A Release Property of High-Permittivity Thin Film Manufactured with Nano-Transfer Method


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Abstract
It is useful to be able to further miniaturize printed wiring boards (PWBs) to achieve more compact and multi-functional mobile electronics. Since about 40–50% of the surface of a PWB is covered with passive elements such as capacitors, it is clear that miniaturization would improve performance. On the other hand, PWBs have a low temperature resistance, and thus the boards cannot use capacitors that require higher processing temperatures. The nano-transfer method, which consists of release and transfer steps, solves this problem. After the capacitor is fabricated on a high-temperature-resistant substrate, it is released from the substrate and mounted on the PWB. The purpose of this study is to clarify the release process in order to establish a fabrication technology for embedded substrates.

Keywords: Embedded substrates, Nano-transfer method, Thin film, Capacitor, MOD method, Tape peel test

1. Introduction
At present, 40 to 50% of the surface of a PWB is covered with passive elements such as capacitors. It is clear that such passive elements impede the miniaturization of PWBs. Using an embedded substrate is an approach to addressing that problem and this means loading electronic elements not onto a PWB but into it. As a result, capacitors on the PWB surface can be removed to achieve greater miniaturization. However, PWBs cannot resist temperatures of 300 degrees and cannot use the high-permittivity dielectrics that require higher processing temperatures. The nano-transfer method (Fig. 1) is a solution to this problem. It consists of release and transfer processes. First, a capacitor is fabricated on an outer substrate that has high heat resistance, and then it is peeled from that substrate and transferred to the application substrate. The first objective of this study was to clarify the influence of the Pt electrode thickness and the PZT thin film thickness on the release properties. The second objective was to fabricate a low-cost Cu electrode capacitor and test its utility.

2. Examination
We first describe the examination process using a Pt electrode. A 4-inch Si substrate was used. A 300 nm SiO₂ film was formed in an oxidation furnace. Then, the Pt layer for the bottom electrode was deposited by sputtering. In this process, a few nm of Ti are usually deposited between the SiO₂ and Pt to enhance the adhesive force, but in this study we required a low adhesive force between them to enable the release and transfer. Pt was sputtered variously from 15 to 1000 nm to investigate the relationship between the Pt thickness and the release property at the interface. The Si wafers were diced using a wet method into 20 mm × 20 mm samples. After that, lead zirconate titanate (PZT) was formed on the bottom electrode using the metal organic decomposition (MOD) method. PZT is a high permittivity dielectric and the MOD method is a chemical solution deposition (CSD) method that is similar to the sol-gel method. Pure water, acetone, and isopropyl alcohol (IPA) were used for surface cleaning. The PZT was depos-
ited using a spin coater at 2500 rpm and followed by rapid thermal annealing (RTA) with the following temperature regime: 2 minutes at 120 degrees (evaporation temperature), 4 minutes at 250 degrees (pyrolyzing temperature), and 2 minutes at 700 degrees (crystallization temperature). These MOD processes, consisting of deposition and annealing, were repeated 10 times to build up adequate PZT thickness to prevent leakage current. The properties of this capacitor were then measured. The structural properties were measured using x-ray diffraction (XRD) and the electrical properties were measured using an LCR (inductance, capacitance and resistance) meter.

Next, a tape peel test (Fig. 2) was performed on the samples. This is a qualitative examination that tests whether or not the thin film is releasable from the substrate by the tape detaching force. We used kapton tape (Permacel P-221) and measured manually. The Pt film stress was also measured to investigate its effect on the release property.

The problem of replacing Pt with Cu is the high temperature of 700 degrees that is required for PZT films because Cu oxidizes at such high temperatures. Then the all-Si substrate replaces the Cu and practiced processes on the Cu foil using the same methods as on the Pt electrode. This enables the capacitor release process to be skipped because it doesn’t use the Si wafer, and the Cu substrate is thick enough (100 μm) so that non-oxidized Cu remains on the Cu foil substrate. A transfer examination is performed using the Cu foil sample (Fig. 3). After removing the unnecessary oxidized Cu, we performed the transfer process using conductive double-faced tape. In this process, the capacitor’s dielectric constant and leakage current of transcription before and after were measured to investigate changes in the capacitor properties.

3. Results and Considerations
3.1. Release property on Pt electrode

We used XRD analysis to study the thin film capacitor properties on the Pt electrode before and after detachment. The analysis showed an intense peak of (100) orientation, which is the PZT perovskite structure (Fig. 4). This orientation was caused by our use of 250 degrees for the pyrolyzing temperature. The dielectric constant was about 1260 and the leakage current is shown in Fig. 9 with the Cu foil data which will be discussed later.

Fig. 5 shows the hysteresis loop. This loop shape is a common one and the residual polarization was good at 20 μC/cm².

The result of the tape peel test is shown in Fig. 6. This is a release property investigation map for the interface between the SiO₂ and Pt. The Pt thickness and PZT thickness are used as parameters. The PZT film thickness is about 250 nm per layer. As the figure shows, the thicker the Pt and the thinner the PZT, the more easily the film releases. The reason for this may be the diffusion and adhesion of PZT. PZT is attached and cannot release from SiO₂ if it is deposited directly onto SiO₂ and annealed. PZT also cannot release when deposited directly onto Pt. When PZT was in the interface between the SiO₂ and Pt it could not release.
not release, and if the Pt was thin, the PZT could diffuse through the Pt and reach the interface. When the Pt layer was thin (100–500 nm), a significant amount of PZT diffused through the layer and prevented release, but when the Pt layer was over 1000 nm, it was thick enough to prevent such diffusion. However, we cannot explain why the Pt layer could not be released when the layer thickness was under 100 nm and PZT was not deposited. We think the adhesion was related to the residual stress of Pt and checked the relationship between the Pt thickness and its residual stress. The result is shown in Fig. 7. This graph is from a Stoney equation with substituted Pt residual stress and thickness. This figure shows that the Pt compression stress increased dramatically in the thin area. This compression stress could explain the inability-to-release phenomena because in thin areas it is greater than the tape tension force and cannot release.

3.2. Capacitor property on Cu foil electrode

When we fabricated the capacitor on the Cu foil electrode, the PZT perovskite structure was oriented (110), though we used the same conditions as when fabricating the Pt electrode (Fig. 8). The result was a decreased dielectric constant of 306 before the transfer process onto the Cu. Oxidation of the Cu occurred between the PZT and Cu bottom electrode and also affected the decrease of the dielectric constant.

After the transfer process, the dielectric constant was 324, and as such, the transfer process did not likely contribute to the change of the dielectric constant. The I-V property changed as shown in Fig. 9. Before the transfer onto the Cu foil, the leakage current was 4 orders higher than on the Pt. However, it decreased about 2 orders after the transfer process. As such, the leakage current property was enhanced by the transfer process. The reason why the leakage current was so high before the transfer is due to the effects of the Cu deflection caused by cracking due to thermal stress.

However, the hysteresis loop changed to the nearly circular form shown in Fig. 10. The residual polarization was
20 µC/cm² at the same value on Pt, but its anti-electric field was much higher. This result was caused by the orientation (110) as seen in XRD analysis.

4. Conclusions
This study first investigated the release property of a thin film capacitor on a Pt electrode. The release property is an important factor in deciding the proper thickness of Pt and PZT in the nano-transfer method. To prepare PZT over 1 µm for the nano-transfer method, the Pt thickness has to be thicker than 1000 nm. However, this is very thick, so to consider cost reduction, a parameter other than Pt or PZT thickness should be introduced to fabricate a thinner capacitor that can release. Candidates for such a parameter are fabrication temperature at Pt sputtering or density of the PZT solution. These properties have effects on the residual stress.

Secondly, a thin film capacitor on a Cu foil electrode was successfully achieved using 100 μm Cu foil. Further study into preventing oxidation can allow for a reduction in the Cu thickness and will enhance its capacitor properties significantly.

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References