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Quantitative evaluation of bending reliability for a flexible near-field communication tag

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ABSTRACT

Flexible electronic devices under repetitive use inevitably entail damage accumulation that can cause failures in the components and interconnects. The main aim of this study involves proposing test procedures and corresponding testers that can be used to systematically evaluate the bending reliability of flexible electronic devices. In contrast to conventional bending test techniques based on a collapsing radius method, in the present study, the flexible devices were wrapped onto a roller to ensure a constant strain. An example of a near-field communication tag for smart phones was examined to verify the proposed test methods and testers. The results indicated that the critical curvature for cyclic failure was significantly lower than the static critical curvature. Curvature-life diagrams as evaluated by the proposed test method revealed that bending radius and alignment methods significantly affected the reliability of the tags. Thus, the curvature-life diagrams can be used to design a roller radius based on a predefined product life.

1. Introduction

Currently, several previous studies focus on flexible electronics to overcome the limitations of existing electronic products, such as displays and solar cells, which simultaneously require portability and a large area. A study by Wong and Salleo [1] detailed the need for flexible electronics, their applications, and the technical issues to be solved. One of the biggest threats in flexible electronic devices lies with the reliability and lifetime because mechanical stresses induced from mechanical flexing of the substrate can lead to rapid degradation of system performance [2]. Several flexible electronic devices were developed albeit not introduced in the market because the reliability problem has not been solved to date. Sibiński and Znajdek [3] reported the degradation of flexible thin-film solar cells due to a mechanical strain. Dagdeviren et al. [4] reviewed on the recent research progress in flexible and stretchable piezoelectric devices but none of them was commercialized yet. It is necessary to accurately measure cyclic behavior to consider reliability issues related to loading in bending. Additionally, prior to the advent of flexible electronics, various cyclic endurance reliability test methods were extensively investigated for yarns or lines [5,6], textiles [7], and films [8–12]. The test methods are classified into tension [13], torsion, and bending [14] from a mechanical loading viewpoint.

Among the fore-mentioned tests, bending tests are particularly important because several flexible devices are designed such that they are bendable [15], foldable [16,17], or rollable [18,19] during their respective operation periods. There are several types of bending tests [20]. The most common technique involves the collapsing radius test [21,22], which was adopted for a standard test method for conductive thin films on flexible substrates [23]. A more sophisticated technique called the *X-Y-θ* test [24,25] was developed for accurate radius feedback control. However, it is difficult to apply the developed test methods for the bending tests of flexible electronic devices. Most flexible devices include various components in them. Interconnects supported on flexible substrates are flexible when compared with batteries, sensors, actuators, and processing chips that are relatively hard. It is very difficult to accurately control the curvature (or radius) of a device due to the various types of components included in the device.

Kao et al. [26] performed static and cyclic bending tests with nMOSFETs via a curvature bending vehicle with a maximum radius of 7.5 mm. The cyclic tests were performed, and the electronic characteristics were monitored up to 1000 cycles by repetitive wrapping and unwrapping. Li et al. [27] tested their solar cells by wrapping the cells on a mandrel. Torrisi et al. [28] performed bending tests by manually bending the samples over cylinders with different radii of curvature. The advantage of the test methods included accurate curvature control irrespective of the devices that were tested. However, it is time consuming to manually wrap and unwrap the devices, and it is also inconvenient to simultaneously probe the characteristics. Hamasha et al. [29] performed cyclic bending tests with indium tin oxide (ITO) thin film on PET substrate by reciprocating a set of bending dies vertically. They tested the ITO films up to 10,000 cycles at a frequency of 1.25 Hz. In

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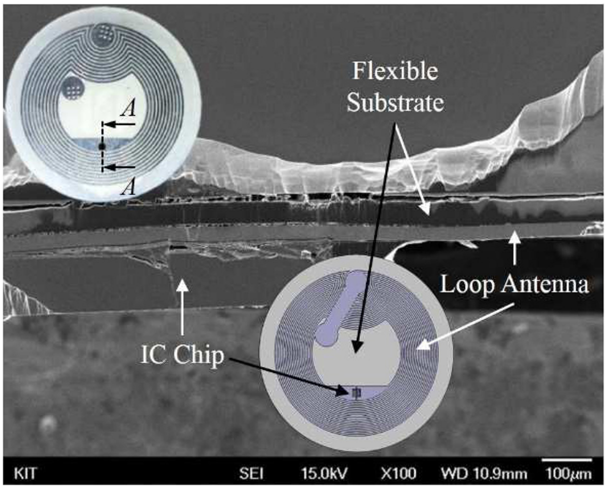

Fig. 1. An electron micrograph scanned along the section *A-A* of an NFC tag. The optical image (upper left) and the corresponding CAD model (lower middle) are inserted to illustrate the main components of the NFC tag.

this test, a certain amount of tensile force is required to flatten the film. Recently, Li and Jackson [30,31] suggested three platforms for flexible device testing: a simple push-to-flex apparatus, a roller-flex apparatus, and an on-belt-flex apparatus. The on-belt-flex apparatus that uses a secondary flexible substrate has advantage of providing controlled-radius bending without additional tensile stress.

The main aim of the present study included developing test procedures and testers that could be used for static and cyclic bending tests of flexible devices. A curvature-life approach is adopted to quantitatively estimate the life of near-field communication (NFC) tags based on the critical curvature data as estimated by the proposed test method.

2. NFC tag, static and cyclic test procedures

In principle, any flexible electronic products, which are flexible enough to conformably deform around a roller and have a flat substrate, can be a test structure. A commercial NFC tag (NTAG-203, EMFO) was selected and tested since it was readily available and widely used. The NFC tag included a few simple albeit essential constituents such as a flexible substrate, a moderate flexible antenna (that can be considered as a type of interconnection), and a hard processing chip. The real tag and its CAD model are shown in the inset in Fig. 1 to illustrate the main components and the section to be observed with a scanning electron microscope (SEM). An NFC tag was cut along section *A-A* using a focused ion beam and the cross section was observed using an SEM (JSM-6500F, Jeol). The thicknesses of the chip, substrate, and antenna approximately corresponded to 120 μm, 45 μm, and 30 μm, respectively.

A commercial static bending tester conforming to the ASTM standard [32] was partly modified and is shown in Fig. 2a. The roller in the roller block of Fig. 2a and b initially consisted of a simple solid cylinder to press the films, coatings, or certain other flat specimens. The roller was machined to create a circumferential groove in the central part, which is denoted as a dashed rectangle as shown in Fig. 2b, due to a few specific components in the middle of the NFC tags. It is necessary that the roller should not interfere with any components of a flexible device during a test. The NFC tags were wrapped around the cylindrical mandrels with various diameters corresponding to 1 mm, 1.5 mm, 2 mm, 2.5 mm, 3 mm, 4 mm, 5 mm, 6 mm, 8 mm, 10 mm, 12.5 mm, and 16 mm. Generally, a test was performed by changing from a larger diameter to a smaller diameter mandrel. An NFC reader (ACR1252, EMFO) was used to check the functionality in real time during each static bending test.

A cyclic bending test system was built as shown in Fig. 3. The system is a kind of on-belt-flex apparatuses [31]. It consisted of an AC motor, a speed reducer, a flexible coupling, a set of driving and driven rollers, a supporting secondary belt, and a controller. The rotation direction was automatically reversed when a short rigid plate attached to the end of the supporting belt reached one of the proximity sensors that were

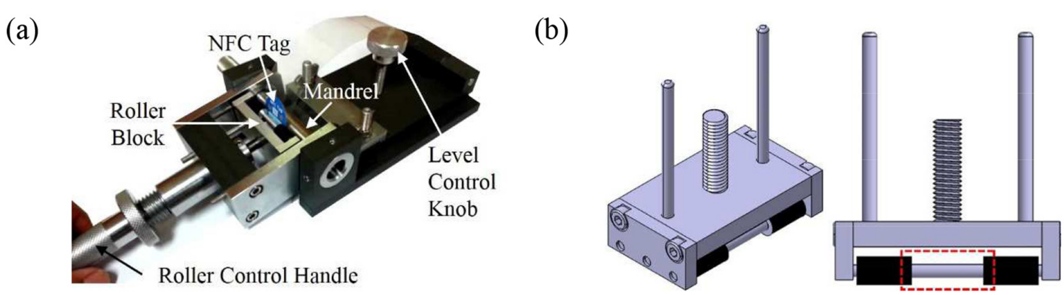

Fig. 2. Static bending tester (a) modified by machining a circumferential groove in the center of the roller in the roller block (b).

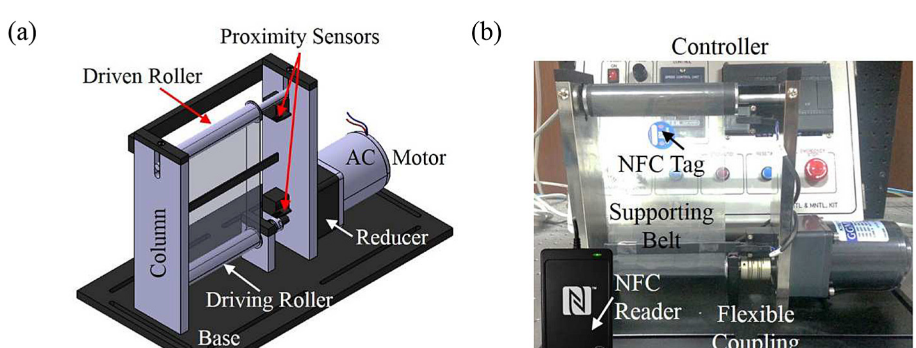

Fig. 3. The schematic model (a) and the real testing system (b) of the cyclic bending tester.

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