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RECENT ADVANCES IN UNDERSTANDING THE MYSTERY OF ANÇIENT CHINESE "MAGIC MIRRORS"

A Brief Summary of Chinese Analytical and Experimental Studies

by

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and

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For the past thousand years, writers have periodically investigated a rare type of ancient Chinese mirror called *t'ou kuang ching* 透光镜, literally "light-transmitting mirror." These mirrors have the uncanny ability to project patterns from the back when light is shining on the front (see Figures 1 and 2).[2] When a strong light strikes the undecorated, polished front surface and is reflected onto a wall or screen, the patterns decorating the back of the mirror mysteriously appear in the reflection. A type of mirror first made during the Western Han period (206 B.C. - A.D. 9), " light-transmitting" mirrors characteristically have a very thin (5mm or less), slightly convex body, and a thick rim. Decorations are cast in relief on the back and often include an inscription. Like other Chinese mirrors, they are composed of a bronze alloy containing primarily copper, tin and lead.

In English these mirrors have been called "light-penetration mirrors," " diaphanous mirrors," and "magic mirrors," the last term being the most familiar and memorable. The name "magic mirror" is also applied to a group of 19th-century Japanese mirrors that exhibit a superficially similar phenomenon. However, the optical properties of the image reflected by a Japanese magic mirror differ from those of a Han magic mirror; and the two types of mirror were not made by the same process. In this article, we shall be concerned primarily with the Chinese type of

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2 The figures are from *Acta metallurgica sinica*, 1976, *12*. 1: pl. 1/1 and 2/6.

the Han period. Our aim is to present a summary of recent scientific investigations into techniques that may have been used to create Han magic mirrors, to explain the phenomena, and to suggest areas for future research.

The most recent and comprehensive study was inspired by the late Premier Chou En-lai's interest in these mirrors when he visited the Shanghai Museum in 1961. In 1975, research teams from several institutions in Shanghai, including Chiao-t'ung University 上海交通大学, the Shanghai Museum 上海博物馆, Fu-tan University 复旦大学, the Shanghai Instrument Foundry and Forge 上海仪表铸锻厂, and the Shanghai Science and Technology Association 上海科技协会 began intensive investigations. These teams not only studied Western Han magic mirrors in the collection of the Shanghai Museum, but also fabricated mirrors capable of producing the same effect as the ancient artifacts.

The investigators first reviewed theories previously advanced to explain how such mirrors were made in ancient times, and then proposed tentative explanations of their own. Next, they made replicas using various methods suggested by these theories and compared the results with Western Han magic mirrors. They concluded that a combination of casting and polishing conditions caused the formation of minute variations in the curvature of the convex reflecting surface, corresponding to the arrangement of decorations on the back of the mirror. When light is reflected from this uneven surface, the rays are scattered more by the areas that are more convex. The reflected image thus shows areas of

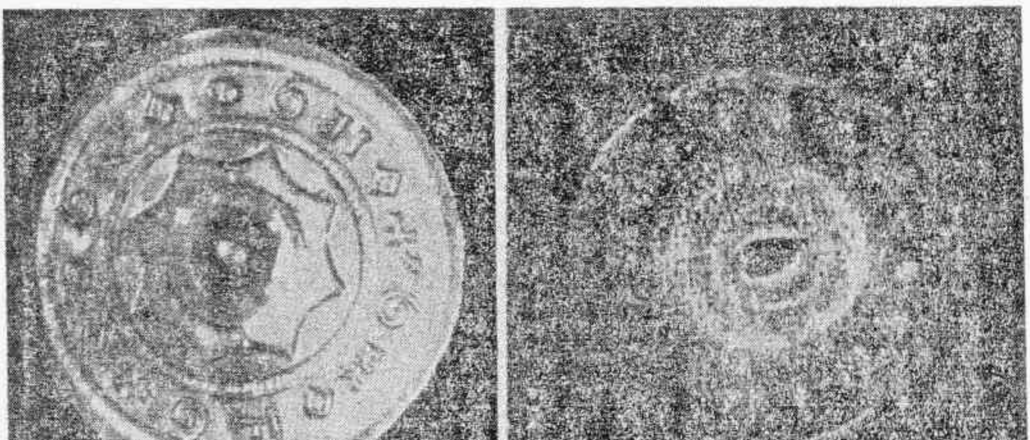

Figure 1. : Bronze "magic" mirror; Chinese, Western Han period, ca. first century B.C. The illustration on the right is the image reflected on a flat surface.

relative darkness and brightness, reproducing the pattern of the decorations on the back of the mirror. This explanation supports a theory first proposed by the Northern Sung scholar Shen Kua 沈括 (1031-1095).[3]

The Shanghai researchers evaluated three other fundamentally different hypotheses about how Western Han magic mirrors were made. The first method, called the "inlay method," was quickly rejected. According to the inlay theory, another metal with a different reflectivity was inlaid on the front surface of the mirror in a design corresponding to the patterns on the back. Thus, the image on the screen merely reproduced a design on the front of the mirror. In an experiment at Fu-tan University, brass and copper were inlaid on a piece of bronze and the surface polished smooth. The image reflected from this surface in bright light con-

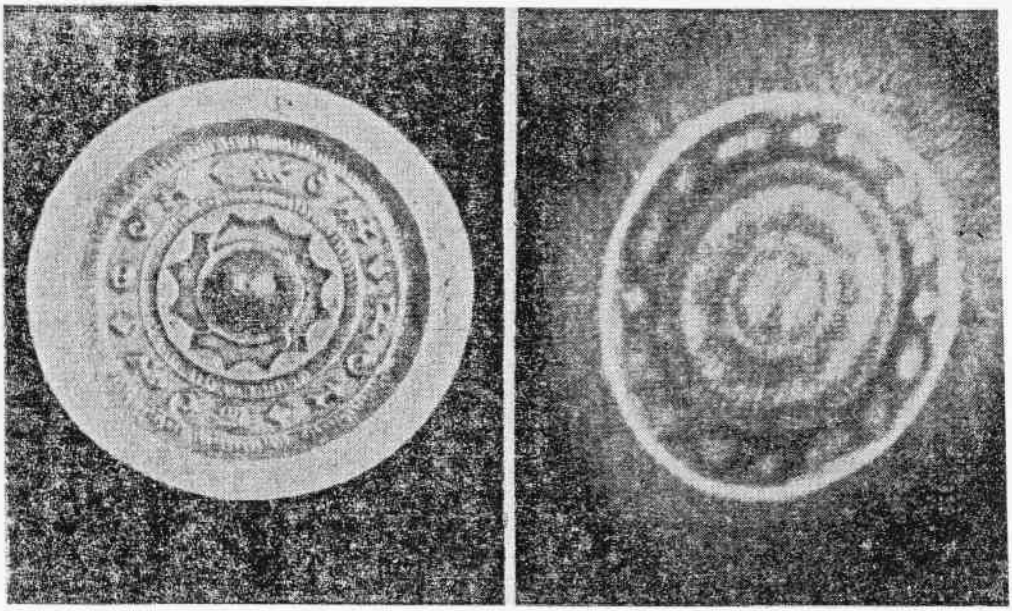

Figure 2. : Modern replica of the mirror shown in Figure 1 on page 2.

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[3] Shen Kua, *Meng-ch'i pi-t'an* (completed by 1095; *Meng-ch'i pi-t'an chiao cheng* 夢溪筆談校證 ed. of Hu Tao-ching 胡道靜, Beijing, 1959), *1.* 19 (item 330): 634-636, translated and discussed in Joseph Needham, *Science and Civilisation in China*, IV. 1, 94.

tained sharp boundaries, corresponding to pattern areas formed by the different inlays, instead of the smooth transition from dark to light found in images reflected by Western Han magic mirrors. Furthermore, it was obvious that a different pattern could be inlaid on the front of a mirror without any relation to the designs on the back.

The second method, termed "grinding and scraping," has been endorsed in one form or another by many Western scholars, particularly those who studied the 19th-century Japanese magic mirrors made by this process. According to this theory, hand-polishing causes the thin areas on the reflecting surface (where there is no corresponding relief decoration on the back) to buckle. When the pressure is removed, these areas rebound as slight convexities on the reflecting surface, becoming visible through the amplifying effects of reflection. The Chinese researchers found that the "grinding and scraping" process created slight concavities on the reflecting surface along the borders between thick and thin areas (corresponding to the outlines of the decoration on the back of the mirror). When light is reflected onto a screen from a mirror so treated, the image appears as a bright, double-outline pattern which focuses at a short distance. By contrast, the Western Han magic mirrors reflect bright, solid patterns that have no focal point but become larger as the distance to the screen increases.

The third category of methods examined by the Shanghai researchers is labeled "reheating." The application of heat to a finished mirror causes thin areas to expand quickly and become slightly convex, thus scattering the light reflected from these areas and producing the same kind of reflected image as the Western Han magic mirror. However, these convexities subside as the heat dissipates, and the image on the screen consequently disappears. The changes in shape can be permanently fixed by cooling the mirror in water immediately after heat is applied. The team working at Fu-tan University published a report in 1975 claiming that this reheating and tempering technique was the one used to make magic mirrors in antiquity. The researchers at Chiao-t'ung University, however, pointed out in an article published the following year that the mirrors were too brittle to have withstood such a process because of their high tin content and because of the internal stresses engendered by reheating and tempering thin objects with thick rims. Furthermore, the Chiao-t'ung group found no textual support for a theory requiring the reheating and tempering of mirrors.

To test their own theory about special casting and polishing conditions leading to the creation of magic mirrors, the Chiao-t'ung group made a mirror of about the same size and thickness as a typical Western Han magic mirror. They prepared a mold from another old mirror in the Shanghai Museum with similar dimensions and decor. They cast the replica using an alloy containing about 73% copper, 23% tin, and 4% lead. After it cooled, they ground the surface of the mirror until it was only about 0.5mm. thick in the undecorated areas. They found that the images reflected from the replica were just like those produced by the Western Han magic mirrors. The fact that no unusual techniques were required, only a very careful application of standard procedures, suggested that this was the way Western Han magic mirrors were made.

To discover what characteristics of the magic mirror made it able to transmit its image, the Shanghai teams made sophisticated measurements and analyses. Their results show that mechanical factors rather than metallographic features were responsible. They found that although variations in the metal microstructure (grain size and form) of the front of the mirror corresponded somewhat to the pattern of decorations on the back, there was no change in the reflected image when the surface was coated with a thin film of gold (Fu-tan team), silver, or aluminum (Chiao-t'ung team). If the reflected image contained bright and dark areas because of differences in the reflectivity of various types of grains, coating would have obscured these differences and caused the image to disappear. Likewise, the research teams rejected the possibility that slight variations in the hardness of minute areas on the reflecting surface affected their ability to reflect light, because microhardness variations correlated poorly with the designs on the back of the mirror. Finally, experiments showed that different alloy compositions had no significant effect on the ability of mirror surfaces to transmit designs from the back.

Laser interferometry confirmed the presence of exceedingly small differences in the curvature of the convex reflecting surface, in a pattern whose infinitesimal ups and downs corresponded to the design on the back of the mirror (see Figure 3 on page 6).[4]
Measurements of residual casting stress showed that the thick (decorated) and thin (plain) areas were stressed differently after casting because they cooled at different rates of speed.[5] Thick and thin areas also exhibited differences in structural flexibility; thin metal is more flexible than thick. All of these differences were accentuated by the grinding and polishing process that followed casting, resulting finally in minute unevenness of the reflecting surface.

The Shanghai group also found that an ordinary mirror could become a magic mirror when ground thin. Conversely, a magic mirror lost much of its pattern-transmitting ability when its rim was cut off. In both instances, the distribution of internal stress was altered, as demonstrated by measurements with a strain gauge. The rim compresses the reflecting surface, and thin areas respond by becoming more convex; thick areas are less flexible and change less. These minute variations in the curvature of areas on the mirror surface affect the amount of light each area reflects onto the screen. The reflected image shows darker areas where light is scattered by the more convex places (the thin, undecorated spots), and brighter areas where light is reflected by less convex or flat places (the thick, decorated spots).

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4 See the article cited in fn. 2, pl. 5/12a.

5 Shen Kua argued that plain and decorated areas cooled at different speeds, forming minute "wrinkles" on the front surface of the mirror.

Figure 3. : Detail of laser interferogram taken of the surface of the modern replica shown in Figure 2 on page 3.

The Shanghai experiments have helped elucidate the reasons why Han magic mirrors behave as they do; these experiments should be duplicated and extended. Several questions deserve further study; for example, how thin must a mirror be in order to produce the magic mirror effect? The relationship between the thin mirror body and the much thicker rim needs to be clarified. It is also possible that the influence of different grain size (especially differences in grain behavior during polishing) has been dismissed too quickly. Finally, it would be helpful to set out more exactly the range of conditions within which magic mirrors can be created, with attention to alloy composition, casting temperature, cooling temperature, duration of cooling, and the abrasives and supports used in grinding and polishing.

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