How to Deal with Resonances in Wirebonding

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Abstract

Resonance effects can seriously impede or prevent wire bond formation. The two major kinds of resonance are discussed: sharp resonances on eigenfrequencies and passive, following resonances. Changing the ultrasonic frequency will remove the true resonance while the passive resonance is independent of the US frequency and can only be cured by the right fixation of the bonded parts.

There is more than one way for bond surfaces to move

Every practitioner of wirebonding knows that there are two major preconditions to guaranteeing good and constant bond quality: clean bond surfaces and rigid positioning of the bonded parts. The latter is important because wirebonding is a friction welding process carried out by ultrasonic vibration. Hence it is very sensitive to any other vibrations interfering at around the same frequency because this will interfere. Therefore bonding will be compromised if the part to be bonded cannot be mounted sufficiently rigidly. There are two main cases where this happens: firstly, the part may show a resonance oscillation when excited by the bonding ultrasonic; secondly, the bonding surface may be fixed with too much compliance so there is passive motion when the ultrasonic oscillation is applied. We will discuss these two phenomena in turn.

The first is a true resonance phenomenon: the part under consideration shows a specific oscillation with a certain eigenfrequency which is determined by the mechanical and geometrical properties of the part. Hence it will be the same for all parts and will change only if the part design is altered. This resonance frequency will show up if – and only if – excited close to its center value. The further away the excitation frequency, the smaller the excitation response will be, unless the external excitation hits an overtone which in most cases will be twice the eigenfrequency (i.e. the first overtone) and higher multiples. The resonance response is usually a Lorentzian curve with a rapid fall-off away from the peak. It is important to note that the resonance can have a larger amplitude than the exciting oscillation, as shown by the well-known example of the bridge collapsing due to resonance oscillation.

The second phenomenon is non-specific and purely passive: the bond pad simply follows whatever vibration it is excited by, because it is mounted on a soft or pliant underground. Here the excitation frequency does not matter. This is not a true resonance but just a passive following oscillation (in German referred to as “Mitschwingen”). Here, a design change usually has much less influence (unless it changes the compliance considerably), and the passive oscillation always has a smaller amplitude than the excitation frequency.

Below we will discuss two typical examples, one from each type: first a true resonance case, second a passive following oscillation.

A case of true or sharp resonance

Fig. 1 shows a sensor chip mounted on a cube-shaped quartz pedestal about 3 mm along the edges which exhibits (Fig. 2) a very sharp resonance at 101.2 kHz (black curve) and a first overtone at 202.5 kHz (red curve) when measured with a laser vibrometer during bonding on the side of the chip. (Bonding frequency was 101,2 kHz.) The first overtone of the resonance develops during the bond time to as much as 175 nm which is not far from the tool amplitude itself of around 300 nm, while the bonding frequency (which one would expect to observe at the chip as the bond develops) shows up at a very low amplitude of barely 25 nm. Clearly, this overtone resonance makes bonding next to impossible.

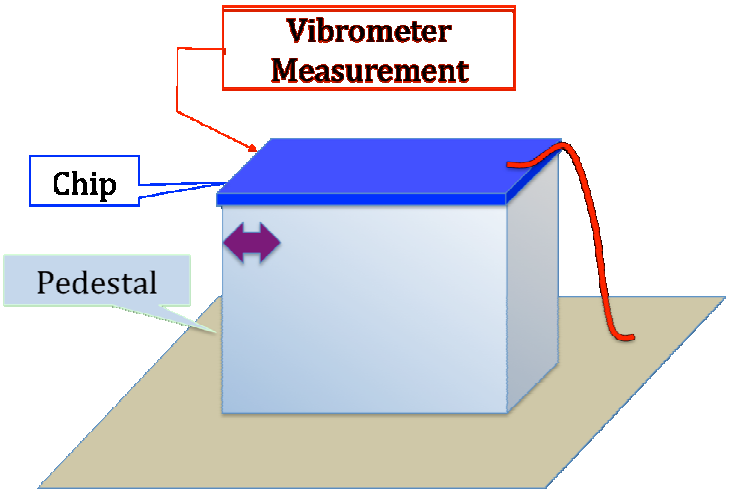

Fig. 1 Sensor chip mounted on resonating quartz pedestal

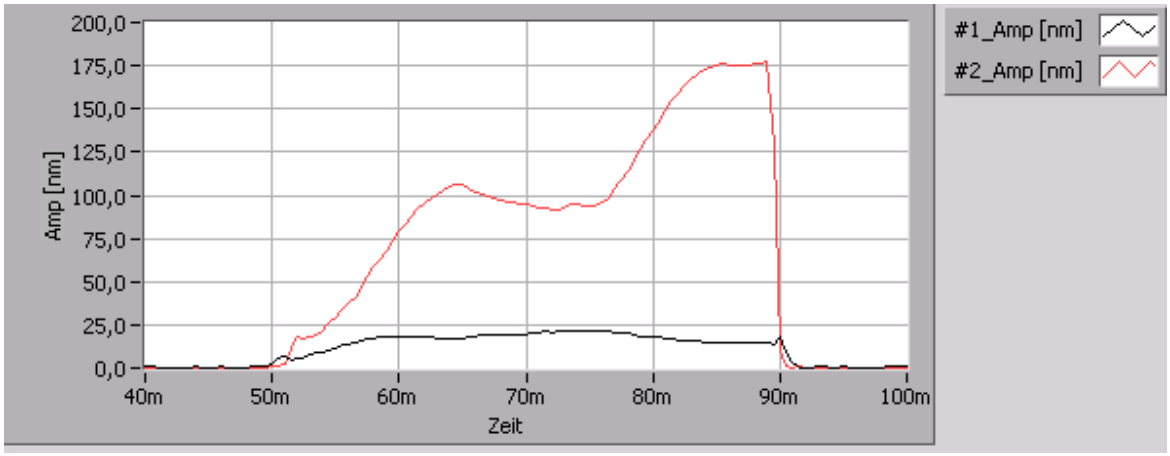

Fig. 2 Resonance (black curve) at 101.2 kHz and first overtone (red) at 202.5 kHz measured at chip

Interestingly and characteristically, the first overtone shows an even higher amplitude than the base mode, proving that true resonance occurs.

It was quite easy to solve this problem just by changing to a different transducer with a frequency of 140.6 kHz. Fig. 3 shows again the oscillation of 140.6 kHz at the center of the chip (black curve) which, as expected, develops as the bond gets formed and then reaches a maximum of 150 nm while the tool amplitude, shown in Fig. 4, is around 300 nm. (A previous paper in this series explains why one expects the substrate to exhibit a following oscillation as the bond develops, with a maximum amplitude considerably below the tool amplitude.) The red curve in Fig. 3 shows the first overtone at essentially zero amplitude. This is in keeping with the model presented above.

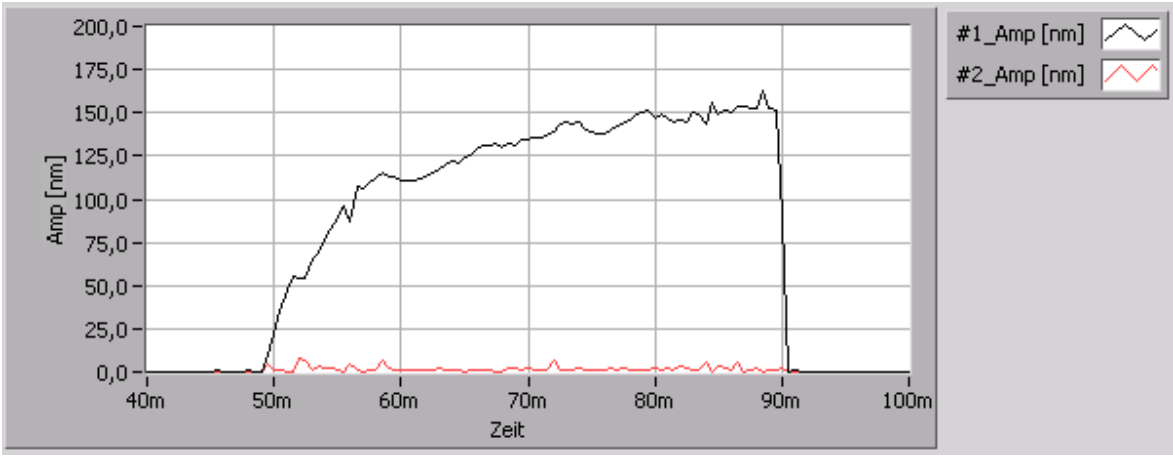

Fig. 3 Passive oscillation at 140.6 kHz measured at chip; no overtone

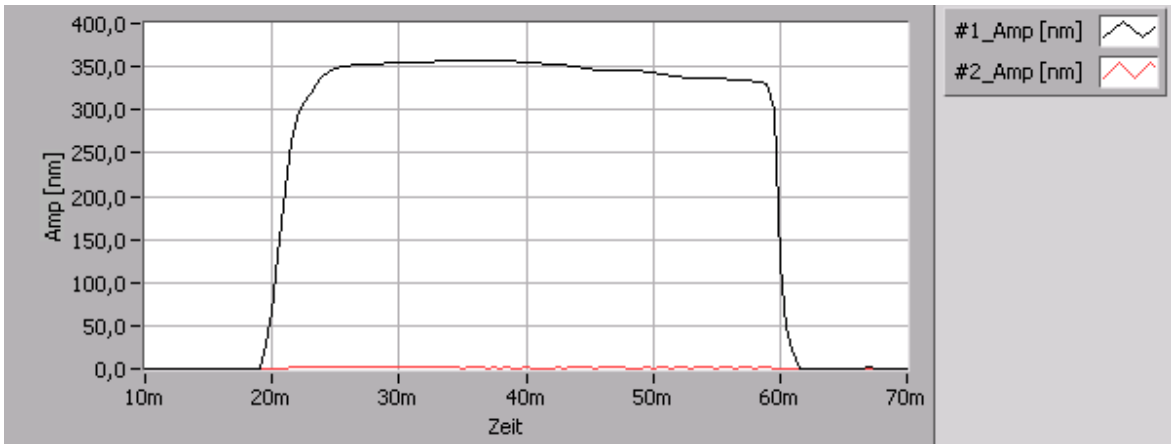

Fig. 4 Amplitude of tool tip during bonding at 140.6 kHz

True resonance problems are by no means as exotic as it may seem: a standard TO header, as often used in sensor or MEMS packaging, may have pins of 0.3 mm thickness, protruding by around 1 mm. A copper pin this size will show a resonance at 147 kHz and hence will make bonding impossible, while another frequency (like 100 kHz) will work perfectly fine.

Soft mounting can lead to passive (parasitic) oscillation

In the second example, Fig. 5 depicts a contact pin which is supported by a polymer collar of two types: one softer, one harder. It demonstrates the effect of higher or lower compliance leading to a higher or lower degree of passive (following) oscillations.

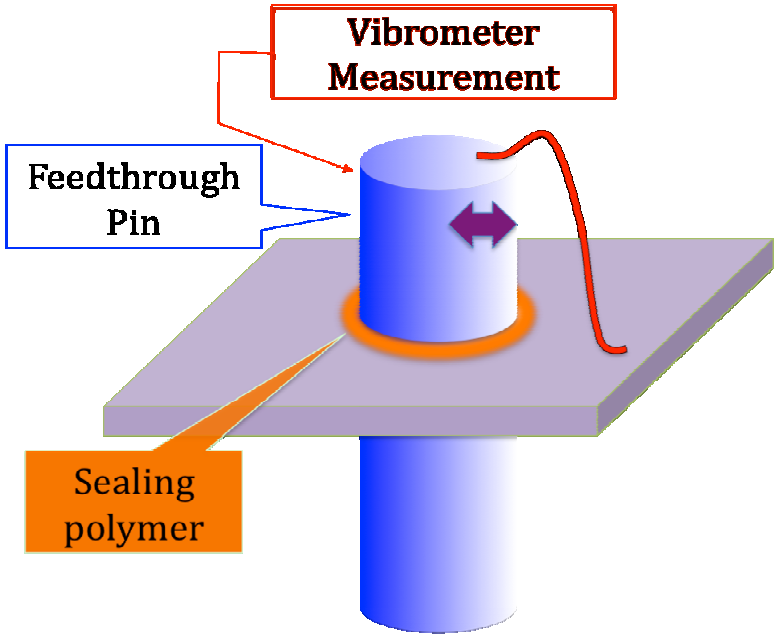

Fig. 5 Feedthrough pin encased by sealing polymer and wire bond

Fig. 6 shows for comparison the tool oscillation itself during bonding at 100 kHz. The oscillation is essentially constant and undamped with an amplitude of 800 nm. Fig. 7, measured just below the tool at the pin, clearly indicates that the pin follows the tool oscillation faithfully and at the same amplitude, making bonding impossible.

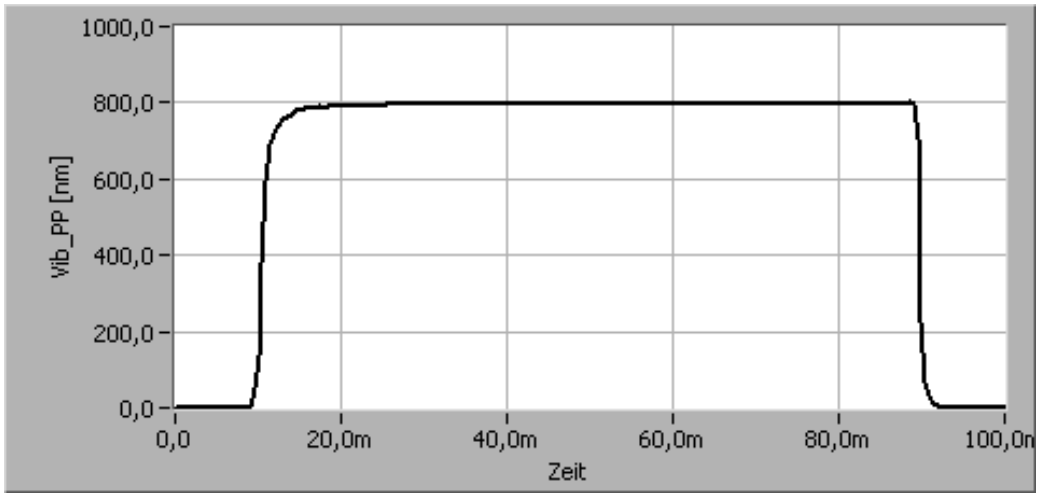

Fig. 6 Tool oscillation measured by vibrometer at tool tip, 100 kHz

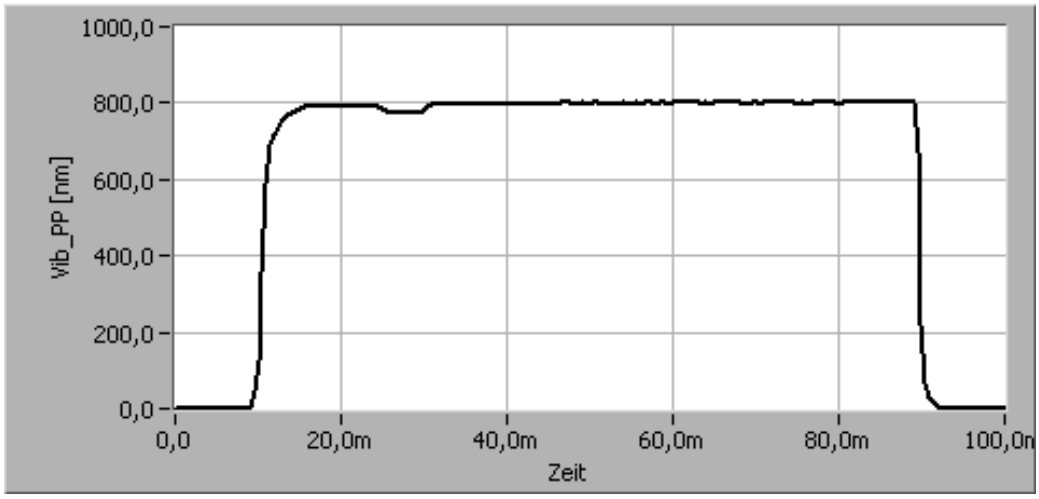

Fig. 7 Large oscillation of contact pin for soft polymer collar (100 kHz)

Changing the polymer support resolves the problem very effectively, as shown in Fig. 8 where the pin now follows the oscillation with much lower amplitude, indicating a good bond.

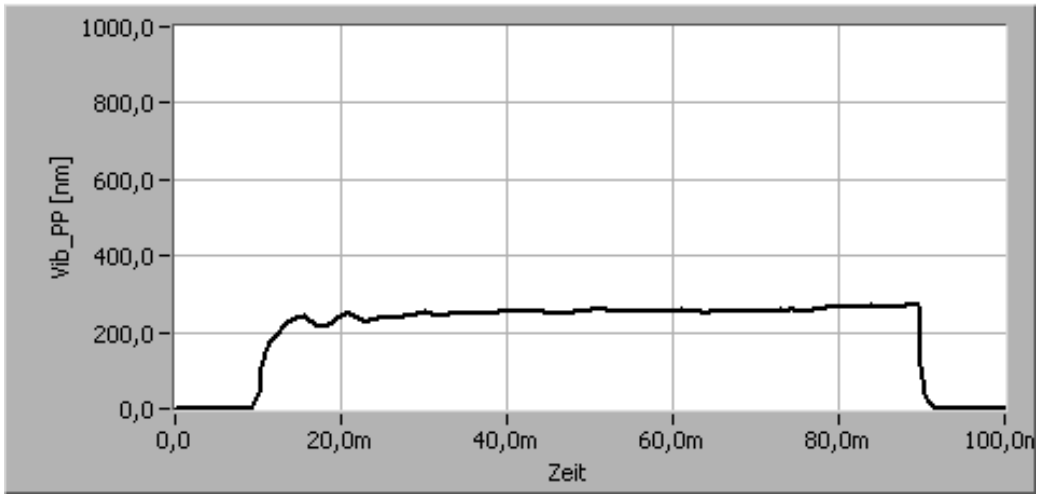

Fig. 8 Smaller oscillation of contact pin for hard polymer collar (100 kHz)

The following figures demonstrate that there is no true resonance frequency, only passive following, in this system. By changing the US frequency to 65 kHz, the amplitude at the tool tip (Fig. 9) was found to be around 1500 nm (cf. the remarks in the earlier paper that higher bonding frequencies often go together with smaller amplitudes), and for the softer pin support, the pin oscillates with the same amplitude (Fig. 10). Changing to stiffer polymer and better support again reduces the following resonance by more than half, just like in the case for 100 kHz, as shown in Fig. 11.

To corroborate these results, the same checks were made for a third transducer frequency of 145 kHz, with exactly the same effect: the passive or following resonance amplitude depends only on the compliance of the bond surface and not on the US frequency (results not shown).

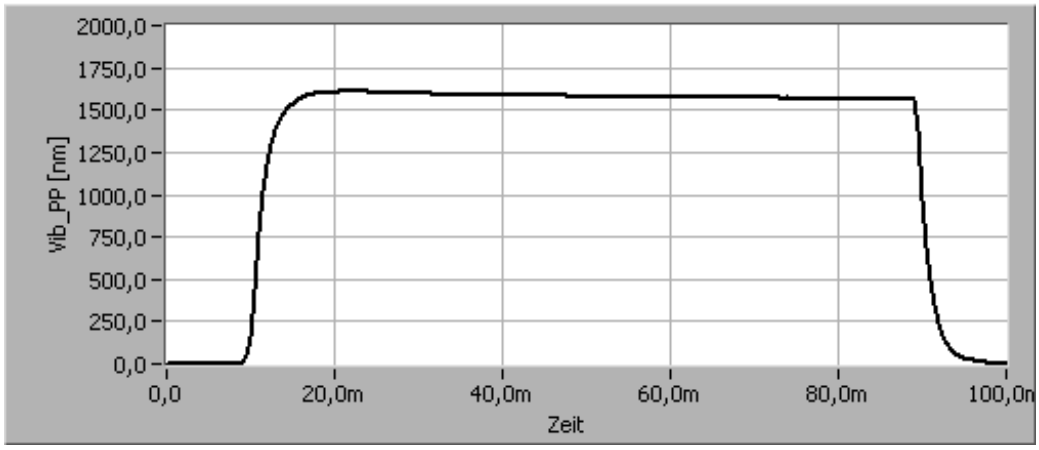

Fig. 9 Tool oscillation measured by vibrometer at tool tip, 65 kHz

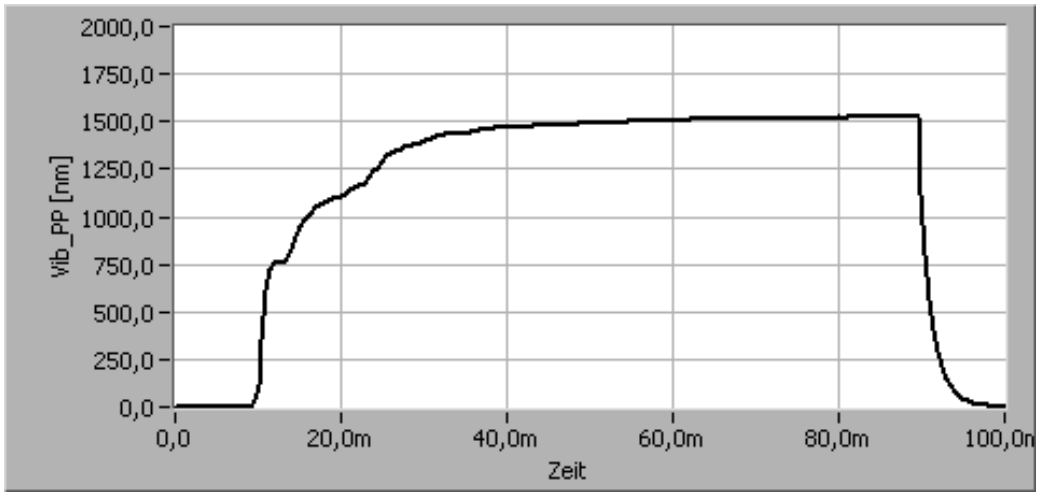

Fig. 10 Large oscillation of contact pin for soft polymer collar (65 kHz)

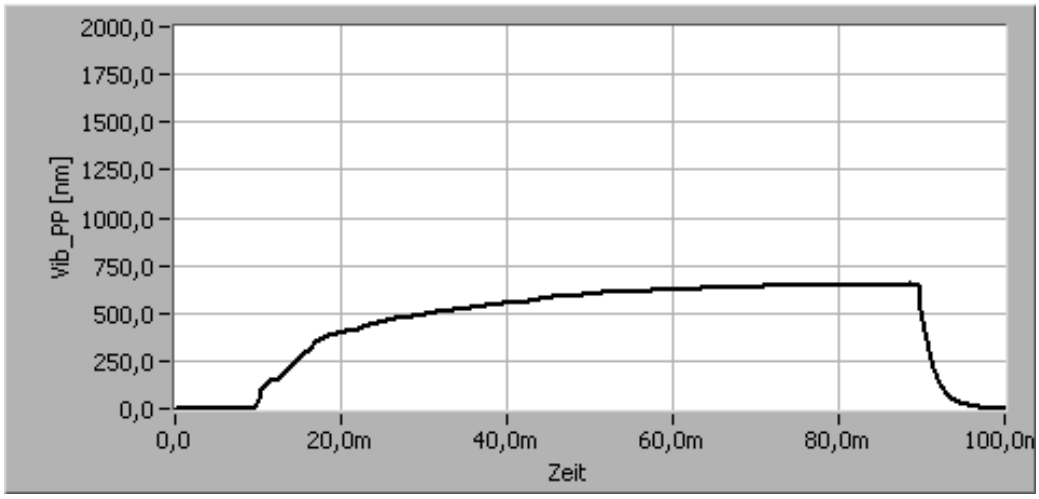

Fig. 11 Smaller oscillation of contact pin for hard polymer collar (65 kHz)

It is worth noting that both types of resonance may show up at the same time: the feedthrough pin discussed above will, of course, have an intrinsic resonance frequency in addition to the overall movement allowed (or prevented) by the compliance of the mounting polymer. As mentioned above, this intrinsic resonance can very well be in the same range as the bonding frequency, so preventing the problem of the soft mount may in fact bring out the other problem even more sharply.

Conclusion and recommendations

Resonance phenomena at the bonding components are sometimes true resonances and sometimes just passive following. They differ in that a change of US frequency will avoid the true resonance while the passive resonance is independent of the US frequency and can only be removed by a stiffer setup. Therefore it is recommended to have a choice of US frequencies in the bonding equipment, especially when both cases of resonance can occur in the same part. Modern bonding equipment usually has digital US generators with switchable frequencies so that only the transducer itself needs to be changed physically.