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Ultrasound aided smooth dispensing for high viscoelastic epoxy in microelectronic packaging

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ABSTRACT

Epoxy dispensing is one of the most critical processes in microelectronic packaging. However, due its high viscoelasticity, dispensing of epoxy is extremely difficult, and a lower viscoelasticity epoxy is desired to improve the process. In this paper, a novel method is proposed to achieve a lowered viscoelastic epoxy by using ultrasound. The viscoelasticity and molecular structures of the epoxies were compared and analyzed before and after experimentation. Different factors of the ultrasonic process, including power, processing time and ultrasonic energy, were studied in this study. It is found that elasticity is more sensitive to ultrasonic processing while viscosity is little affected. Further, large power and long processing time can minimize the viscoelasticity to ideal values. Due to the reduced loss modulus and storage modulus after ultrasonic processing, smooth dispensing is demonstrated for the processed epoxy. The subsequently color temperature experiments show that ultrasonic processing will not affect LED's lighting. It is clear that the ultrasonic processing will have good potential to aide smooth dispensing for high viscoelastic epoxy in electronic industry.

1. Introduction

Dispensing is a key technology in microelectronic packaging, and to guarantee quality, it must be meticulously accurate. The dispensed underfilling material protects neighboring interconnections from short-circuiting and releases residual stress [1]. The most widely used underfilling material is epoxy as it is an excellent electrical insulator and highly stable [2–4]. Typically, the required amount of epoxy is usually on the nanoliter scale with a high degree of consistency (>95%) [5–8]. Yet, due to high viscoelasticity, dispensing of epoxy is extremely difficult [9]. Epoxy is tough to break and residual amounts collect on the nozzle. As it accumulates on the nozzle, dispensing consistency will diminish and blockages will form. Therefore, an epoxy with improved viscoelasticity is urgently required for smooth dispensing.

Two popular methods are employed to lower the viscoelasticity of epoxy, either a diluent is added or the epoxy is heated [10,11]. Though both methods will rapidly reduce the viscoelasticity of the epoxy, its properties are also greatly affected [12]. The modified epoxy may have reduced reliability, which makes it unsuitable for encapsulation. Moreover, heating degrades epoxies, which may cause deformations in the electronics and aggravated stresses during encapsulation. It is necessary to find a better way for improving the dispensing ability of epoxy.

It is well accepted that the high viscoelasticity of epoxy originates from disorder and entanglement of molecular chains [13]. Therefore, it can be inferred that if the molecular chains are streamed by external energy at low temperatures and become ordered, the epoxy will have a lower viscoelasticity with main properties unchanged, and is easier to be dispensed.

One promising option to lower the viscoelasticity of epoxy is ultrasonic processing. Ultrasonic processing is widely used in polymers degradation [14–16] by generating acoustic cavitation [17,18]. High pressures are produced by ultrasounds due to bursting of the numerous bubbles that rapidly form by ultrasonic vibrations in liquids [19]. The pressure gradient can be large enough to drive high-energy chemical reactions, which can modify both organic and inorganic materials [20–22]. However, recent studies also have demonstrated suitable pressures and a relatively smaller energy can be obtained by regulating factors that affect ultrasound sonochemistry, such as ultrasonic intensity, solvent choices, polymeric properties, etc. [23]. Besides, studies also proved that the sonochemical degradation for polymers only takes place when

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their molecular weights are higher than 30,000, below such value no further degradation happens; these effects have been verified in all types of macromolecules in solution and include both organic and inorganic polymers in organic solvents and various polymers in aqueous media. However, the very large pressure produced in the interfacial region around cavitation bubbles when bubbles collapse, and the liquid motion in this vicinity can generate very large shear and strain gradients, these will cause molecules around the cavitation bubble streamed very rapidly and become ordered, causing solely physical changes [24,25]. As the average molecular weights of uncured epoxy resins are usually less than 4000 [26], it is possible to lower the viscoelasticity of epoxy with its main properties unchanged by using suitable ultrasound power to stream molecules only.

In this paper, an experimental setup is developed to improve the dispensing ability of epoxy by ultrasonic processing to reduce its viscoelasticity. In order to prove reduced viscoelasticity while maintaining its main properties, the dynamic modulus and infrared spectrum are compared and analyzed before and after ultrasonic processing. Ultrasonic power, processing time, and ultrasonic energy is varied and compared in order to fine-tune the different factors involved with ultrasounds. Finally, it is demonstrated with a jet dispensing experiment that smooth dispensing is easily achieved for a processed epoxy. The subsequently color temperature experiments show ultrasonic processing will not affect LED's lighting. This clearly indicates that the ultrasonic processing has good potential in aiding the smooth dispensing of a high viscoelastic epoxy during microelectronic packaging.

2. Experiment setup and results

2.1. Experiment setup

As shown in Fig. 1, the experimental setup consists of a computer, a self-developed sandwiched piezoelectric transducer (PZT), an ultrasonic generator (USG) (Uthe, USA), and a 3-axis motion platform. The computer controls the USG, which drives the transducer. The transducer, which includes a piezoelectric driver and a horn, is fixed on the platform with one end immersed in the epoxy. Once the PZT driver is excitated by the USG, ultrasonic vibrations are generated. The ultrasonic vibrations then propagate through the horn until they reach the epoxy, resulting in numerous bubbles needed and causing them collapse.

According to Suslick et al. [24], the reliable and effective intensity of ultrasonic power for laboratory-scale sonochemistry ranges from 50 to 500 W/cm^2. Therefore, the maximum ultrasonic power, $E_{\max}$ which is large enough for ultrasonic processing but without introducing too much local energy can be calculated as follows:

$$E_{\max} \leqslant \frac{\pi d^2 J}{4} \tag{1.1}$$

where d is the diameter of the horn end, of which used in the experiment is 3.6 mm; J is the intensity of ultrasonic power, in this experiment the minimal value 50 W/cm^2 is chosen. So according to Eq. (1.1), the maximum power of the PZT driver $E_{\max}$ was chosen as 5 W.

In order to maximize the order of generated bubbles, the piezoelectric transducer was purposely designed to vibrate in the axial direction only with its working frequency at 63 kHz.

To ensure all the epoxy in the beaker is well and uniformly processed, the beaker was rotated slowly by the 3-axis motion platform.

The epoxy resins used in the experiment was Diglycidyl Ether of Bisphenol-A (DGEBA, CAS No. 25068-38-6) with a number average molecular weight, $Mn < 700$ (corresponding to $n = 0$, or 1), which was purchased from Ausbond Co. Ltd without further purification. Their structures are shown in Fig. 2. In order to eliminate possible curing reactions during the ultrasonic processing, each experiment took about 10 mL epoxy only, without any harder and curing accelerator. The entire processing time was about 5 min.

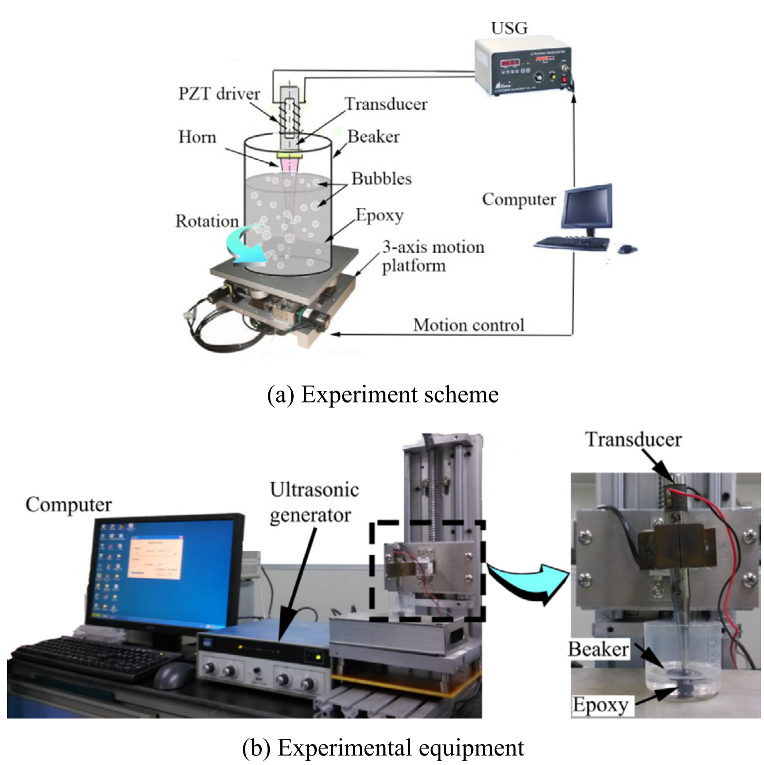

Fig. 1. Experiment setup.