008 Dual-curable acrylic pressure-sensitive adhesives based on UV and thermal processes Macromol. Res. 16 128–33
[20] Zhu M. L, Liu Z. X, Zhang Q. X, Zhang X. J, Li G. H, Abdel-Majid B and Qu X W 2021 Preparation of UV-thermal dual curable environmentally friendly polycrylate pressure-sensitive adhesives by bulk polymerization Polym. Adv. Technol. 32 1104–12
[21] Lee S. W, Park J. W, Kwon Y. E, Kim S, Kim H J, Kim E A, Woo H S and Swiderska J 2012 Optical properties and UV-curing behaviors of optically clear semi-interpenetrated structured acrylic pressure sensitive adhesives Int. J. Adhes. Adhes. 38 5–10
[22] Joo H. S, Park Y. J, Do H. S, Kim H J, Song S Y and Choi K Y 2007 The curing performance of UV-curable semi-interpenetrating polymer network structured acrylic pressure-sensitive adhesives J. Adhes. Sci. Technol. 21 573–88
[23] Joo H. S, Do H. S, Park Y. J and Kim H J 2006 Adhesion performance of UV-cured semi-IPN structure acrylic pressure sensitive adhesives J. Adhes. Sci. Technol. 20 1573–94
[24] Ebe K, Seno H and Horigome K 2003 UV curable pressure-sensitive adhesives for fabricating semiconductors. I. Development of easily peelable dicing tapes J. Appl. Polym. Sci. 90 436–41
[25] Horigome K, Ebk K and Kuroda S I 2014 UV curable pressure-sensitive adhesives for fabricating semiconductors: II. The effect of functionality of acrylate monomers on the adhesive properties J. Appl. Polym. Sci. 93 2889–95
[26] Kim P S, Lee S W, Park J W, Park C H and Kim H J 2014 Synthesis and characterization of thermally stable acrylic PSA using silicone urethane methacrylate with a semi-IPN structure J. Adhes. Sci. Technol. 28 15–30
[27] Jamaluddin A and Lee M C 2013 Properties of UV-curable solvent-free pressure sensitive adhesive J. Adhes. Sci. Technol. 27 905–11
[28] Shima G S, Kima J S and Kim H J 2020 Behavior and adhesion performance of acrylic PSAs using Semi-IPN structure and UV/UV stepwise curing J. Ind. Eng. Chem. 89 139–46
[29] Kim P S, Lee S W, Park J W, Park C H and Kim H J 2013 Kinetic and characterization of UV-curable silicone urethane methacrylate in semi-IPN-structured acrylic PSAs J. Adhes. Sci. Technol. 27 1866–72
[30] Kim S W, Ju Y H, Han S, Kim J S, Lee C J, Lee C R, Jung S B, Kim Y and Kim J W 2019 A UV-responsive pressure sensitive adhesive for damage-free fabrication of an ultrathin imperceptible mechanical sensor with ultrahigh optical transparency J. Mater. Chem. A 7 22588–95
[31] Hao P P, Zhao T, Wang L L, Liu S J, Tang E J and Xu X D 2019 IPN structured UV-induced peelable adhesive tape prepared by isocyanate terminated urethane oligomer crosslinked acrylic copolymer and photo-crosslinkable trifunctional acrylic monomer Prog. Org. Coat. 137 105281
[32] Han J S, Zhou Y W, Bai G W, Wei W, Liu X Y and Li X J 2021 Preparation of photo-crosslinkable acrylic copolymer and its debonding property on silicon wafer J. Adhes. Sci. Technol. 1–13
[33] Park Y J, Lim D H, Kim H J, Joo H S and Do H S 2008 Curing behavior and adhesion performance of UV-curable styrene-isoprene-styrene-based pressure-sensitive adhesives J. Adhes. Sci. Technol. 22 1401–23
[34] Pang B L, Ryu C M and Kim H J 2014 Effect of naphthyl curing agent having thermally stable structure on properties of UV-cured pressure sensitive adhesive J. Ind. Eng. Chem. 20 3195–200
[35] Pang B L, Ryu C M, Jin X and Kim H J 2013 Preparation and properties of UV curable acrylic PSA by vinyl bonded grapheme oxide Appl. Surf. Sci. 285 727–31
[36] Ryu C M, Pang B L, Han J H and Kim H J 2012 Effect of photo-crosslinking on clean debonding of acrylic pressure sensitive adhesives from silicon wafer J. Photopolym. Sci. Tec. 25 705–12
[37] Kasper F K, Tanahashi K, Fisher J P and Mikos A G 2009 Synthesis of poly(propylene fumarate) Nat. Protoc. 4 518–25
[38] Cemali G, Aruh A, Kosea G T and Can E 2020 Biodegradable polymeric networks of poly(propylene fumarate) and phosphonic acid-based monomers Polym. Int. 69 1283–96
[39] Wang L, Guo D G, Zhu H and Xie L 2015 Light emitting diodes (LEDs) encapsulation of polymer composites based on poly(propylene fumarate) crosslinked with poly(propylene fumarate)-diacrylate RSC Adv. 5 52888–95
[40] Liu J C, Zhou Z, Su X Z, Cao J C, Chen M J and Liu R 2020 Stiff UV-curable self-healing coating based on double reversible networks containing diels-alder cross-linking and hydrogen bonds Prog. Org. Coat. 146 105699
[41] Tenorio-Alfonso A, Sanchez M C and Franco J M 2021 Impact of moisture curing conditions on the chemical structure and rheological and ultimate adhesion properties of polyurethane adhesives based on castor oil and cellulose acetate Prog. Org. Coat. 161 106547
[42] Tao C, Bao J J, Cheng Q, Huang Y P and Xu G W 2019 Preparation of waterborne polyurethane adhesives based on macromolecular-diols containing different disocyanate J. Adhesion. 95 814–33
[43] Meng Y Y, Lv P, Liu Q, Liao B, Pang H and Liu W Q 2019 Preparation and characterization of soybean oil-based waterborne polyurethane/acylate hybrid emulsions for self-mattting coatings New J. Chem. 43 19193–9
[44] Yong Q W, Chang J M, Liu Q, Jiang F, Wei D D and Li H J 2020 Matt polyurethane coating; correlation of surface roughness on measurement length and gloss Polymers 12 326
[45] Meng Y Y, Yong Q W, Liao B, Zeng W and Pang H 2020 Synthesis, characterization and formation mechanism of acrylate emulsion-based self-mattting coatings New J. Chem. 44 13971–8
[46] Sun Z, Fan H J, Chen Y and Huang J J 2018 Synthesis of self-mattting waterborne polyurethane coatings with excellent transmittance Polym. Int. 67 78–84