New Evaluation Methods for Pressure Sensitive Adhesive (PSA) Tapes Used in the Semiconductor Industry

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ABSTRACT We propose new evaluation methods for pressure sensitive adhesive (PSA) tapes using a high-resolution tester for shearing adhesion and a pendulum-type mechanical apparatus, by means of which we can evaluate the mechanical properties of the pressure sensitive adhesion (PSA) layer, and of products, in the form of PSA tapes. Using these methods we evaluated the adhesion of a blend of acrylate copolymer with UV-curable urethane acrylate oligomer, and two kinds of UV-curable acrylate copolymers. The high-resolution tester for shearing adhesion made it possible to clarify differences in the properties of PSA tape that cannot be evaluated by the usual methods, and the pendulum-type mechanical apparatus made it possible to detect differences in the mechanical properties of adhesion before and after UV irradiation. We expect that these methods will clarify the relations between the practical properties and mechanical properties of PSA tapes utilized in the semiconductor industry, and will prove useful to the design and quality control of PSA tape.

1. INTRODUCTION

1.1 Semiconductor Manufacturing Processes Where PSA Tape Is Used

Figure 1 shows processes used in semiconductor manufacture. Pressure-sensitive adhesive (PSA) tape is used in the back-grinding process and dicing process. These PSA tapes must have strong adhesion during processing, and weak adhesion after processing ends, and to meet this need, UV-curable tape has been developed and marketed. These PSA tapes must have been higher quality and more advanced features for thin-film wafers, and semiconductor device of a larger scale of integration. For example, in the wafer back-grinding process, the PSA tape is required to ease the

unevenness of the wafer surface and to grind thinly and flatly. In the dicing process, the PSA tape is required to reduce chipping (breakage of a chip) and to be able to pick up a chip easily. Although the cause of chipping is not certain, various factors, such as mechanical properties and adhesion properties, are considered to have had a complex influence. In designing the PSA tape, we have carefully studied semiconductor manufacturing conditions and have met the above-mentioned requirements by optimizing the thickness and the mechanical properties of PSA tapes.

1.2 Composition of PSA Tape

UV-curable PSA adhesive is composed of a blend of adhesive acrylic copolymer, UV-curable resin, and photo-polymerization initiator. The adhesive acrylic copolymer is obtained by the copolymerization of acrylates (butyl acrylate, 2-etyl hexyl acrylate, etc.) and/or acrylic acid (and/or vinyl acetate). The UV-curable resin is a monomer or oligomer, which has at least two doubled carbon-carbon bonds, such as the acryloyl group (for example, polyester acrylate, epoxy acrylate, urethane acrylate, etc.) A UV-curable adhesive acrylic copolymer may also be used, which introduce the functional group of UV reactivity into a side chain of the acrylic copolymer. UV-curable adhesive acrylic copolymer can also be used independently as a UV-curable adhesive. To obtain cohesion, as in an adhesive acrylic copolymer for this use, it is common to blend a crosslinking agent. Adhesion can be adjusted by the type of acrylic copolymer, the value of a polar factor (such as acrylic acid), the molecular weight, and the amount of crosslinking agent. The backing film of PSA tape uses polyolefin resin
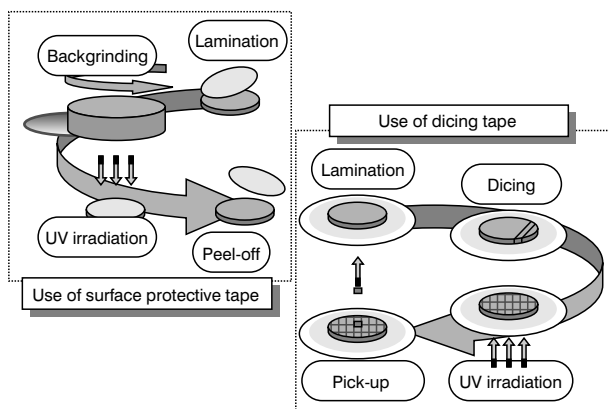

Figure 1   Backgrinding process and dicing process.

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(for example, polyethylene, polypropylene, etc.), and has been designed to have appropriate thickness and material composition.

1.3 Evaluation Methods for PSA tape

As methods of evaluating PSA tape, Japanese Industry Standards mentions adhesion, holding power, tackiness, etc., which are specified in JIS Z 0237. Although these evaluation methods are used widely and considered to be effective as quality control techniques, they may not satisfy design and development requirements and are not necessarily effective. Moreover, holding power is the method of measuring the power by which a PSA tape bears shearing stress when the tape is applied to a test panel and fixed. Since the holding power is represented by the displacement in a predetermined time or by the elapsed time required to fall from the test panel, measurement accuracy is not enough for the properties of PSA tape utilized in the semiconductor industry. On the other hand, viscoelasticity is measured to determine the dynamic mechanical properties of a PSA layer. But since the thickness of the specimen needs to be about 2 mm, this method is not suitable for the measurement of practical PSA tapes which consist of a PSA layer and a backing film layer, making it difficult to be used for quality control. Researchers and manufacturers of PSA tape have therefore developed various equipment and methods for the testing of PSA layer, and have been performing evaluation and analysis of PSA products [1].

1.4 New Evaluation Methods for PSA Tape

1.4.1 Measuring Shearing Adhesion of PSA Layers

Equipment for measuring the shearing displacement of PSA layer has been proposed by Miyagi and others [2]. Displacement is detected using laser, and with resolution in the 10^{-6} to 10^{-3} meter order, performance is sufficient. The equipment is shown in Figure 2. The laser detector measures displacement when the angle of reflection from a target changes. The displacement of PSA layer due to load is measured by detecting the displacement of the target block which is placed on a PSA tape fixed on the test panel. Since the elasticity of
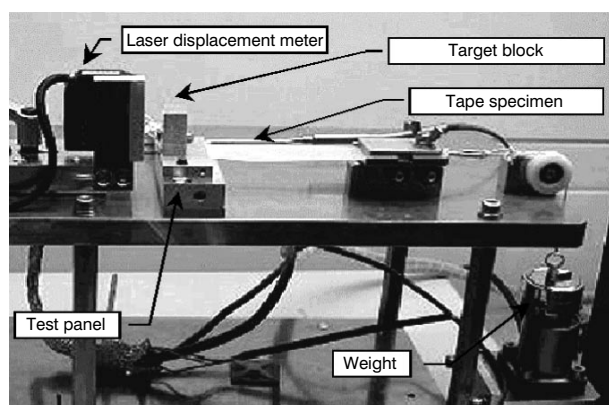
PSA layer is sufficiently lower than that of the backing film, it virtually has no influence on the displacement of the backing film. In addition, the equipment can change the test panel and the weight. The advantage of this measuring method is that it can evaluate a PSA layer using practical PSA tapes. What is more, the measuring technique can evaluate viscoelastic properties based on a static model, from which elasticity, viscous property, etc. can be calculated for analysis. Since this equipment has sufficient measuring accuracy and can evaluate viscoelasticity while measuring shearing adhesion, we consider it is effective for evaluating PSA tapes used in the semiconductor industry.

1.4.2 Pendulum-type Mechanical Apparatus

Figure 3 is a schematic diagram of a pendulum-type mechanical apparatus. The edge is placed on a specimen and the pendulum is drawn near with an electromagnet. The magnetism is then released allowing free movement of the pendulum. At this time, attenuation of the pendulum and change of cycle arise from the resistance resulting from the mechanical properties of specimen and edge. By evaluating the temperature dependence of the rate of attenuation, the glass transition temperature of a polymer material can be measured, and by evaluating the time dependence, knowledge of the UV-curing and/or crosslinking conditions of the PSA layer can be obtained. In addition, we also used this measurement technique to evaluate the coating material of optical fibers, and evaluation of the hardening state in the two-layer coating material of optical fibers is reported [3].

2. EXPERIMENTAL

2.1 Materials

Three kinds of samples were used as UV-curable PSA adhesive: specimen A is composed of a blend of adhesive acrylic copolymer (Mw=400000) and urethane acrylate oligomer (Mw=3000); specimen B is a UV-curable adhesive acrylate copolymer (Mw=800000); and specimen C is a UV-curable adhesive acrylate copolymer (Mw=200000). Each of the specimens has a crosslinking agent added. In addition, specimen A
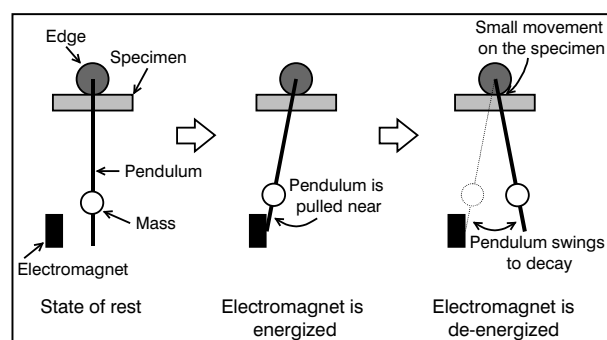

Figure 2   High-resolution tester of shearing adhesion of PSA layers.

Figure 3   Schematic diagram of pendulum-type dynamic mechanical apparatus.

has large amounts of crosslinking agent to take a highly crosslinked structure, and B and C have only a small amount of additive. The three abovementioned kinds of adhesion agents were coated on backing film of a polyolefin to make PSA tape.

2.2 Measurements

PSA properties were measured according to JIS Z 0237. The probe tack of PSA tapes was measured by a TAC-II probe tack tester made by RHESCA Co., Ltd. An ARES dynamic mechanical analyzer made by Rheometrics Co., Ltd. measured the temperature dependence of the dynamic viscoelasticity of PSA at a frequency of 1 Hz. The shearing adhesion of PSA layer was measured at high resolution. Changes in mechanical properties before and after UV irradiation was measured by a pendulum-type mechanical apparatus.

3. RESULTS AND DISCUSSION

3.1 PSA Properties

Adhesion and tack of each PSA tape are shown in Table 1. Values differ according to the composition of the PSA, or the molecular weight of the acrylic copolymer. Specimen A (before UV irradiation) has the maximum adhesion. The mobility of the urethane acrylate oligomer, and the interface chemical characteristic and dynamic characteristic of the base polymer are considered to have contributed to this. In terms of tackiness, specimen C provides the maximum and A the minimum. Whereas tackiness shows the ease of adhesion for a short time, it is thought that this is a result of the crosslinking of PSA and the participation of the glass transition temperature and/or the complex effects of molecular weight. Holding power could not be measured, since neither displacement nor fall was observed on all specimens.

3.2 Dynamic Viscoelasticity

Figure 4 shows the temperature dependence of the storage modulus G' and loss tangent $\tan\delta$. Below room temperature the value of G' for specimen A is higher than that for B and C, but lower than B at high temperatures. Moreover, the peak value of $\tan\delta$, equivalent to the glass transition temperature, occurs at 5°C. It is assumed that this results from the use of a blend comprising an acrylic copolymer with a high glass transition temperature and a urethane acrylate oligomer of a low molecular weight. When specimen B and C are compared, the glass transition temperature of the acrylic copolymer is lower than for A, and the change of G' is small between

the glass transition temperature and room temperature. However, in the temperature range beyond room temperature, specimen B has a small change in G' and its value of $\tan\delta$ is small. It is assumed that the difference in the molecular weight of the acrylic copolymers has affected the behavior of the G' vs. temperature curve and the $\tan\delta$ vs. temperature curve.

3.3 Shearing Adhesion of PSA Layer

Figure 5 shows the change in shearing behavior for the specimens, each of which differs greatly. Specimen A is a blended urethane acrylate oligomer, while B and C have the structures of acrylic copolymer only, but despite being of the same structure, their molecular weights differ greatly. The difference among these structures is conjectured to have influenced the action of displacement. In other words, the degree of crosslinking
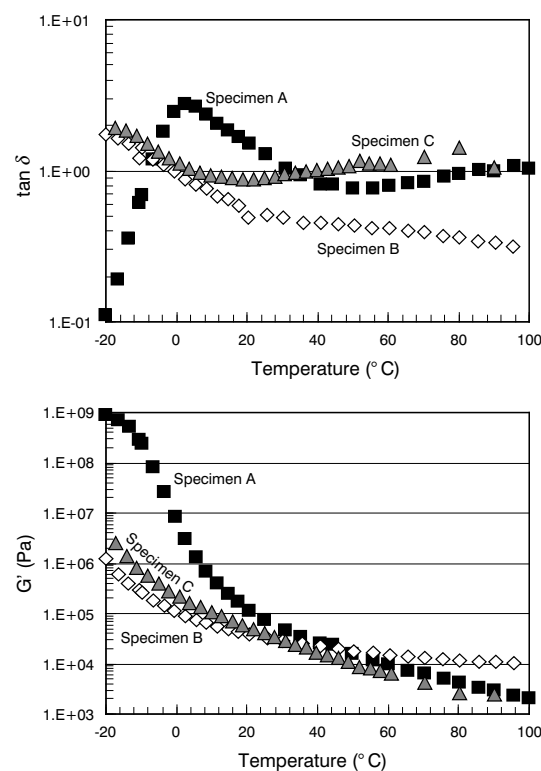

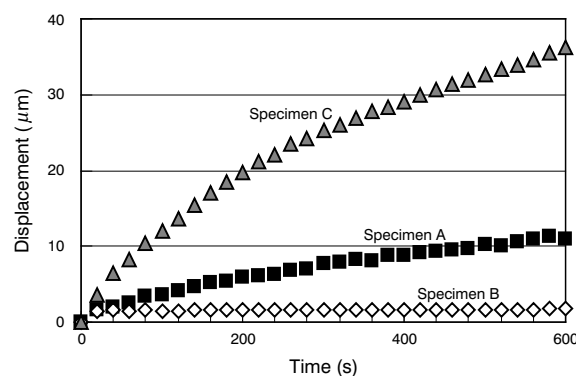**Figure 4** **Temperature dependence of dynamic viscoelasticities.**

Table 1 **Adhesive properties of UV-tapes.**

Specimen		A	B	C
Adhesive force (N/25 mm)	Before UV	10.3	5.1	6.3
	After UV	0.16	0.26	0.3
Probe tack (kPa)		364	587	674

Figure 5 **Change in shearing displacement of adhesive layer.**

of PSA and/or the degree of intertwinement of the polymer chain resulting from molecular chain length influence the behavior of displacement. Consequently, PSA with low degree of crosslinking and/or short molecular chain length would have a large displacement.

3.3.1 Static Model of Viscoelasticities of PSA Layer

Static model of viscoelasticity is thought to be best suited to understand the shearing adhesion of PSA tapes. According to this model, PSA is a typical viscoelastic body and is considered to have the properties of both a Newtonian viscous body and an ideal elastic body. In this report, PSA is analyzed using a static model of viscoelasticity shown in Figure 6 whereby a Maxwell element and a Voigt element is combined [4), 5)]. In this viscoelastic model strain γ and stress σ are related by the equation

$$\gamma = \sigma\{(1/G_1)+[1-\exp(-t/\tau)]/G_2+(t/\eta_3)\}$$
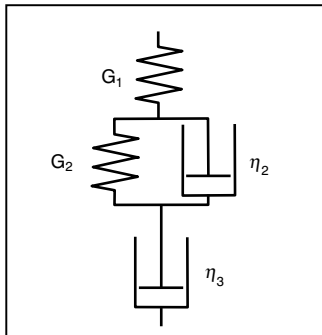
where τ is relaxation time ($\tau = \eta/G$).

Figure 6　Viscoelastic model of shearing adhesion of PSAs.

The parameter that contributes to the initial stage of displacement is G_1, and η_3 is the parameter that represents the displacement in proportion to time. Although displacement in the interface between the test panel and a PSA layer is also assumed to exist, it is included in η_3 in this report. Figure 7 shows agreement between analytical results and actual measurements for each sample. In all results, the displacement behavior obtained by actual measurement and by the static model of viscoelasticity was in good agreement, so that it is judged that the model used in this report is appropriate. Of these specimens, specimen B showed the largest value for all parameters, and specimen C the smallest value.

3.4 Measurement of Mechanical Properties by Pendulum-type Dynamic Mechanical Apparatus

The pendulum was placed on the PSA tape, and UV was irradiated from the upper and lower sides, carrying out free attenuation of the pendulum oscillation. Behavior of mechanical properties (logarithmic attenuation factor and oscillating period) in UV-tape before and after UV irradiation is shown in Figure 8. UV irradiation caused the oscillating period to fall and saturate at a fixed value. This suggests that molecule movement is restrained by the formation of crosslinked structures. On the other hand, the logarithmic attenuation factor increased under UV irradiation, fell after that, and was saturated at a fixed value. It is thought that the logarithmic attenuation factor increased during the formation of crosslinked structures since the structure was not stable, and that it is stabilized after formation of the crosslinked structures since the structure became stable.
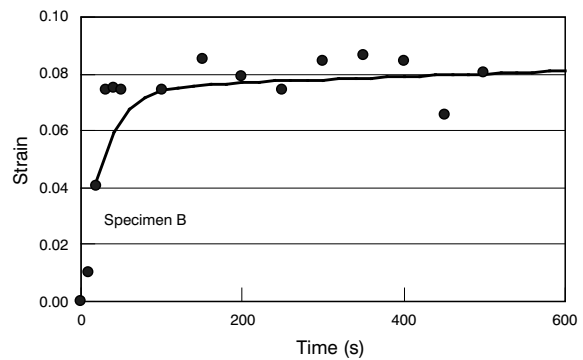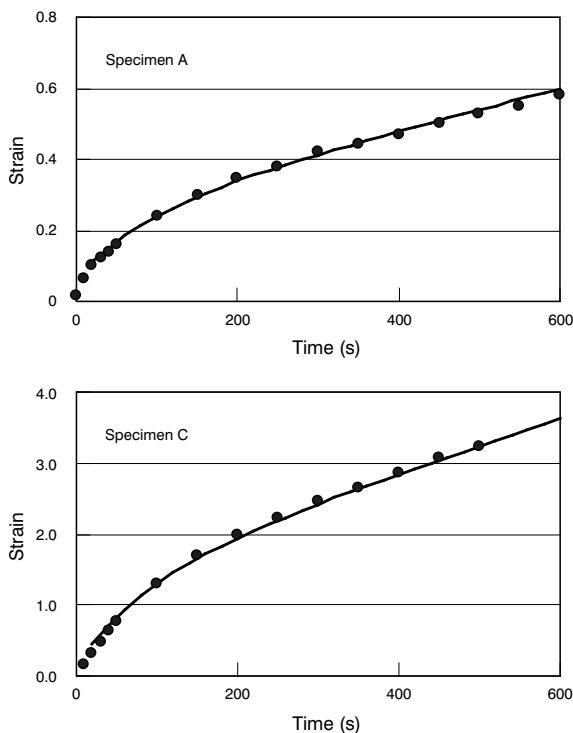
Specimen	G_1(Pa)	G_2(Pa)	τ (s)	η_3(Pa·s)
A	2.37×10^4	9.01×10^3	94	2.61×10^6
B	1.57×10^5	2.41×10^4	29	1.57×10^8
C	1.04×10^4	1.38×10^3	91	4.00×10^5

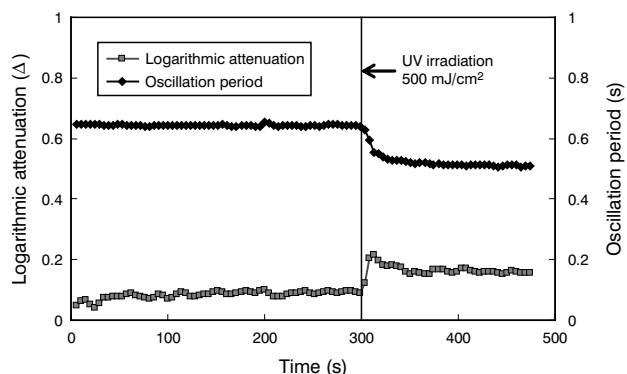**Figure 7　Viscoelastic properties of UV-tapes.**

Figure 8 **Behavior of mechanical properties in UV-tapes before and after UV irradiation.**

4. CONCLUSION

We proposed new evaluation methods for UV-PSA tape using a high-resolution tester of shearing adhesion and a pendulum-type mechanical apparatus. The shearing adhesion of PSA can measure the minute action of modification of PSA, which has not been evaluated by the usual holding power test, and can be quantified using the viscoelastic model. Moreover, the pendulum-type dynamic mechanical apparatus can evaluate mechanical properties by changes in the logarithmic attenuation factor and oscillating period, and can evaluate the characteristic before and after UV irradiation. Since these evaluation methods are able to evaluate easily the PSA tape in the form of products, it is also expected that they are applicable to quality control methods. In future, we will accumulate data using these techniques in order to clarify causal relationships with the practical characteristics, adhesion properties, or dynamic mechanical properties.

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