Characterization of Piezoelectric Ring Used for Wire Bonding Transducer Application

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ABSTRACT

Resonant vibration modes excited in a piezoelectric PZT ring which is closely related to its geometry and dimensions were studied. By a thinning test of the ring, the electromechanical properties of the ring were measured as a function of its thickness and shifts in resonance vibrations were noted. Thickness of the ring was also optimized in relation to the electromechanical performance of the ring used for wire bonding application.

Index Terms — piezoelectric, ring, electromechanical, transducer

I. INTRODUCTION

Nowadays, ultrasonic wire bonding, used as the first–level packaging technique, is a crucial technique of microelectronic packaging [1]. With the rapid development of IC chips in recent years, not only the circuits inside the chips become complicated due to the multi-functional design, but also their size tend to be as small as possible for reducing the defective fault and for raising the operation speed. So, there is a need to develop a higher frequency bonder transducer in order to obtain higher yield.

Increasing the transducer's operation frequency would raise a problem of the reliability on its operation performance. The reason is that the operation resonance mode existing in the transducer would be easily coupled with other higher resonance modes such as radial, wall thickness modes and their harmonics exciting in the piezoelectric PZT rings which are clamped together in the transducer, thus causing difficulties in transducer control. Furthermore, PZT material has a high mechanical Q factor, locking the operating frequency in a designated range becomes increasingly difficult as the frequency goes up.

Therefore, a study of vibration modes and electromechanical properties of the ring is extremely important for optimising the transducer's performance operating at higher frequency.

II. FABRICATION OF A PZT RING

The ring is made of modified lead zirconate titanate (PZT)-802 powder supplied by Piezo Kinetics Inc. This is a hard PZT material that can withstand high levels of electrical excitation and mechanical stress and it is commonly used in making high voltage or high power generators and transducers [2].

There are three steps in the fabrication of PZT rings [3]:

1. Ceramic powder was poured in a steel mould and formed into a ring by dry pressing.
2. The ring sample was calcinated at 750°C for 60 minutes to remove PVA binder.
3. Calcinated sample was sintered at 1325°C for 90 minutes so that combined reaction in the powder can be completed.

In order to elicit piezoelectric performance of the ring, the sintered sample was then poled along the thickness direction by applying a d.c. field of 6 kV/mm for 30 minutes at 120°C.

III. RESONANCE MODES IN A PZT RING

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There are three possible fundamental modes of vibrations in a piezoelectric ring when an electric field parallel to the poling direction (Fig. 1) was applied to the electroded face [4].

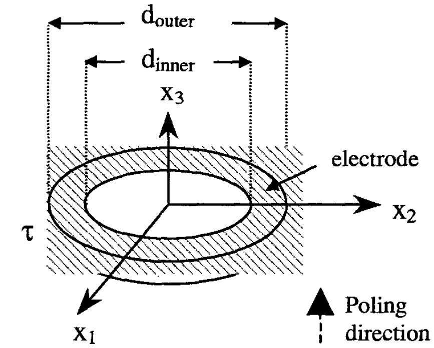

Fig.1: Schematic diagram of a PZT ring.

1. The thickness mode vibration occurs when the applied frequency is close to the thickness resonant frequency $f_{r\text{-}thk}$ which induces a change in thickness $\tau_r \pm \Delta\tau_r$.
2. The radial mode vibration occurs when the applied frequency is close to the radial resonant frequency $f_{r\text{-}rad}$ which induces a change in the mean diameter $d_{mr} \pm \Delta d_{mr}$. The radial mode always appears as the lowest frequency as the diameter is the largest dimension.
3. The wall thickness mode $f_{r\text{-}wall}$ occurs when the frequency is close to the resonant frequency along the wall thickness direction, causing a change in the wall thickness $w_r \pm \Delta w_r$. The resonant frequencies of each mode [5] are given by

Thickness resonant frequency $\mathbf{f_{r\text{-}thk}}$

$$f_{r-thk} = \frac{1}{2\tau_r\sqrt{\rho \cdot s_{33}^D}} \quad \text{(1)}$$

Radial resonant frequency $\mathbf{f_{r\text{-}rad}}$

$$f_{r-rad} = \frac{1}{\pi d_{mr}\sqrt{\rho \cdot s_{11}^E}} \quad \text{(2)}$$

Wall thickness resonant frequency $\mathbf{f_{r\text{-}wall}}$

$$f_{r-wall} = \frac{1}{2w_r\sqrt{\rho \cdot s_{11}^E}} \quad \text{(3)}$$

where $d_{mr}=(d_{outer}+d_{inner})/2$ is the mean diameter, $w_r=(d_{outer}-d_{inner})/2$ is the mean wall thickness, ρ is the density and τ_r is the thickness of the ring. s_{11}^E and s_{33}^D are the elastic compliances at constant electric field and constant charge density, respectively.

Dimensions of the PZT ring used in studying the characteristics of the vibration modes are: thickness τ_r = 1.78 mm, outer diameter d_{outer} = 13.00 mm and inner diameter d_{inner} = 5.20 mm. Three strong resonance vibrations can be identified from the electrical impedance and phase as a function of frequency as shown in Fig. 2.

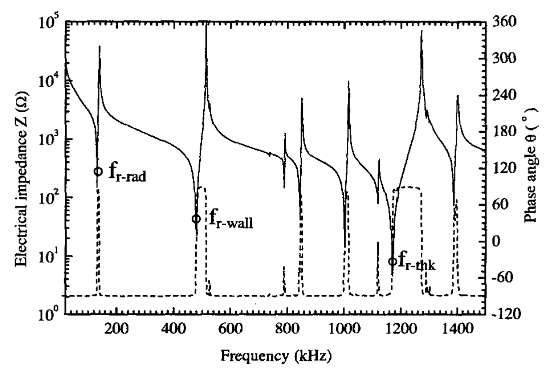

Fig. 2: Electrical impedance Z and phase θ against frequency of a PZT (PKI 802) ring of thickness = 1.78 mm.

Measured resonant frequencies of each mode can be compared with the calculated values and are shown in Table 1.

Table 1. Measured and calculated results

Resonant frequency	*Measured value (kHz)*	*Calculated value (kHz)*	*Error (%)*
$f_{r\text{-}rad}$	130.40	121.17	-7.12
$f_{r\text{-}wall}$	478.25	444.10	-7.14
$f_{r\text{-}thk}$	1170.85	1183.90	1.11

The optimal ring thickness of 1.78 mm has been selected from the thinning test and will be discussed in the next section. Error between the measured and calculated thickness mode is relatively small. Errors in the radial and wall thickness mode is larger due to the variation in the inner and outer diameter.

IV. THINNING TEST RESULTS OF A RING

By thinning a PZT ring of 4.6 mm thick, it is possible to find how various material parameters such as k_t, Q_M, N_{3t} and resonant frequencies of different vibration modes change with thickness. This knowledge is extremely important for optimizing the dimension required for specific ultrasonic applications.

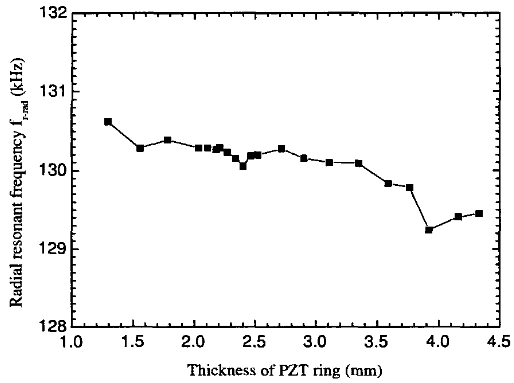

Fig. 3: $f_{r\text{-}rad}$ vs thickness of the PZT ring.

$f_{r\text{-}rad}$ is slightly lower in thicker ring (> 4 mm thick) as shown in Fig. 3 which may be due to the presence of a strong thickness mode near to the radial mode. When the outer diameter d_{mr} is larger than 2.7 times the thickness τ_r, the radial frequency is quite constant indicating that it is independent of the thickness.

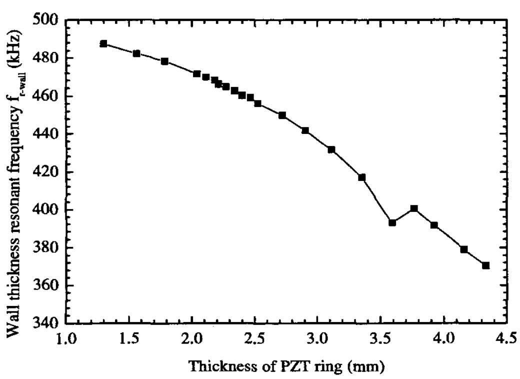

Fig. 4: $f_{r\text{-}wall}$ vs thickness of the PZT ring.

It is also observed in Fig. 4 that the wall thickness resonant frequency decreases almost linearly with the increase in thickness.

Thickness resonance is the strongest vibration mode in a ring poled along the thickness direction. A strong and pure thickness mode is extremely important if the thickness mode is to be used in ultrasonic applications. Fig. 5 shows how the thickness mode resonance varies with the thickness of the ring.

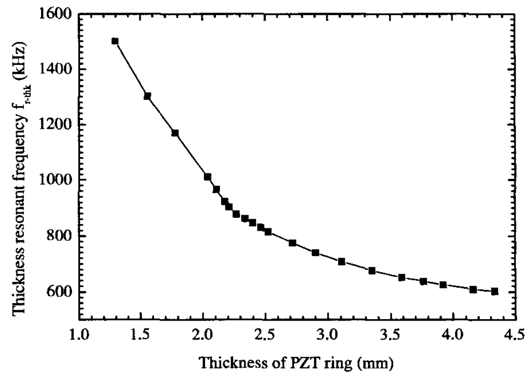

Fig. 5: $f_{r\text{-}thk}$ vs thickness of the PZT ring.

The strongest and pure thickness resonance was found at a thickness of 1.78 mm and the material parameters of the PZT ring show good agreements compared with the data supplied by Morgan [2].

The ring with this thickness exhibits the highest electromechanical factor k_t of 0.43 (Fig.6) and has a minimum electrical impedance of 2.7Ω at the thickness mode resonance (Fig.7). Furthermore, high mechanical quality factor Q_M of 1213 (Fig. 8) and thickness frequency constant N_{3t} of 2084 Hz-m (Fig. 9) has been obtained at the thickness of 1.78 mm. Another strong and pure resonance mode at a thickness of 2.5 mm was also found but its material parameters are a little bit lower than that of the PZT ring with a thickness of 1.78 mm. This can be another criteria for the choice of the ring thickness. When the thickness is over 3 mm, the material parameters measured are getting worse presumably due to the thickness resonance mode is approaching the wall thickness resonance causing strong mode coupling.

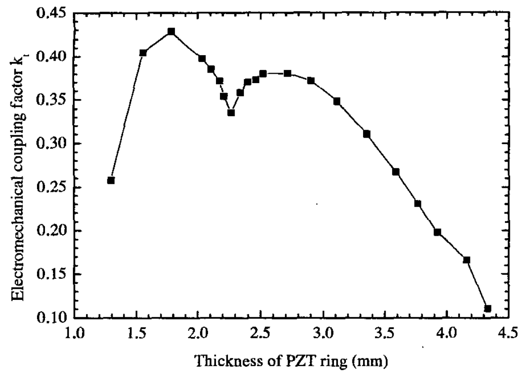

Fig. 6: k_t vs thickness of the PZT ring.

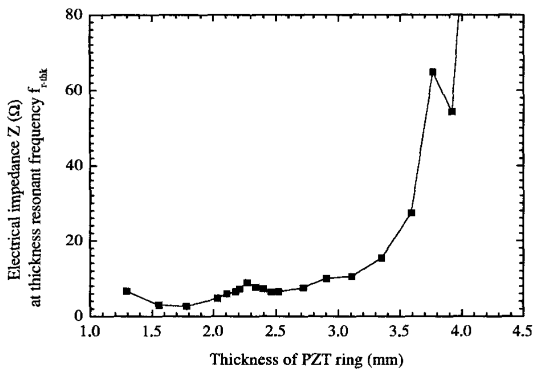

Fig. 7: Z vs thickness of the PZT ring.

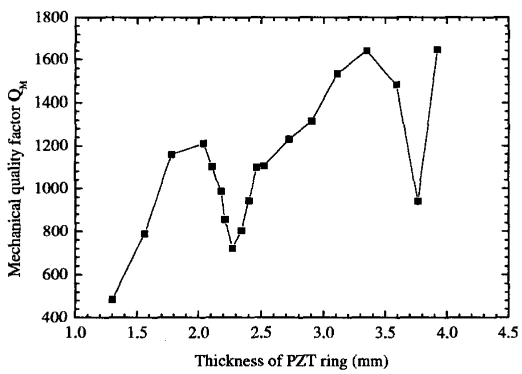

Fig. 8: Q_M vs thickness of the PZT ring.

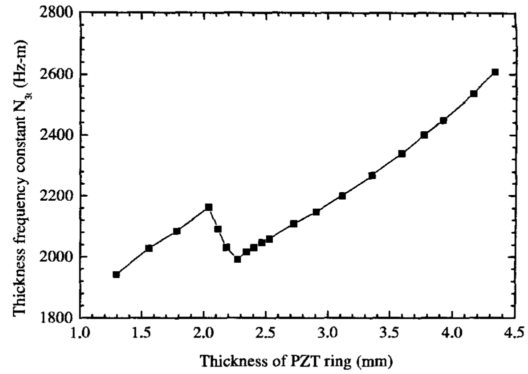

Fig. 9: N_{3t} vs thickness of the PZT ring.

V. CONCLUSION

By carrying out thinning tests of the PZT ring, mode coupling and the electromechanical properties have been studied. Optimal thickness of the PZT ring can be selected for making a transducer for ultrasonic wire bonding application.

ACKNOWLEDGEMENT

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