Biodegradable Packing Materials for LSIs

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In general, the plastic LSI packing material used to transport and mount LSIs is discarded after the LSIs have been removed from the material and mounted. We investigated ways to use biodegradable plastic to decrease the environmental load due to discarded plastic. We developed a biodegradable LSI-packing material that is also electro-conductive. This material protects LSIs against electrostatic discharge and is also decomposed in soil by natural microorganisms. Moreover, it does not produce harmful gasses when it is incinerated. This paper describes this biodegradable LSI packing material and how it has been put to practical use in LSI trays and embossed carrier tape.

1. Introduction

Electronic device assembly and installation lines produce large amounts of waste plastic LSI packing materials. These materials protect LSI parts used in mobile phones and PCs from electrostatic discharge. They also protect terminals and other parts from vibration during transportation and are used when installing LSIs in electronic circuit boards. Different forms of packing materials, for example, trays and embossed carrier tape (hereafter referred to as carrier tape), are used according to the application, but in most cases these materials are made from polystyrene and other plastics. As a rule, trays are reused, but if they are found to deviate from their standard dimensions, they are discarded. The carrier tape is cut off and discarded after the LSIs have been installed due to limitations in the mechanical design of mounting units and the excessive cost of reusing tape. When large amounts of these types of packing materials are discarded, a burden is placed on the environment. Reducing the environmental burden resulting from plastic waste has become an important issue.[1),2)]

In order to reduce the environmental burden resulting from LSI packing materials, Fujitsu has focused its attention on biodegradable plastics[3)] that are broken down by microorganisms in the soil and do not generate toxic gases, even when they are incinerated. We have developed a biodegradable packing material for LSIs using this type of plastic which offers both biodegradability and conductivity to protect LSIs from electrostatic damage.

In this paper, we describe the features of biodegradable plastics and the biodegradable packing materials (LSI trays and carrier tape) that have been used up to now.

2. Features of biodegradable plastics

Biodegradable plastics are plastic materials that can be used in the same way as regular plastic materials but can be returned to the environment by being broken down into water and carbon dioxide by microorganisms and naturally occurring degrading enzymes. It is expected that biodegradable plastics will be used in products that are used in natural environments and when recycling after use is difficult. These materials are being actively applied in agriculture, forestry, and fisheries, and their usage volumes are steadily increasing—from around 60 tons in 1992 to 4000 tons in 2000.[4)]

Fujitsu is leading the world in promoting applications of biodegradable plastics in the electronics field. As a first step, we have developed biodegradable plastic LSI packing materials for use in the transport of LSIs and in assembly lines.

Table 1 summarizes the features of various types of biodegradable plastics. Biodegradable plastics are divided into two main groups: aliphatic polyesters and starch-based materials. Some of the raw materials for biodegradable plastics are petroleum and biomass generated by plants and microorganisms. The raw materials for aliphatic polyesters include copolymer polyhydroxybutyrate-polyhydroxyvalerate (PHBV), which is created by microorganisms; polylactic acid (PLA), which is a synthetic lactic acid created by fermenting biomass; and poly butylene succinate (PBS), which is made from petroleum. Starch-based materials are generally made from a mixture of starch and polyvinyl alcohol (PVA).

Table 1
Features of biodegradable plastics.

Type of biodegradable plastic	Aliphatic polyesters			Starch-based
	PHBV	PLA	PBS	PVA + starch
Raw materials	Biomass (microorganisms)	Biomass (plants)	Petroleum	Blend of petroleum and biomass (plants)
Production method	Synthesis by microorganisms	Chemical synthesis		
Mechanical strength	Poor	Good	Good	Poor
Moisture resistance	Good	Good	Good	Poor
Biodegradablilty	Excellent	Good	Good	PVA: Poor

note) PHBV: Copolymer polyhydroxybutyrate-polyhydroxyvalerate
PLA: Polylactic acid
PBS: Poly butylene succinate
PVA: Polyvinyl alcohol

Chemically synthesized PLA and PBS are mechanically stronger than starches. Also, aliphatic polyesters have better moisture resistance than starches, which have many hydroxyls. Lastly, aliphatic polyesters also have superior biodegradability than starches, which contain PVA.

3. Development of LSI trays

Fujitsu's first use of biodegradable LSI packing materials was in LSI trays. In 1996, we became the first company in the world to use conductive, biodegradable plastic LSI trays (**Figure 1**).

After several reuses, LSI trays deviate from their standard dimensions and therefore become waste products. Fujitsu follows a basic policy of reusing trays, but trays that are shipped to overseas customers often fall out of this recycling loop in between uses because of the complexity of the distribution routes or the high cost of recovery. Fujitsu recognized the need to also consider these exceptions.

Furthermore, LSI trays must have good flatness and mechanical strength so they can be stacked during transport but still precisely position LSIs for the tools that pick them up and mount them.

The LSI trays therefore had to fulfill the following conditions without losing their most basic characteristic of biodegradability:

1) Conductivity
2) Mechanical strength
3) Low cost

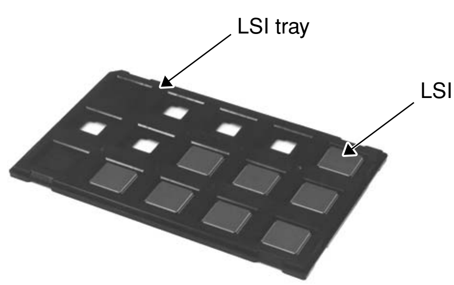


Figure 1
LSI tray.

Conductivity is required to protect the LSIs from static electricity during transport and during use on assembly lines. Carbon black is commonly used to make trays conductive. Out of consideration of biodegradability, we wanted to minimize the use of added materials, so we investigated the correlation between conductivity and the amount of carbon black. Also, although increasing the amount of carbon black increases the flexural strength, we found that it also reduces the shock strength. We therefore determined the optimum amount of carbon black and developed a new resin with this amount.

The cost of trays made with the new resin is dramatically affected by the cost of the resin, because the resin accounts for the greatest part of this product. In the development stage in 1996, we selected PBS, which offers a good balance between cost and mechanical strength.

We tested the biodegradability of some prototype trays made from the new resin by leaving them in a tank that circulated river water containing microorganisms and monitoring the changes in weight.[5] In the molding process, we determined the optimum molding conditions for the resin's melting temperature and viscoelasticity and accordingly controlled the flow of resin in the mold to achieve the required evenness in the tray.

Using the above technologies, we developed a biodegradable tray that stands up to practical use. We have been using this type of tray in some in-house shipments of logic LSIs. Furthermore, we have returned to Japan from overseas plants used LSI trays made from this material and have confirmed that it is possible to reuse this type in the same way as regular trays.

4. Development of carrier tape

Figure 2 shows a reel of carrier tape. When LSIs are mounted, the carrier tape is taken off the reel with a one-dimensional operation, making it possible to mount the LSIs at high speed. Furthermore, unlike the case with trays there is no need for 2-dimensional operations during LSI pick-up, so space can be saved on the mounting lines. For these reasons, the demand for carrier tape is increasing every year.[2]

It is also necessary to maintain a low cost for the containers, called pockets, that hold the LSIs. Fujitsu therefore minimizes production costs by forming the pockets using a continuous process such as vacuum forming, pressure forming, or press forming.

Because most types of carrier tape cannot be reused for the reasons discussed above, the need to reduce the environmental load is even more critical than is the case with LSI trays.

Like trays, biodegradable tape must offer conductivity and low cost in addition to biodegradability. It must also be mechanically strong to function correctly as a continuous tape.

Below, we discuss some technological developments in biodegradable carrier tapes that were put into practical use at the end of 2000.

4.1 Adoption of biodegradable plastics of plant origin

The biodegradable plastics adopted for the LSI trays discussed above are materials synthesized from petroleum. In the context of carrier tapes, development of which has been continuing since 1999, Fujitsu studied plant-derived

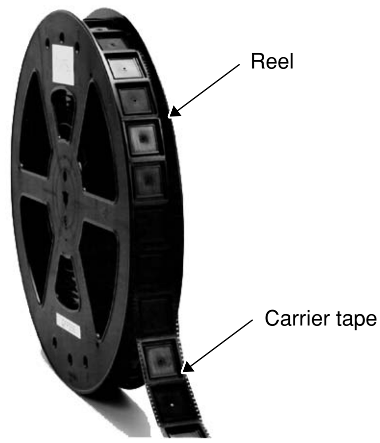


Figure 2
Carrier tape.

biodegradable plastics that present an even lesser burden on the environment.

PLA is synthesized by fermenting a biomass (corn starch) that has been fixed within a living organism through plant photosynthesis. In addition to the fact that it does not generate toxic gases during incineration and biodegrades after disposal, its main raw material requires little energy—which is to say little fossil fuel—and so it can be generally regarded as a material with a low environmental burden.

Figure 3 shows a manufacturing energy comparison[6),7)] for PLA, polystyrene (PS), and polypropylene (PP) materials that are commonly used in carrier tapes.

We divided the manufacturing energy into the following three categories for comparison:

1) Stock energy
This is the fossil-fuel energy present in petroleum-derived resins; it can be consiered as the energy released when such a resin is incinerated.
2) Process energy
This is the total energy cost required to produce a material in all production stages from the extraction of raw materials to the final synthesis. In the case of PLA, the process energy includes the energy required for sowing and cultivating corn as a raw material.
3) Renewable energy
This is the energy released from a material by combustion. In the case of plant-derived resins such as PLA, almost all of the material in the resin originates from atmospheric carbon dioxide and water and is broken down into the original carbon dioxide and water by the degrading effects of microorganisms. The renewable energy in a petroleum-derived resin is equal to its stock energy.

The total fossil fuel energy that is removed from reserves to produce a petroleum-derived resin is its stock energy plus its process energy.

If we compare these fossil fuel energies, we find that the process energy for PLA is 56 MJ/kg, while the stock energy + process energy for PS is 69 MJ/kg. Thus, if PLA is used in place of PS, we can reduce the fossil fuel energy consumption by about 20%. Therefore, in terms of minimizing the environmental degradation caused by the use of fossil fuels, we can say that PLA is a superior ma-

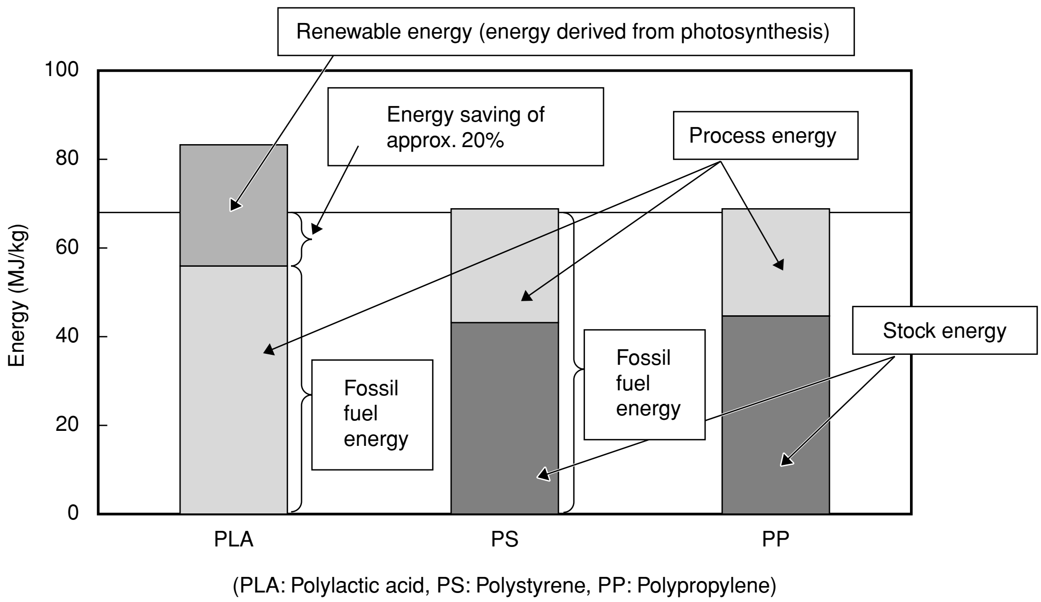


Figure 3
Comparison of manufacturing energies of plastics.

terial.

Up to now, petroleum-derived resins had cost superiority over plant-derived biodegradable plastics because the raw materials could be mass-produced at a lower cost. However, a large-scale PLA production plant was started up in mid-2001,[8] offering promise for this material in the future. Furthermore, PLA's glass transition temperature is room temperature or higher. As a result, it has the highest rigidity of any degradable plastic[9] and is mechanically stronger than PS, which has been commonly used in the past.

Based on the results of the above investigations, we adopted PLA as the base resin in this carrier tape.

4.2 Structure of carrier tape

Figure 4 shows the structure of the carrier tape we developed. The core layer of the tape is a layer of biodegradable plastic, the base of which is PLA. As in the case of LSI trays, carbon black is used to provide conductivity. In order to minimize the amount of carbon black, we adopted a method in which a thin conductive layer is added to the face of the carrier tape.

We used the press-forming method to enable continuous forming and ensure accuracy in the structure of the LSI pocket at low cost. In this way, the conductive layer is not severed even after pocket forming, making this a carrier tape that maintains a highly stable pocket shape.

4.3 Tape biodegradability

The molecular weight of high molecular weight PLA is mainly reduced by hydrolysis. Biodegradation through fermentation of microorganisms is added to hydrolysis to break down the PLA and thereby achieve a remarkable reduction in molecular weight. Finally, the PLA is further broken down into a lactic monomer, which is absorbed into the bodies of the microorganisms and completely metabolized into carbon dioxide and water.[6),10)] **Figure 5** outlines the biodegradability test performed to asses the effects of the carbon black on the hydrolysis and biodegradability of the embossed tape.

We used a simple compost to increase the speed of biodegradability evaluation. The compost was produced by combining leaf soil and dog food in a 2:1 ratio. Moist air was supplied constantly to ensure that the compost did not become dry, and the test was conducted under aerobic conditions with abundant oxygen available.

Samples 0.3 mm thick were placed in sample nets (Figure 5) and buried in the compost, the temperature of which was maintained at 40°C. The samples were removed from the compost periodically so they could be weighed and photographed to record their appearance.

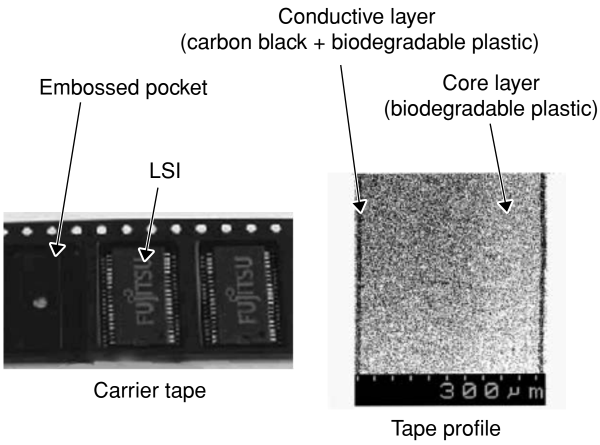


Figure 4
Structure of embossed carrier tape.

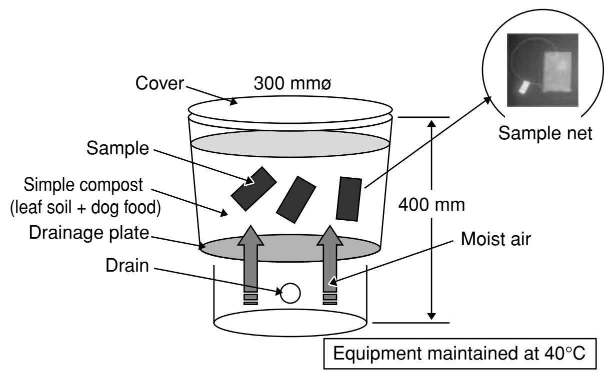


Figure 5
Biodegradability test.

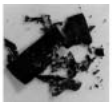
Burial time (weeks)	0	4	8
Sample			
Weight retention (%)	100	58	27

Figure 6
Biodegradability test results.

The test results are shown in **Figure 6**. Four weeks after the samples were buried, their conductive layer began to peel, although only partially, and their weight retention rate was 58%. At eight weeks, most of the conductive layer had peeled and decomposition had progressed steadily, with a weight retention rate of 27%.

Therefore, our new carrier tape provides conductivity and decomposes in compost.

4.4 Mechanical strength

Because the carrier tape is supplied in the form of a reel and used to transport and mount LSIs, it must have good folding endurance strength, tensile strength, and tear strength as well as good pocket strength.

Table 2 shows the strengths of the new carrier tape and polystyrene tapes (PS tapes) that are currently in common use. Because the pocket strength is strongly affected by the pocket shape, the comparison was conducted using tapes that were pressed from the same mold. The "crush strength" is the maximum load weight immediately before the carrier tape pocket is crushed. The base material of PLA tape has a high rigidity, and as shown in Table 2, even after conductivity has been added, it has superior mechanical strengths than PS tape.[11] We were therefore able to confirm that PLA tape is strong enough for use as a carrier tape for LSI packing.

This commercialized carrier tape is already being used at the Fujitsu Nasu Plant to mount the LSIs of mobile phones.

Table 2
Mechanical strengths.

	Folding endurance strength (no. of folds)	Tensile strength (Mpa)	Crush strength (N)	Tear strength (N/mm)
Polylactic acid type	4600	2900	120	180
Polystyrene type	2500	1900	50	100

5. Conclusion

In this paper, we introduced a biodegradable plastic LSI packing material developed by Fujitsu that reduces the environmental burden. The 21st century has been referred to as the Century of the Environment, and the creation of environment-friendly products and manufacturing processes has become an important issue.

Replacing conventional plastics with biodegradable plastics is an effective way to reduce the environmental damage caused by plastic waste, which is expected to increase in volume in the future, and there are high expectations for biodegradable plastics in various fields. Fujitsu is already using these materials in LSI trays and carrier tapes, and is the first to make such efforts in the electronics field.

Having taken this first step, Fujitsu will continue to pursue new developments in biodegradable plastics as an environment-friendly material for electronics parts and for use in manufacturing plants.

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