CADMIUM WHISKERS

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THE growth of needle-like crystals on cadmium deposits has caused considerable annoyance in the radio industry. These crystals are known as "whiskers". They grow between condenser plates of variable condensers and, being electrical conductors, actually short circuit the plates, thereby putting the radio set out of operation. Not much is known about the cause of the growth of these crystals, and a moderate search of pertinent literature reveals very little. A few of the facts and theories have been gathered together here from at least a dozen sources, including the National Bureau of Standards.

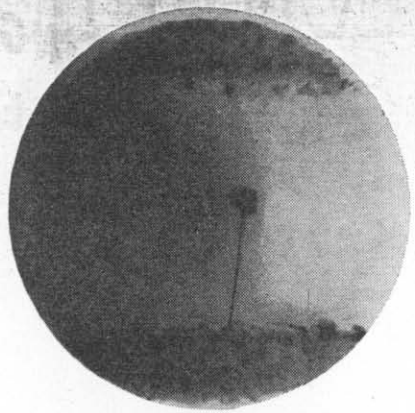

Fig. 1. Single crystal, one-year-old with particle of dust attached. X32.

Appearance

The whiskers as seen under a low power microscope are mostly straight, cylindrical, needle-like, and of constant diameter throughout their whole length (Fig. 1 and 2). They appear to be opaque to transmitted light but reflect light when illuminated from the direction of the observer. Their diameter is estimated at between .00001 and .00005 in. and they have been known to grow .040 in. long. They usually grow perpendicular or nearly perpendicular to the surface of the plate. The whiskers in photo-micrograph Fig. 1 were about one year old and perfectly straight. Those in Fig. 2 were found between the plates of a variable condenser which was over ten years old. The drawings in Fig. 3 to 7 were made by an artist who studied this condenser. They present a clearer picture of the details. A number of the longer whiskers are crooked. Higher magnification reveals a cellular appearance of some of the longer whiskers. This might be due to dust or foreign matter or possibly an aging effect. Most whiskers are straight and without the cellular appearance.

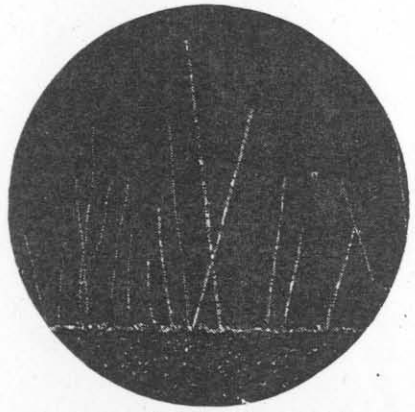

Fig. 6. Detail A in Fig. 5. Enlarged further.

Conditions of Growth

The examination of many whiskers has not revealed any evidence of any accumulation of material around their bases from which they might grow. Also, if they grow from pores, these could not be identified as such. They appear to start from the flat surface of the cadmium deposit.

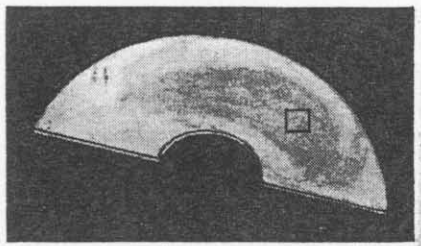

Fig. 3. Perspective view of ten-year-old condenser plate with cadmium whiskers. Hand drawn, nearly actual size.

The whiskers grow best from thin, irregular, and contaminated cadmium deposits. Most crystals have been observed on deposits less than .00015 in. thick and on darkened areas of low current density. There is no record to the author's knowledge that they grow from bright cadmium deposits over .0002 in. thick. They have been found on cadmium deposits over both brass and invar. In variable air condensers they grow mostly between the plates in the low current density areas, although sometimes they are found on the outside areas of such assemblies.

Although some persons claim they can be grown in a matter of days, it usually requires six to nine months for the formation of whiskers.

Properties

The whiskers are not brittle but can be bent over flat against the surface without breaking.

They are electrical conductors and the resistance of one crystal, approximately .020 in. long and .00003 in. diameter, is of the order of magnitude of 300 ohm.* When a high voltage is applied across a gap containing the whiskers, the tips fuse down to a point where the voltage cannot jump. For example, two condenser plates spaced .025 in. apart contained a miniature forest of whiskers. Five hundred volt DC was applied across these plates whereupon numerous tiny scintillations appeared momentarily. Then 1000 volt DC were applied and more scintillations appeared for an instant. Each time the voltage was increased the same phenomenon would occur. This method might be used to free condensers of whiskers, but a much easier way is simply to blow air between the plates.

*EDITOR'S NOTE: This is equivalent to a specific resistivity of 5.9×10^{-3} ohm/cm. cube as compared to the much lower specific resistivity of metallic cadmium of 7.5×10^{-6}. Streintz, Ann. Phys. (4), 9, 805 (1902), obtained almost the same value as for the whiskers, namely 5.5×10^{-5}, when a small rod of highly compressed cadmium oxide was heated to 400° C., allowed to cool to room temperature and then tested. Baedeker, Ann. Phys. (4), 22, 729 (1907), obtained a value of the same order of magnitude, 1.2×10^{-5}, for cadmium oxide prepared by burning in air a cadmium film deposited on glass or mica by cathodic atomization.

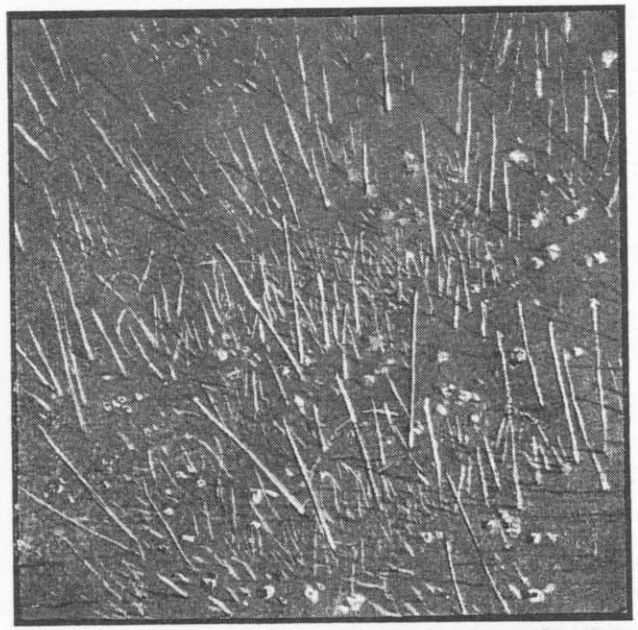

Fig. 4. Perspective view of cadmium whiskers. Found in the square shown in Fig. 3. Hand drawn. X22

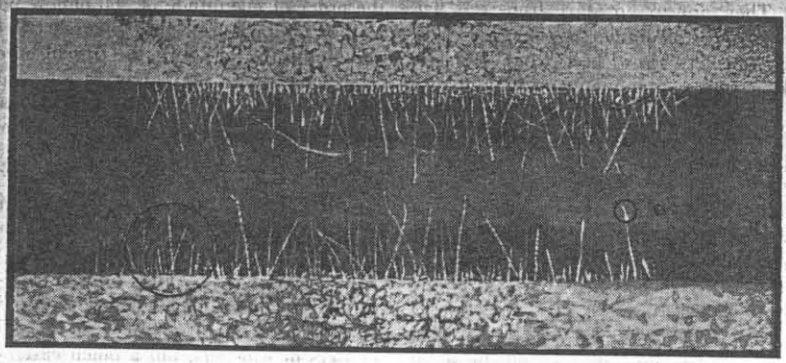

Fig. 5. Cadmium whiskers between ten-year-old condenser plates spaced 0.080 in. apart. Hand drawn, enlarged.

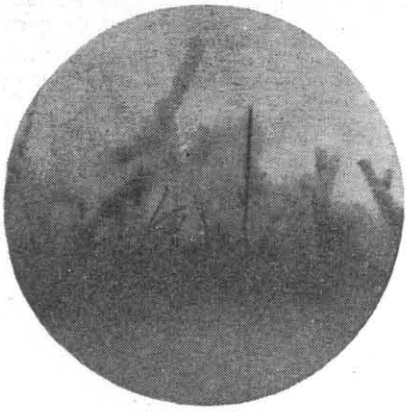

Fig. 2. Crystal forest on ten-year-old condenser. X42.

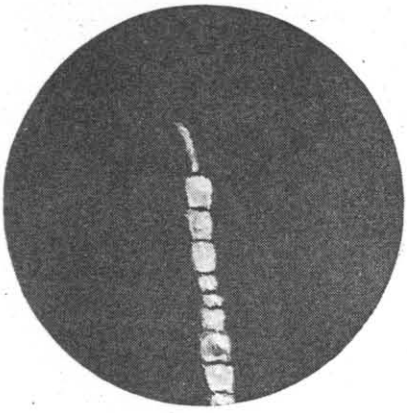

Fig. 7. Detail B in Fig. 5. Enlarged further.

In one experiment a steel needle was manipulated near a whisker which then bent toward the needle due to an electrostatic force.

Proposed Theories as to Growth

It is quite generally agreed among those familiar with the problem, that poor cadmium plating is the greatest factor in promoting the growth of whiskers. Poor plating implies a thin, pitted or rough deposit or one with impurities occluded in the plate. Among the causes of these conditions are improper cleaning of the base metal, impurities suspended in the plating bath, improper current density, improper final bright dip, and insufficient final rinsing. It is held by some that chromic-sulphuric acid is better than nitric acid as the final bright dip. Correction of these factors and an increase of the thickness of the deposit will go far to discourage the growth of whiskers.

Various specific theories have been proposed to account for their origin and growth. One such theory is that chemicals are trapped in the pores of the metal and in time react with the cadmium. The new compound takes up water of crystallization, increases in volume and is extruded through the pores. The author has observed a similar phenomenon to occur within a period of a few minutes on a piece of aluminum which had soaked in a sodium carbonate solution until pitted. On normal drying, a white pencil of material was seen under low magnification to extrude from one of

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the pits. It has not been determined whether the cadmium whiskers are metal or a compound. If they are metal there must be another explanation.

Another theory proposes that organic vapors from such substances as bakelite, linseed oil, or fatty acids combine with the cadmium to form needle-like crystals.** One manufacturer of variable resistors was troubled by a growth of these crystals (possibly whiskers) which escaped the eye but definitely short circuited the resistors. The trouble was overcome in this case by eliminating the fume-forming bakelite.

In Mellor's "Comprehensive Treatise on Inorganic and Organic Chemistry", Vol. 3 under Silver, there is described a phenomenon of the growth of "long, delicate fibres of silver which protrude from minute rounded masses of sulphide." This phenomenon takes place under artificial conditions of high temperature and in an atmosphere of hydrogen. The parallel formation of long fibres of silver and our formation of cadmium whiskers might be significant.

Mr. G. A. Lux of Oakite Products Company has found that tree-like crystals grow on the surface of silver when exposed to sulphur fumes in a heated closed container. He has determined these crystals to be silver sulphide. This is obviously a direct chemical combination but bears an interesting association with the problem of whisker growth in that the crystals emerge from the surface of the metal.

**EDITOR'S NOTE These crystals, which consist of cadmium formate, butyrate and the like, are generally very bulky and easily visible without magnification. They appear on any cadmium surface, and not only on thin, poor coatings. It is extremely doubtful that any cadmium salt would have as low a resistivity as shown for the whiskers discussed here. Most salts have a specific resistivity of 10^{-14} — 10^{-17} at room temperature.