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INTRODUCING A NEW MEMBER TO THE FAMILY: GOLD WHISKERS

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The growth of whiskers on tin-plated terminals of electronic devices has a long history of problems related mostly to passive components, such as chip ceramic capacitors, relays, resistors, inductors, and fuses. The importance of this problem for all types of components, including discrete semiconductor devices and microcircuits, increases with the transfer to green electronics and the tendency to use lead-free solder and pure tin finishing. Tin whiskers can be long enough to cause malfunction or even catastrophic failures in electronic systems. A detailed description of failures in high-reliability electronic systems attributed to tin whiskers, as well as known conditions facilitating their growth and mechanisms of formation, can be found at the Goddard Space Flight Center (GSFC) [1] and CALCE [2] web sites.

So far, whiskers were observed only on a limited number of metals, namely on tin, zinc, and cadmium surfaces. The purpose of this paper is to report on observations of whiskers grown on gold plating.

In this work, gold whiskers were revealed during internal SEM examination of micromachined relays, which had metal elements (contacts, springs, and actuators) made of nickel plated with gold. The elements were fabricated using a nickel surface micromachining process, in which high aspect ratio structures (the thickness of nickel is 20 μm) were manufactured by electroplating nickel onto lithographically defined copper plating stencils [3]. Gold was electroplated over the nickel to a thickness of approximately 2 μm. The tips of the stationary and movable contacts were additionally plated with hard gold to a thickness of ~ 5 μm.

Similar to tin whiskers, the revealed gold whiskers varied by size, shape, diameter, and density. Typical whiskers had lengths of several micrometers and diameters of approximately 200 nm (see Figure 1). Small, micrometer-sized whiskers with diameters from 100 nm to 400 nm were found in most of the inspected parts (see Figure 2). Figure 3 illustrates needle-like whiskers with diameters of 100 nm to 200 nm and lengths from 2 μm to 4 μm. Large, grass-root-like whiskers, of approximately 10 μm in length and ~1 μm in diameter, which were observed on several parts, are shown in Figure 4. Giant, irregularly shaped, toothpaste-like whiskers of more than 20 μm in length were observed in two out of 22 inspected parts (see Figure 5).

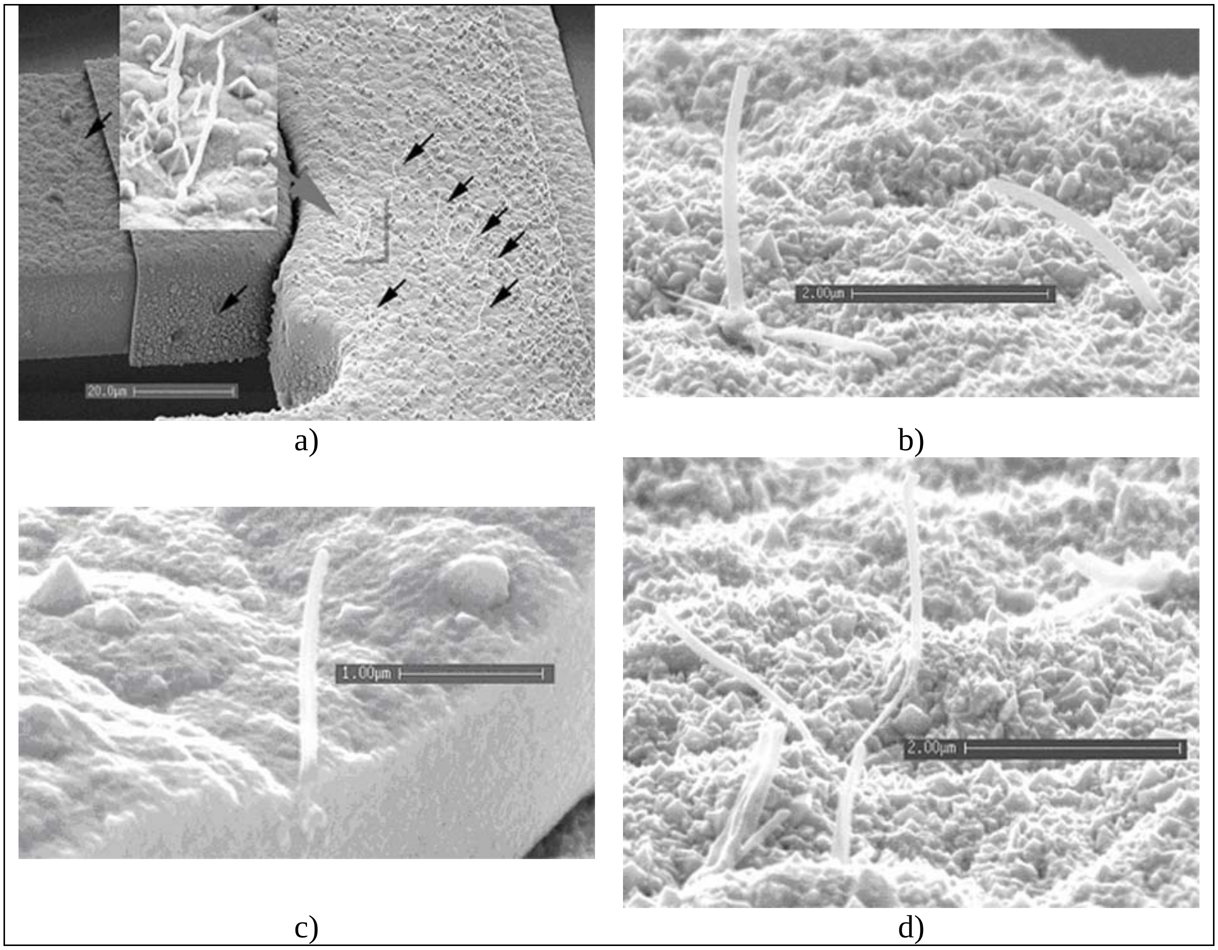

Figure 1. Typical whiskers observed on gold plating had lengths of a few micrometers.

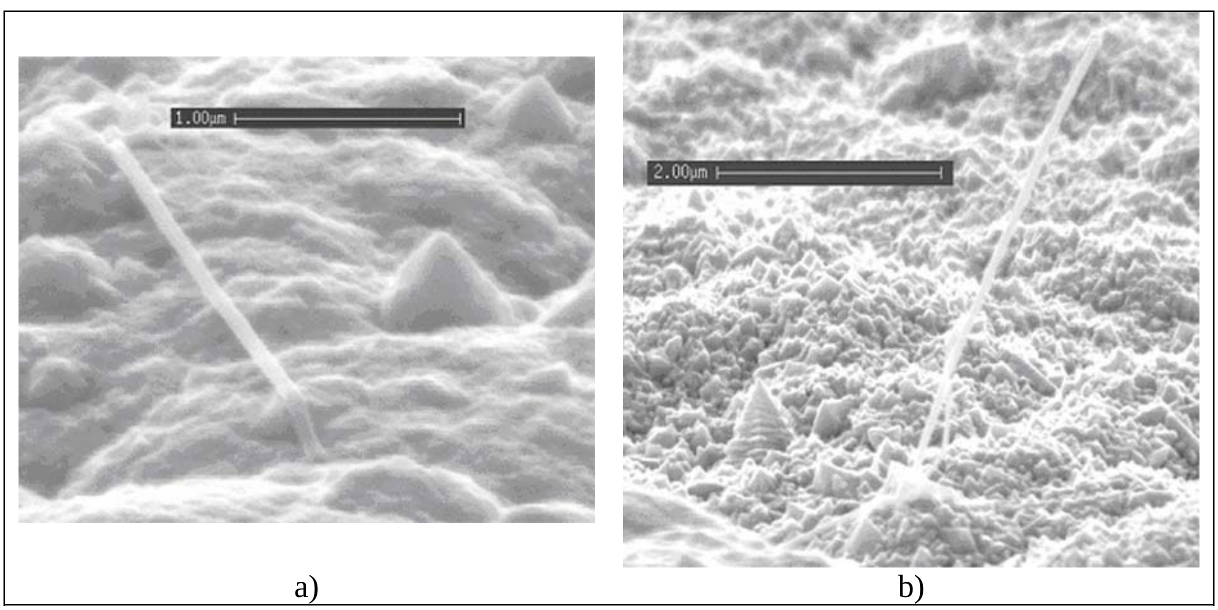

Figure 2. Needle-like whiskers.

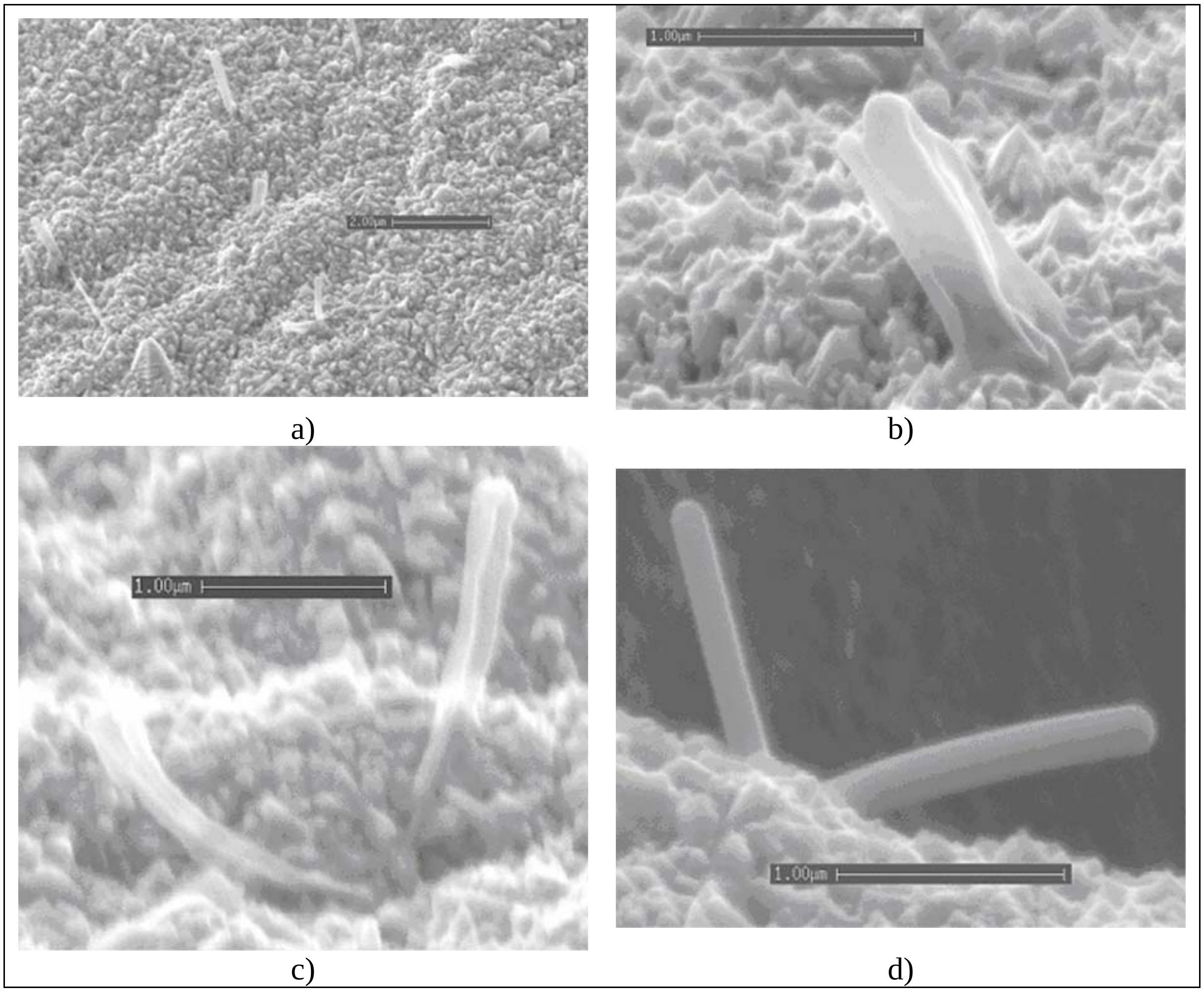

Figure 3. Micrometer-sized whiskers observed on most of the parts varied from smooth cylinder to irregular shapes.

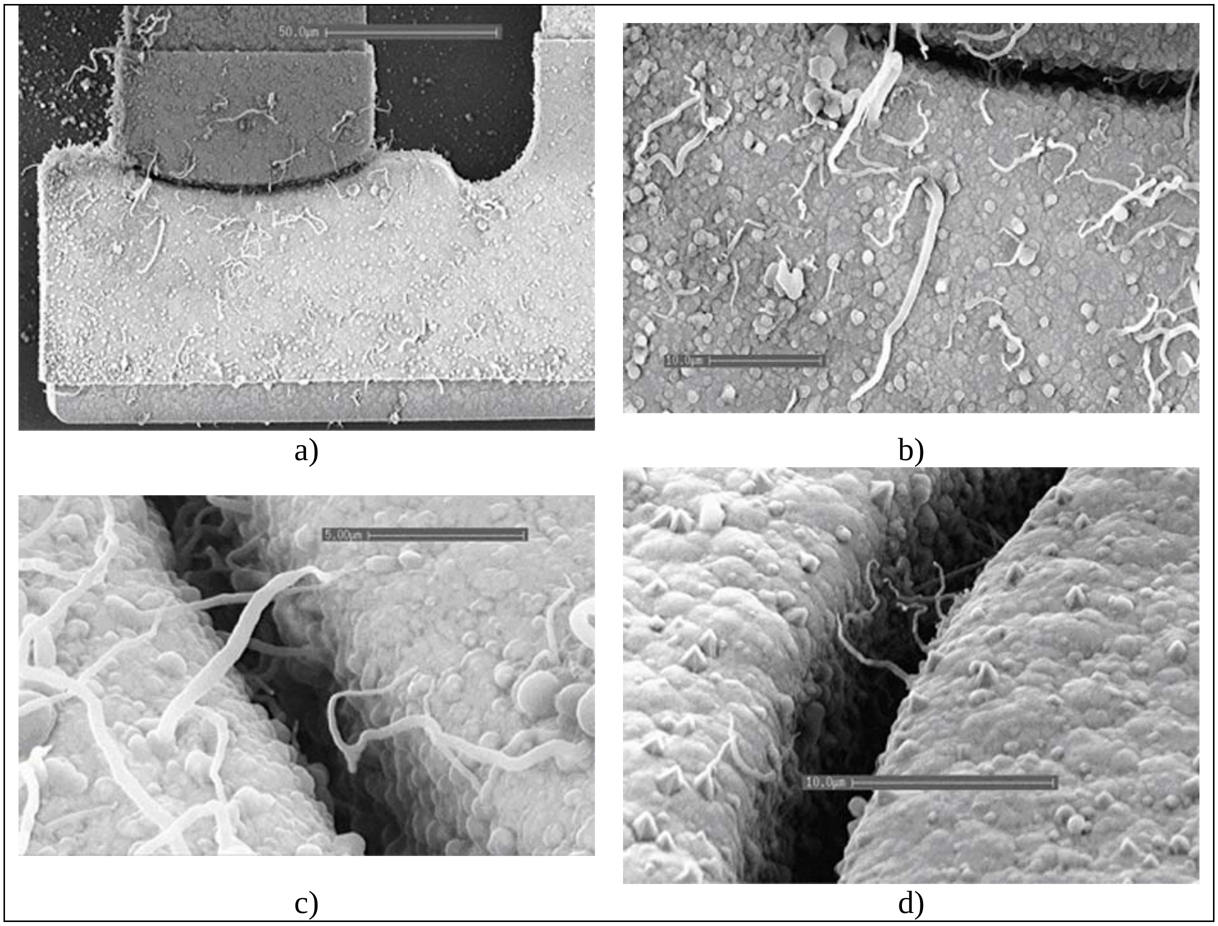

Figure 4. Grass-root-like whiskers had lengths of 10 μm to 20 μm and diameters of approximately 1 μm.

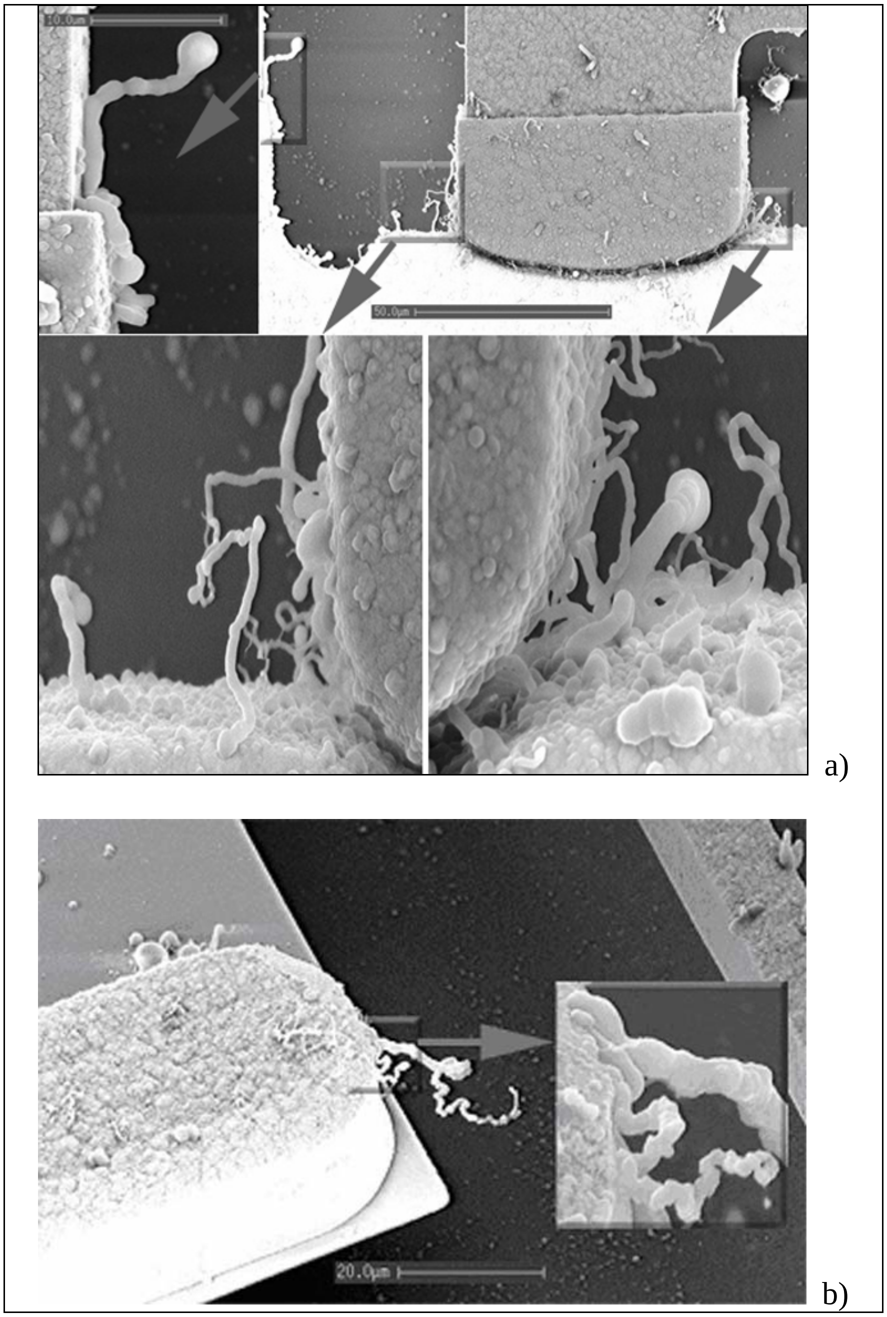

Figure 5. Giant, irregularly shaped, toothpaste-like whiskers had lengths of more than 20 μm.

In addition to whiskers, a large amount of tetrahedral microcrystallites, similar to those shown in Figure 4d, was observed on the surface of gold plating. The microcrystallites had sizes of 0.5 to 1 μm and their density on the contact tips' gold plating was much larger than on other gold plated elements of the devices.

X-ray microanalysis revealed nickel in the composition of the gold plating used for all elements of the device. Nickel is typically used in cyanide bath chemistry to harden gold plating for the contacts in separable electronic connectors. Microanalysis of the gold plating on the contact tips in areas with excessive density of the crystallites showed that the gold plating also contained rubidium. It is known that alkali metal gold intermetallics might create tetrahedral structures, in particular, for Rb_3Au_7 composition [4]. The origin of rubidium in the gold plating on the microrelays is not clear and was most likely a result of contamination of the electroplating bath.

It is generally accepted that the growth of whiskers is due to internal mechanical stresses in metal coatings, and the propensity to whiskering in electrochemically plated metal films is affected by the bath chemistry. The presence of impurity is also a known prerequisite for microcrystal nucleation. Maekawa and Okuyama [5] reported observation of both, gold microcrystallites of different shapes and tiny monocrystalline gold whiskers with lengths of ~500 nm and diameters of ~ 50 nm. These microcrystallites and whiskers were observed on gold wires sputtered with silicon at temperatures of ~300-400 ^{o}C after Ar^{+}-ion bombardment at a few keV.

As is conventional with all kinds of whiskers, the reasons and conditions of their growth are not clear, although it is possible that the contamination of gold plating with rubidium during manufacturing of the microrelays played an important role in formation of the microcrystallites and whiskers. In any case, part engineers, failure analysts, and quality assurance specialists should be aware of the possibility of formation of whiskers on gold platings.

References.

1. http://nepp.gsfc.nasa.gov/whiskers/
2. http://www.calce.umd.edu/lead-free/tin-whiskers/
3. Wood R., Mahadevan R., Dhuler V., Dudeley B., Cowen A., Hill E., Markus K., MEMS microrelays, Mechatronics, 8, 1998, pp. 535-547.
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5. Maekawa A., Okuyama F., Nano and microcrystallites of gold grown by argon-ion bombardment, Surface Science Letters, 481, 2001, pp. L427-L432.