Secrets of the Chinese magic mirror replica

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Secrets of the Chinese magic mirror replica

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Abstract

We examine the structure of five Chinese magic mirror replicas using a special imaging technique developed by the authors. All mirrors are found to have a two-layered structure. The reflecting surface that gives rise to a projected magic pattern on the screen is hidden under a polished half-reflecting top layer. An alternative method of making the magic mirror using ancient technology has been proposed. Finally, we suggest a simple method of reconstructing a mirror replica in the laboratory.

Introduction

The ‘Chinese magic mirror’ has become a topic of interest for science educators and teachers in recent years (Swinson 1992, Tao 1998, Yan 1992). The mirror, cast in bronze, is an ancient artifact that dates back to the Han Dynasty (206 BC–24 AD). It is magic in the sense that when sunlight or nearly parallel light from a laser shines on the polished convex surface of the mirror, the pattern on the back of the mirror mysteriously appears on a screen in front of the mirror (figure 1). This observation tends to suggest that light from the back of the mirror can be transmitted through the bronze mirror and that a convex mirror can form a real image on the screen. Since the bronze mirrors were first reported some 2000 years ago, the original technique for making them might have been lost over the centuries. Using modern technology, scientists in some Asian countries, such as China and Japan, have succeeded in making replicas of the magic mirror with varying effects. A number of hypotheses have been put forward to explain how the mirror works, but the scientific principles involved remain a puzzle to many physics teachers and students. This article attempts to examine the validity of some of the explanations offered against empirical evidence.

Figure 1. A projected pattern with dark contour lines.

A most popular theory for explaining the magic mirror is that there are slight changes in curvature on the reflecting surface that are dependent on the pattern formed on the back (Swinson 1992, Yan 1992) during solidification.

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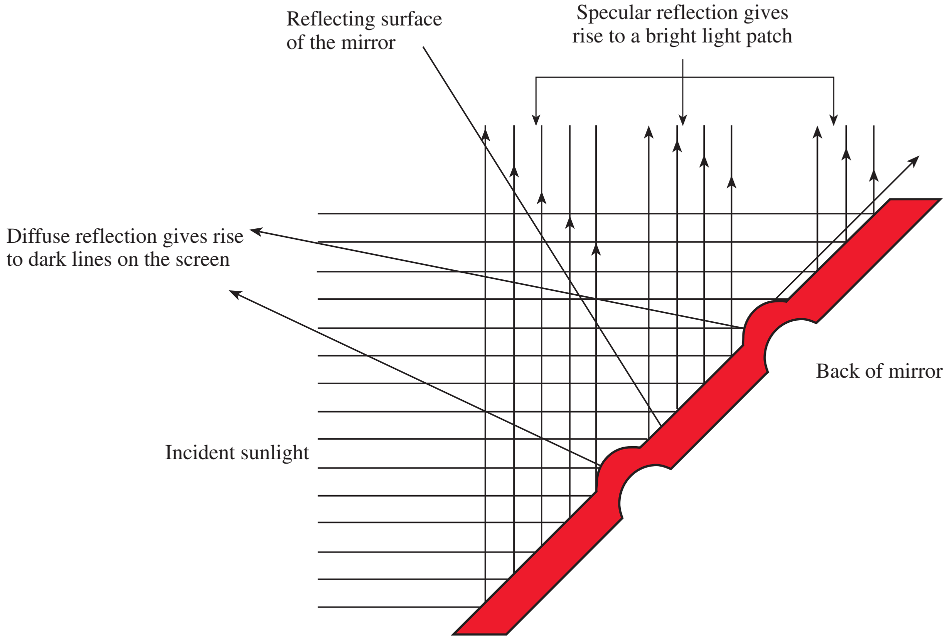


Figure 2. An earlier explanation of the projected pattern.

The thicker parts of the mirror form a smooth reflecting surface that gives rise to the bright regions on the screen; the thinner parts, being more narrow and slightly elevated, give rise to the dark regions (figure 2) (Tao 1998). This mechanism of light reflection explains (1) how an image of the pattern on the back of the mirror is formed with dark lines on a bright background (figure 1) and (2) why the image is equally sharp for any distance of the screen but its size increases with the distance between the image and the screen.

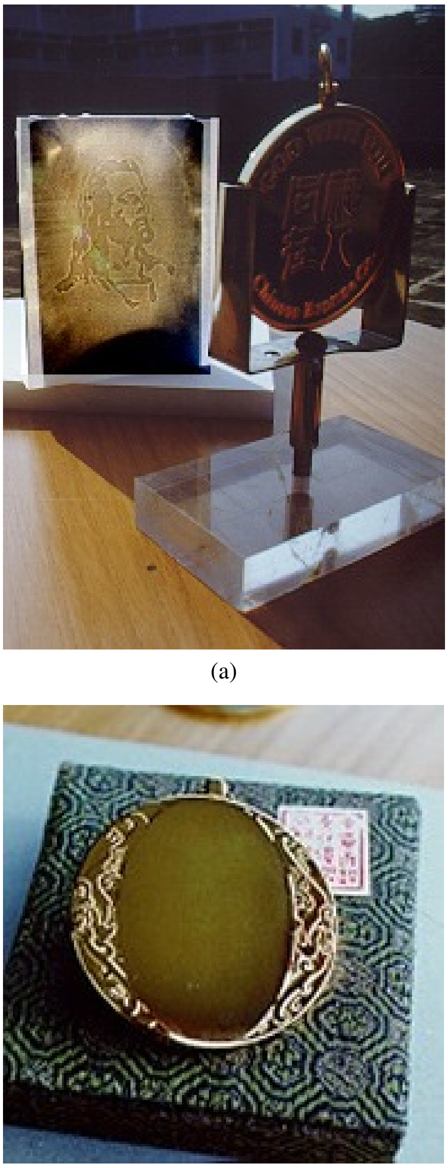
Two explanations have been proposed to account for the differential curvature on the reflecting surface. In making the mirror, molten bronze is first poured into a mould with the pattern of the back of the mirror; the front surface is then ground and polished to a convex surface. Swinson (1992) suggests that, as the surface is polished, the thinner parts of the mirror bend slightly inward under stress and experience a smaller scraping force than the thicker parts. At the end of the process, the smooth surface has slight elevations that repeat the pattern on the back. Yan (1992), however, suggests that as the molten bronze solidifies, the thinner parts cool faster than the thicker parts, resulting in the slight elevations on the reflecting surface.

Process of investigation

In order to test the validity of the above explanations, we have examined five magic mirror replicas purchased from different sources. Based on our findings listed below about the nature of the images formed and the structure of the mirrors, we conclude that the suggestions made by Swinson and Yan cannot provide a comprehensive explanation of the effect of the mirror replica.

(1) Our samples of magic mirrors produce images that can be divided into three different types of pattern. The simplest pattern is one

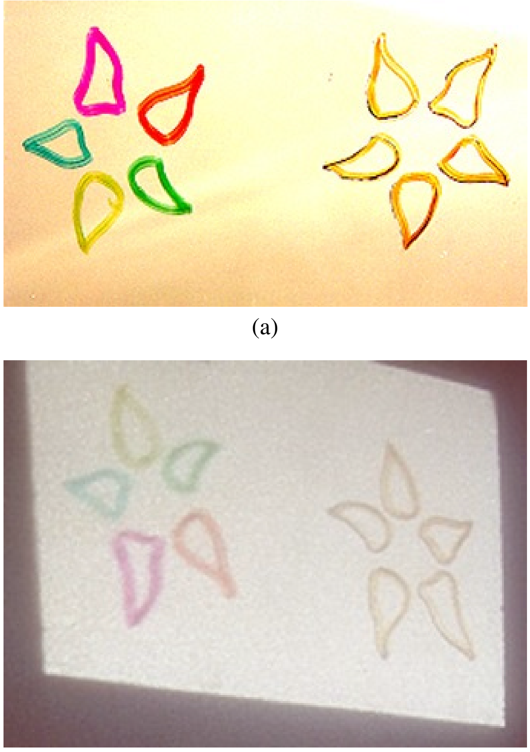
Figure 3. A projected pattern with bright contour lines.



(a)

(b)

Figure 4. (a) Portrait of Jesus Christ formed on the screen with Chinese and English words ‘GOD WITH YOU’ on the back of the mirror. (b) The mirror surface producing the portrait of Jesus Christ.



(a)

(b)

Figure 5. (a) Flower patterns on the mirror. (b) Projected pattern of part (a).

with dark lines standing out against a brighter background (figure 1). The second pattern is characterized by bright lines showing up against a darker background (figure 3) (Swinson 1992). Unlike the first pattern, which can be captured by a screen in any position, images of the second type need to be focused. That is, in order to catch the sharpest image, the screen must be held at a certain distance from the mirror. The third pattern has dark lines several centimetres long with full or half-tone patches of area no less than 1 cm^2 (figure 4(a)). The size of light patch produced by the whole mirror is of the same order of magnitude as the mirror itself, so by simple proportion the surface structure on the mirror should in principle be easily seen by the eye. However, figure 4(b) shows that the opposite is true. The image formation for the last two types cannot be satisfactorily accounted for by the theory outlined in the introduction.

(2) In some mirrors, the figure at the back is different from the pattern projected on the screen (figure 4). This means that the theory of slight elevations on the reflecting surface caused by uneven thickness of the mirror is not applicable to this kind of mirror.

(3) On a plastic mirror surface, an oil-based felt-pen drawing will produce a projected pattern with coloured lines against a bright background (figure 5), while indented lines made by a blunt pencil will produce an image with bright lines

Figure 6. (a) Pencil mark on a PVC plastic mirror sticker. (b) Projected pattern of part (a).

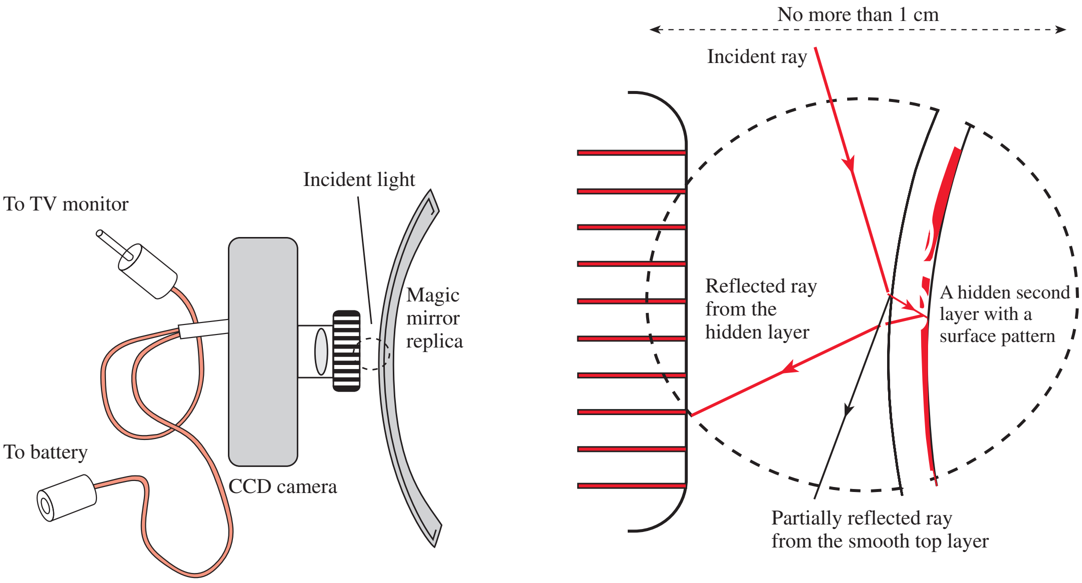


Figure 7. Imaging a hidden layer under the mirror surface using a CCD camera. The enlarged ray diagram on the right shows light and UV rays scattered by the second layer.

against a darker background (figure 6). Also, a partially frosted region of the reflecting surface can produce half-tone dark patches. These simple experiments provide clues for us to put forward an alternative mechanism of image formation for our samples of mirror replicas.

(4) As no marks or surface irregularities are detected on the surface of any of the magic mirrors examined, we propose that the image pattern of a magic mirror has been engraved on a hidden surface covered by a very thin partially reflecting top layer.

(5) We find that when dilute acid is dropped onto the reflecting surface of a magic mirror, a very thin surface layer is etched away. This suggests that the reflecting surface of the mirror may have been electroplated with a very thin layer of alloy that is less acid resistant than bronze.

(6) The hidden layer structure can be imaged using a CCD camera capable of focusing objects at near zero object distance (figure 7). To do this, a human hair is attached to the mirror surface for reference and a CCD camera is held a few mm away from it. The mirror is illuminated by light

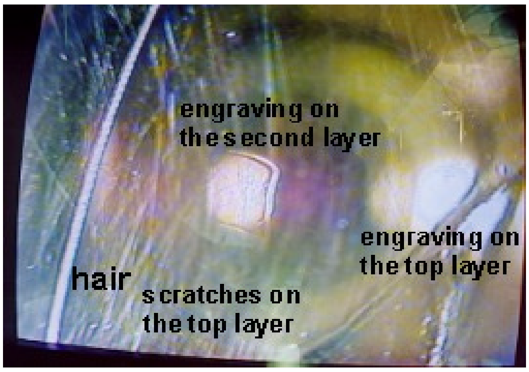
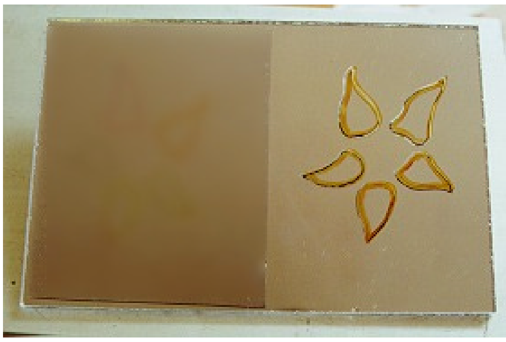


Figure 8. Photograph taken from a TV screen showing the human hair, scratches and engraving on the mirror surface and the structure in the second layer.

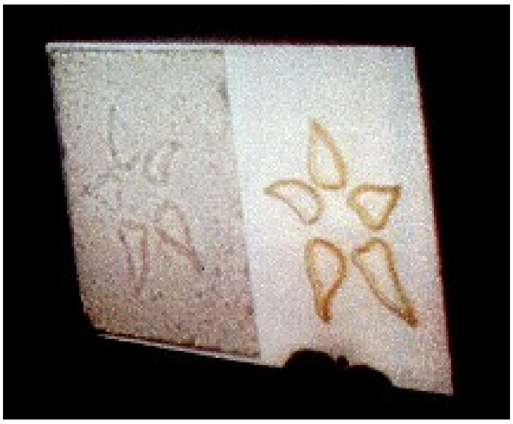
at a grazing angle. The focus of the camera is adjusted so that a clear image of the hair can be formed on the screen of a TV monitor. Because specular reflection occurs on the top surface, most of the light reflected by this surface will not enter the camera lens. However, the pixels (Breithaupt 1995) in the camera have a sensitivity to light that is about ten times greater, and a threshold wavelength about 0.2 μm shorter, than the unaided human eye. Any structure on the second layer that can scatter visible or ultraviolet light into the camera, albeit slightly out of focus, will be detected on the monitor screen (figure 8). This method enables us to detect the presence of engraving in the second layer for all samples tested and provides rigorous support for our hypothesis.

A simple homemade model

Based on our hypothesis, a homemade magic mirror can be readily constructed by students in the classroom. A plane mirror is used instead of a convex mirror because a partially reflecting curved surface is difficult to obtain. A few drops of water are placed onto the mirror surface over one of the drawings shown in figure 5(a). The drawing is then covered with a partially reflecting silvery plastic film (figure 9(a)). The film is pressed firmly onto the mirror surface by squeezing out the water with the thumb. The drawing under the film becomes almost invisible. When the mirror is placed in sunlight, the hidden pattern is recovered in the projected pattern (figure 9(b)).



(a)



(b)

Figure 9. (a) A simple homemade magic mirror (the left-hand side of the plane mirror). (b) The projected pattern obtained from the homemade mirror.

How could ancient people make the mirror?

This model lends support to our alternative explanation for the structure and working of the modern replica of the magic mirror. It is more plausible and comprehensive than the one given by Swinson and Yan. As we do not have the chance to examine the original ancient artifact, its structure, method of construction and the quality of image remain unknown. There are two possibilities. If the original mirror had no layered structure—a very likely situation—the pattern on the mirror surface can be seen with the unaided eye. A two-layered structure might not be entirely impossible: engraving the pattern in the inner layer required just a combination of skill, effort and time. A thin layer of natural resin could be used to coat the surface and the outer layer could be made of a very thin sheet of pure gold.

A final remark

Although the magic mirror replica has not been easily accessible outside China in the past, it can now be ordered via the internet or, if necessary, purchased by mail-order from the Hong Kong Association for Science and Mathematics Education[1]. As far as teaching is concerned, the magic mirror not only provides an interesting and challenging demonstration, the 'what, how and why' of its mechanism of working can also be assigned as a student project for independent investigation. In doing this, teachers must have a clear picture themselves of how the magic mirror replica is constructed. Thus far, a comprehensive yet consistent solution is still lacking in the literature. It is hoped that the analysis given in this paper can provide readers with a more satisfactory solution.

The skill of detecting forgery, revealing the layered structure of archive painting or imaging the internal organs of a body using different types of radiation is commonly employed in archeology and the medical profession. Due to the lack of resources, these technological applications are often mentioned in the classroom at a chalk-and-talk level, or at best limited to a watching a videotape. The method of imaging a pattern in a hidden layer using the CCD camera provides a real live example of using modern technology in a detective investigation that can be carried out in a school laboratory. So a study on the structure of the magic mirror replica and its reconstruction will bridge the gap in our curriculum about the interactive relationship between science and technology.

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