Plastic Films with Improved Adhesion on Integrated Circuit Packages for Laser Marking

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ABSTRACT: Various plastic films of a melting point above 170°C were selected for IC package in laser marking. These films include: (1) polyacetal, (2) polycarbonate, (3) polyester, and (4) nylon. They are in a form of a homogeneous layer, polymer blend, or multilayer structure. The plastic films were plasma treated and laminated onto the molded compound through transfer molding process. No extra process was introduced except for slight modification of the mold for film placement. The film molded IC package was evaluated in terms of adhesion, laser marking, and thermal and humidity resistance. Design of experiment was employed for the adhesion study. The results indicated that the polymeric material and film thickness were the key parameters affecting film adhesion. Careful selection of the plastic film made it possible for self-triming during product ejection. Two kinds of plastic films, namely, nylon and polyester, were finalized as laser markable and moldable materials. The laser marking effects of the film-molded packages were comparatively better than those of the nonfilm-molded packages. These two films were molded into IC packages and tested for thermal and humidity resistance. The results showed that polyester film-molded packages exhibited superior reliability in thermal shock tests (1000 cycles) and unbias cooker tests (72 h). © 2002 John Wiley & Sons, Inc. J Appl Polym Sci 84: 758–766, 2002; DOI 10.1002/app.10321

Key words: films; modification; adhesion; molding; aging

INTRODUCTION

Two marking processes, ink printing and laser marking, are currently used in parallel for labeling IC packages. Ink printing is a labor intensive and slow process. The printed label has an unstable service life.[1] The ink is also constrained in the environment to which it is exposed,[2] as reports have shown that printing inks contribute to the issue of pollution during handling process. Despite these shortcomings, ink printing is dominant in the market because of good contrast and brightness. On the other hand, laser-marking process is a value-added process.[3–8] It is quick and less labor intensive. The laser-writing label has good service life and the process is environmentally friendly. One inherent disadvantage with laser-writing labels, however, is its poor contrast and brightness.

Current trend for favoring laser marking is due to its good label durability and output rate.[9] However, there are problems in laser marking the molded epoxy compound of IC packages. It is difficult to achieve clear laser-writing label, especially in small fine point. Typical examples can be found in the BGA packages available industrially. To enhance the laser marking ability, modification on either the bulk or surface properties of

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Table I Plastic Films and Suppliers

Polymer Identity	Company
Polyacetal film	Westlake, USA
Polycarbonate, LEXAN films	GE, USA, and Diethelm, Singapore
Polycarbonate and polycarbonate/PBT	Bayer, Singapore
Polyester films	Du Pont, USA, and Jackson and PACCO, Singapore
Polyester window films	Sony Chemical, Singapore
Nylon films	Allied Signal/UNITIKA/PT EMBLEM Asia

epoxy compounds is considered. However, the change on bulk properties of epoxy compounds is not practical because this could introduce undesirable effects on package quality and reliability.

In this article we propose a method of making a laser markable IC package through the use of a plastic film. The laser marking effect of the plastic film bonded to the IC package is enhanced through the use of this method. The process of laminating the film using transfer molding was studied. Plastic films were selected through DoE analysis. The molded IC packages were evaluated in terms of peel strength, laser marking, and thermal and humidity aging studies.

EXPERIMENTAL

Materials

Epoxy Compound

The epoxy compound used was EME 7320C type R (Sumitomo Bakelite Singapore Pte Ltd). The pellet has a diameter of 13 mm and weighs approximately 4 g.

Plastic Films

Six types of the films as tabulated (Table I) were evaluated. The plastic films were provided in the form of homogeneous polymer, polymer blend, or polymer laminate. Each type of the material had at least one grade of the film, which could be in different thickness made from either calendering or stretching processes.

Processing

Plasma Treatment

Plasma treatment of the plastic films was carried out using the March PX-1000 plasma machine. Films of a quarter of the A4 size were cleaned with 2-propanol and placed into the plasma machine for treatment. Such a film was first treated with argon gas to remove the residual contaminants on the surface. It was then treated using oxygen gas to oxidize the surface layer of the film. The power was set at 500 watts and the time 6 min. The treated film was kept in a sealed plastic bag to avoid contamination before transfer molding.

Table II General Molding Conditions for Transfer Molding

Parameter	Molding Conditions
Clamp Force	800 kN
Total cycle time	160 s
Molding temperature	170°C
Transfer piston diameter	44.55 mm

Transfer Molding

Transfer molding was carried out using the molding machine, LAUFFER PRESSEN Model VSKO 135. The process was controlled using the controller, SIEMENS SICOMP PC 32-F and an application software, FlexOS™ 386 of the version release 2.3. The transfer molding conditions were set as shown in Table II. The transfer piston was controlled in five gradients as specified in Table III.

Evaluations

Contact Angle Study

Contact angle measurement was carried out using surface contact angle goniometer made by rame-hart, Inc., USA. It was measured immedi-

Table III Specific Conditions for Transfer Piston Control

Position (mm)	Speed (mm/s)	Pressure (bar)	Time (s)
135	201.38	20	0.67
160	80	20	0.98
170	20	20	1.48
190	10	20	3.48
197	20	20	6.98
197	0	20	8.42
197	0	20	10.00
197	0	20	15.00

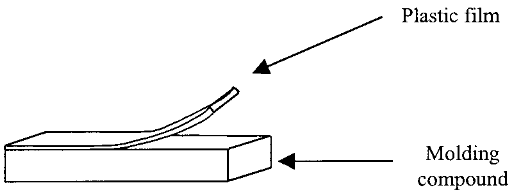

Figure 1 Specimens made for peel strength tests.

ately after the plasma treatment, with a non-treated film as a control. In measuring the contact angle, 2.0 μL of the deionized water was dispersed onto the film, and a time of 2 min was set aside for focusing an image. A time test with an interval of 10 s and 30 cycles was then performed. The initial contact angle was estimated by extrapolating from the linear portion of the graph back to the x-axis.

Peel Strength Tests

The peel strength of the plastic film with the molded compound was evaluated using INSTRON 4505 Universal Mechanical Testing Machine. The machine was controlled with INSTRON Model 4500 Analog Signal Monitor and INSTRON series IX Automated Materials Tester System 8.02.00. Specimens were especially made for peel strength tests. The samples were molded in such a way that there was only partial adherence of the film to the part as shown in Figure 1. These enabled the free end of the film to be used for gripping. The ends were wrapped with double sided-tape to secure a firm grip for the peel strength tests.

The tests were conducted in accordance with ASTM standard-ASTM D903-93.[10] A specimen was cut 26 mm long, 6 mm wide, and approximately 3 mm thick. The crosshead speed for the tests was 152 mm/min. All the tests were carried out in an environment of 60% humidity and a temperature of 22°C. The peel strength was defined as the load per unit width.

Laser Marking Analysis

Laser marking the IC package was carried out using the Infinity Nd:YAG laser, model M690B, NEC Corporation, Japan. The Infinity laser is equipped with a scanning head, and the marking was controlled through Mark Pro computer software, where the beam scanning speed and overlaps could be controlled. The laser parameters used were (a) pulse energy—approximately 12–16 mJ at a wavelength of 355 nm; (b) pulse repetition rate—40 Hz; (c) pulse duration—3 ns; (d) beam separation—0.060 mm.

The printed text was written in Microsoft word, and the PC was interfaced to a laser etcher for printing onto the plastic film.

Thermal Cycle Study

Temperature cycling tests were carried out using WEISS 3 × 120/80-20-200 DU-ST chamber. The testing conditions were set as follows: (a) temperature—−40 to 150°C; (b) dwell time at both extremes—15 min; (c) duration—1000 cycles.

The temperature cycling profile is shown in Figure 2.

Unbiased Autoclave Tests

Unbiased autoclave tests were carried out using the unbiased autoclave, NAPCO Model 8100-TD test chamber. This test was performed on the laser marked samples using JEDEC Test Method of JESD22-A102-B. The test conditions were set as follows: (a) temperature (dry bulb)—121°C; (b) relative humidity—100%; (c) vapor pressure—15 psig; (d) duration—JEDEC test condition "C,"—96 h.

Microscopic Study

Microscopic study was carried out using Reichert Polyvar 2 metallurgical microscope from Leica. Samples after reliability tests were evaluated in

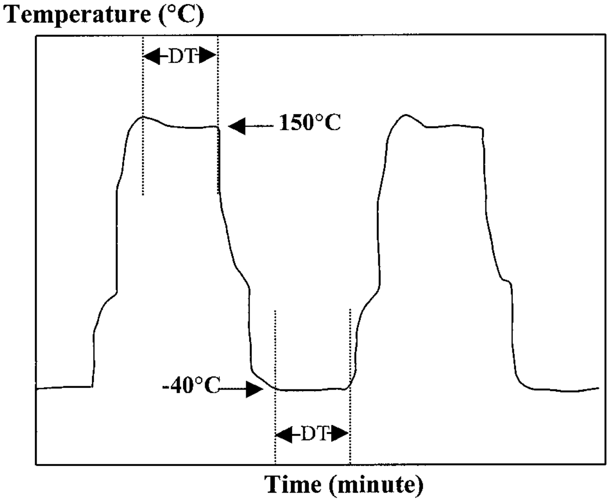

Figure 2 Temperature cycling profile with a dwell time (DT) of 15 min at both extremes.

Table IV Moldability of Plasma Treated Films

Polymer Identity	Adhesion[a]	Remark
Polyacetal film	No	Deformation and not moldable
Polycarbonate, LEXAN films	No	Not moldable
Polycarbonate and polycarbonate/PBT	No	Not moldable
Polyester films	Yes	Moldable
Polyester window films	Yes	Moldable with special handling
Nylon films	Yes	Moldable

[a] Adhesion was evaluated via visual inspection and manual peeling.

terms of laser marking effects and film morphologic alteration.

RESULTS AND DISCUSSION

Ability to Withstand Molding Conditions

Before transfer molding, all the films selected were plasma treated under an oxygen environment for 5 min. After transfer molding, the molded specimens were tested for adhesion. IC chips without any peeling of the plastic film is used as a reference for rating moldability. The molding ability improves as the adhesion increases.

The moldability is summarized in Table IV. Polyester window film is a laminate film with an adhesive layer on one side. The adhesion is provided from the adhesive. Weak bonds between the molded compound and plastic film are formed. This film was excluded because it could be peeled off easily. Polyester and nylon films are nonadhesive thin films. Strong bonds were formed between the molded compound and the treated plastic film. The results show that the polyester and nylon films were suitable for transfer molding. These films were selected as candidate materials for laser marking evaluation.

Nine brands of polyester and Nylon films were plasma treated under an oxygen environment for 5 min. The treated films were molded with epoxy compound to form the laser markable IC packages. More than 200 specimens were molded for the peel strength tests and laser marking.

The quality of the IC packages was evaluated based on the ejection damage and shrinkage of the plastic films. The results are summarized in Table V.

Two failure modes, edge peel and hairy sink, were analyzed. Edge peel appears as a universal failure mode for all the specimens, while hairy sink mode seems a unique mode of failure for nylon 3 and 4 films. It was postulated that the edge peel effect arose from the handling process while the hairy sink was originated from the material properties of the nylon films.

The time lapse from the plasma treatment to the transfer molding seems critical to the failure rate of the molded packages. As the time lapse reduces, failure occurrence is less. An experiment was conducted on the change of the contact angle after the plasma treatment. It shows that there was a substantial change of the contact angle in

Table V Molding Ability of Commercial Polyester and Nylon Films

No.	Plastic Film	Thickness (μm)	Interval[a] (Day)	Failure Rate (%)	Failure Mode
1	Nylon 1	25	2	12	Edge peel
2	Nylon 2	15	1	50	Edge peel
3	Nylon 3	15	1	44	Hairy sink, edge peel
4	Nylon 4	50	4	69	Hairy sink, edge peel
5	polyester-1	12	1	56	Edge peel
6	polyester-2	23	4	62	Edge peel
7	polyester-3	36	1	18	Edge peel
8	polyester-4	50	1	22	Edge peel
9	polyester-5	100	2	66	Edge peel
10	Polyester window	50			

[a] The interval is the time lapse from plasma treatment to transfer molding.

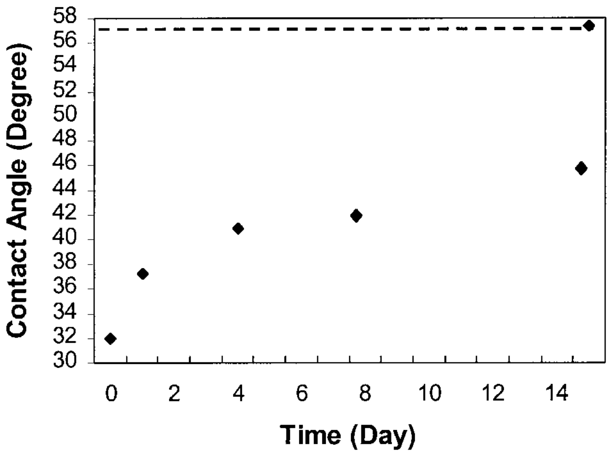

Figure 3 Change of contact angle after plasma treatment. Dot line refers to the contact angle fo the untreated plastic film, the contact angle at zero day is measured (extrapolate to zero second) immediately after surface treatment.

24 h, as shown in Figure 3. It strongly suggests that the plasma treatment and transfer molding should be done consecutively within 1 day.

The relationship of the film thickness with the failure rate appears complex. It shows a trend that the failure rate increases with the film thickness. However, no clear conclusion regarding the optimum sample thickness for transfer molding was apparent. To address this point, the processing conditions were optimized using the Design of Experiment.

DoE Study

Three factors, plasma-treating time, thickness of the films and commercial brands of the films were chosen as basic parameters for study of adhesion and laser marking. A two-level three-factor factorial (2^3) experiment design was employed to study the effect of these parameters on the failure rate and adhesion of the molded parts. The parameters are defined as type of film materials (M), thickness of film (T), and surface treatment (S). The response examined was the failure rate of the peel tests (F). The experimental matrix is shown in Table VI. The template matrix was randomized and listed in Table VII. The experiment analysis was completed, and the results were calculated based on the equation below.

$$E_{\text{average}} = (+y_1 + y_2 + y_3 + y_4 + y_5 + y_6 + y_7 + y_8)/8$$

$$E_M = (-y_1 + y_2 - y_3 + y_4 - y_5 + y_6 - y_7 + y_8)/4$$

Table VI Experiment Matrix Based on a Two-Level Three-Factor Factorial Experiment Design

Exp. No.	M	T	S	F
1	−	−	−	y_1
2	+	−	−	y_2
3	−	+	−	y_3
4	+	+	−	y_4
5	−	−	+	y_5
6	+	−	+	y_6
7	−	+	+	y_7
8	+	+	+	y_8

$$E_T = (-y_1 - y_2 + y_3 + y_4 - y_5 - y_6 + y_7 + y_8)/4$$

$$E_S = (-y_1 - y_2 - y_3 - y_4 + y_5 + y_6 + y_7 + y_8)/4$$

$$E_{MT} = (+y_1 - y_2 - y_3 + y_4 + y_5 - y_6 - y_7 + y_8)/4$$

$$E_{MS} = (+y_1 - y_2 + y_3 - y_4 - y_5 + y_6 - y_7 + y_8)/4$$

$$E_{TS} = (+y_1 + y_2 - y_3 - y_4 - y_5 - y_6 + y_7 + y_8)/4$$

$$E_{MTS} = (-y_1 + y_2 + y_3 - y_4 + y_5 - y_6 - y_7 + y_8)/4$$

where E_M means the material effect; E_{average} means the average effect; E_T means the effect from thickness; E_{MT} means the combined effect from both material and thickness; E_{MTS} means the combined effect from materials, thickness, and surface treatment; y_i means the response of adhesion at the i run of the experiment.

The plasma treatment was carried out in 30 s (−), 165 s, and 300 s (+), respectively. Thickness of the films was in the range of 15 (−) and 50 (+) microns. The film materials are polyester (−) and

Table VII Randomized Matrix for Process Optimisation

Run. No.	Exp. No.	M	T	S	F
1	6	+	−	+	y_6
2	3	−	+	−	y_3
3	7	−	+	+	y_7
4	1	−	−	−	y_1
5	4	+	+	−	y_4
6	6	−	−	+	y_5
7	8	+	+	+	y_8
8	2	+	−	−	y_2

Table VIII Experimental Results for DoE Analysis

Run	Material	Thickness (μm)	Surf Time (s)	Peel Strength (N/mm)	Identity
1	−1	15	30	0.358	Polyester-1
2	−1	50	300	0.626	polyester-4
3	1	50	30	0.805	Nylon-4
4	1	15	300	0.439	Nylon-3
5	1	15	30	0.588	Nylon-3
6	−1	50	30	0.605	polyester-4
7	−1	15	300	0.287	polyester-1
8	1	50	300	1.495	Nylon-4
9	−1	15	165	0.347	polyester-1
10	1	50	165	1.363	Nylon-4

nylon (+). All the molded specimens were tested for peel strength and laser marking ability. The experimental results for DoE analysis are summarized in Table VIII and the analysis results are summarized in Table IX.

The analysis shows that film thickness and the type of film material are the most significant factors affecting the film peel strength. This can be observed clearly from the Pareto Chart and the Normal Probability Plot in Figures 4 and 5. Within the experiment conditions, as the thickness of film increased, the peel strength increased. Of the two materials used, nylon film gave higher peel strengths than polyester films. The surface treatment time does not show significant effects on the peel strength. No obvious interaction was observed among the three factors studied.

Adhesion

When the film was peeled off during the tests, the peel strength measured is a representative of the adhesion of the plastic film onto the molded compound. Unlike the adhesive type of plastic films, the surface treated films have no peeling off process before the film failure. The adhesion of the film cannot be evaluated through the peel strength tests. However, if the film breaks before peeling off, it means the adhesion is stronger than the ultimate strength of the film. Therefore, the adhesion of the film can be estimated in terms of the relationship between the ultimate strength of failure and the peel strength of the film: Ultimate strength of failure (σ_u) < peel strength (σ_p).

The load and displacement curves of the adhesive films and the surface treated films are compared in Figure 6. The maximum value of the ultimate strength for nylon films is 2.765 N/mm, while for polyester films it is 0.99 N/mm. These values are much higher than the peel strength of polyester window films (0.65 N/mm). Moreover, the film broke off wherever the film was attached to the molded compound. No peeling off could be detected, as shown in Figure 7. It indicates that the film had strong adhesion onto the molded compound.

Table IX Estimated Effects for Peel Strength

Factor	Value	Standard Deviation
Average	0.676917	0.005611
Material (A)	0.407667	0.112223
Thickness (B)	0.482667	0.112223
Surface treating time (C)	0.13625	0.122934
AB	0.197833	0.112223
AC	0.16125	0.122934
BC	0.21925	0.122934

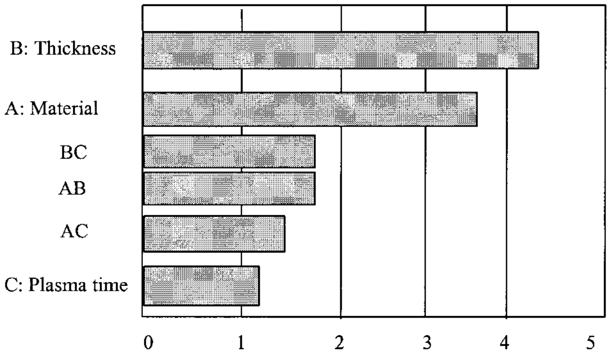

Figure 4 Standardized Pareto chart for peel strength.

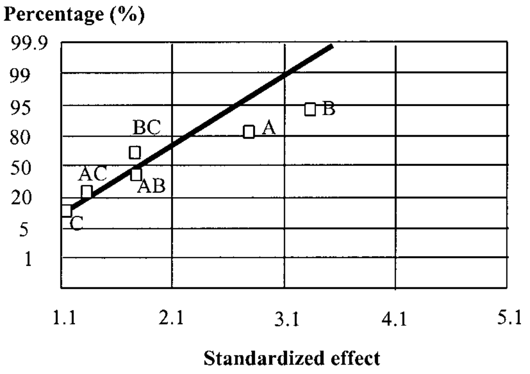

Figure 5 Normal probability plot for peel strength. (A) Material; (B) thickness; (C) plasma time.

Temperature Cycle Tests

Two types of films, nylon and polyester, were used for making molded samples. These samples were studied for temperature endurance through 1000 temperature cycles. The results show that the polyester film withstood the temperature cycle test without significantly changing the properties of the film. The polyester film shows no color change as shown in Figure 8, and the laser marking remains clear and bright as the control sample and was not aged, as shown in Figure 9. However, nylon film shows obvious color change, and the aged sample becomes brown and brittle, as shown in Figure 8. The laser marking on the nylon film faded significantly (Fig. 9).

The molded samples were placed under a optical microscope to inspect the detailed change of laser marking and film after 1000 temperature cycles. The micrographs show no obvious change in films, and the laser marking also had no significant change except for the deformation of the pinhole of the laser burns as shown in Figures 10 and 11).

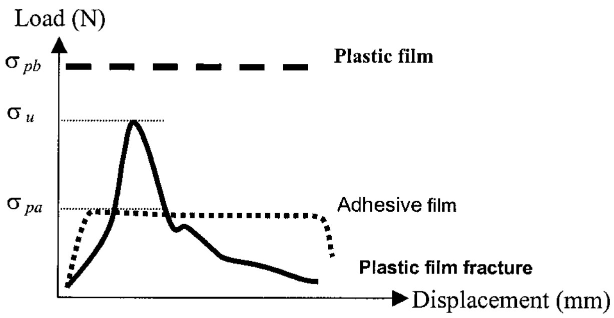

Figure 6 Load–displacement curve in peel strength tests. σ_{pa} is peel strength of adhesive film, and σ_{pb} is peel strength of plasma film.

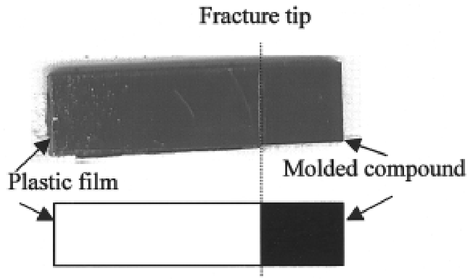

Figure 7 Brittle failure of the plastic film.

Nylon film was not considered to be suitable for laser marking because the nylon film became too brittle and its color changed after the cyclic temperature test. In addition, the laser marking was significantly affected after temperature cycles. On the other hand, polyester film is rated as a suitable candidate for laser marking because it is found to be stable during the thermal aging process.

Unbiased Autoclave Tests

Polyester film was selected as a laser markable film. The laser marking and film were tested for humidity endurance. The molded samples with and without laser marking were placed in a cooker testing chamber and studied for their humidity endurance. After 96 h of cooker tests, the molded samples showed a visible failure of the film; however, the laser marking still existed. Samples were inspected under the microscope,

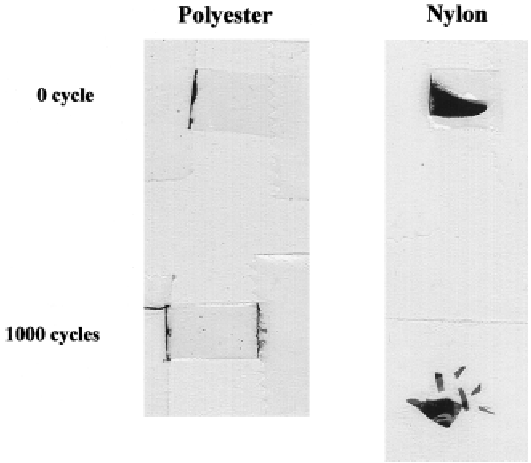

Figure 8 Molded plastic films before and after 1000 temperature cycles.

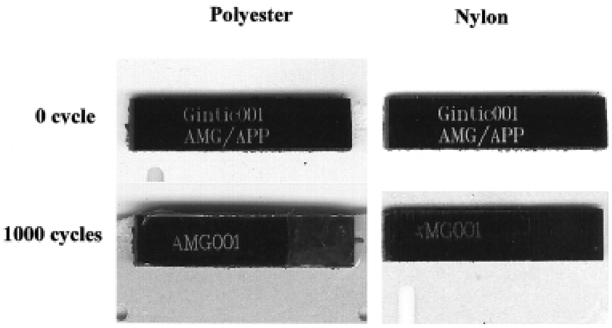

Figure 9 Laser marking effect before and after 1000 temperature cycles.

and film fracture was observed after a long duration of pressurized cooking. Figure 12 shows the crack initiation and propagation with the increase of the cooking time. The micrographs show that polyester film passed a 72-h cooker test without significant fracture of the film or fading of the laser marking. However, cracks appeared after 72 h but the pinhole of the laser marking remained spherical.

CONCLUSIONS

In this work, various plastic films were selected for making laser markable IC packages. Lamination of the films was studied, and the results showed two films, namely, nylon and polyester, were laser markable and transfer molding feasible. The adhesion of both films was much stronger than their ultimate fracture strength. This made it possible to eject the IC package and trim the film automatically. Polyester film was considered as the promising candidate for laser markable package in terms of its reliability in temperature cycle test and in unbiased autoclave tests.

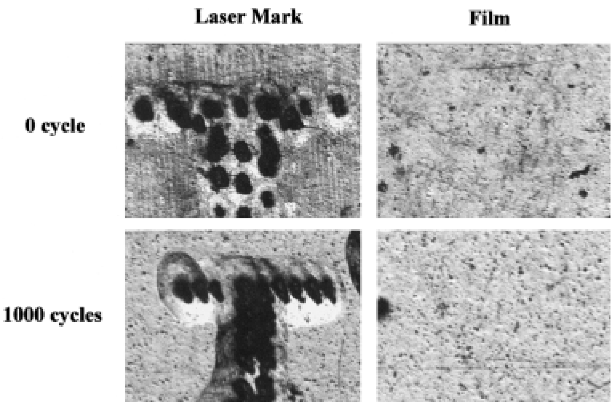

Figure 10 Micrographs of polyester film molded samples after 1000 temperature cycles.

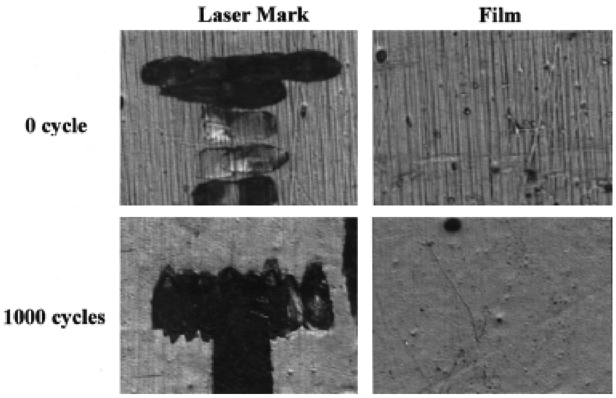

Figure 11 Micrographs of nylon film molded samples after 1000 temperature cycles.

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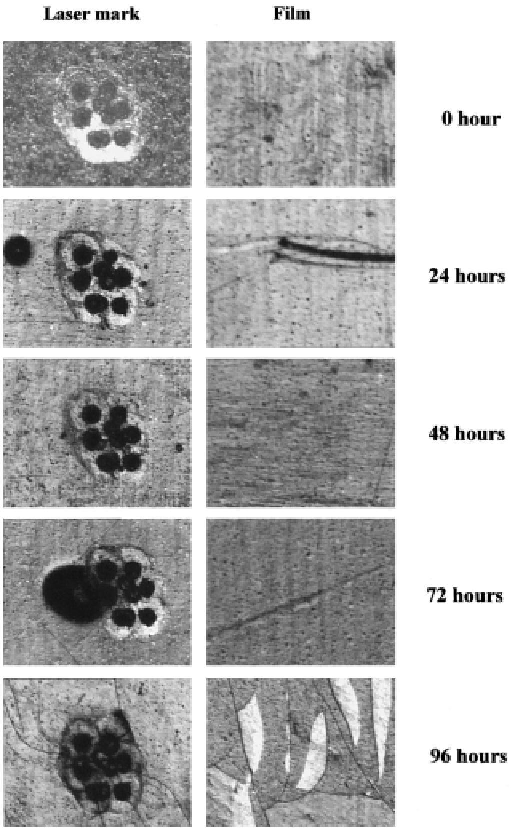

Figure 12 Aging of polyester films with (left) and without (right) the laser marking in the cooker tests.

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