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Mirrors: Metal Mirrors from India

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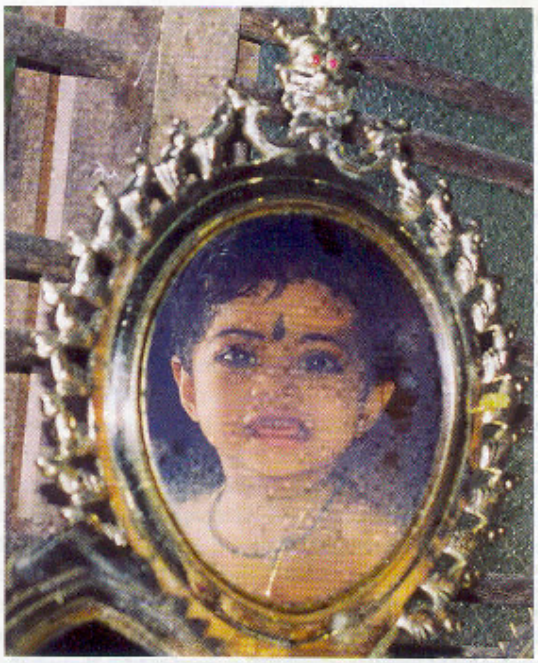
Metal mirrors have a long antiquity in various parts of the Old World and Asia. Mirrors have had considerable magico-religious and aesthetic significance in parts of Asia, for example in China and India. The English word 'speculation' comes from the Roman words meaning magic for telling the future by looking in a mirror (speculum), and mirror divination is still taught in the Tibetan Buddhist tradition. The motif of the celestial maiden, deity or dancer admiring herself in a mirror is an enduring one in Indian sculpture, as exemplified by a Kushan sculpture of a Yakshi or tree nymph from Sanghol (first and second century CE).

Fine bronze mirrors with figurines on the 'tang' or the shank that fit onto their handles are found from ancient Egypt. Early flat, circular or tanged mirrors come from Harappan contexts in the northwest of the Indian subcontinent at Quetta and Harappa in Pakistan (ca. 2000 BCE) and Dholavira in Gujarat, India. These would have been made of bronze with a low-tin content (i.e. less than 10%).

Subsequently bronze mirrors of a higher tin content came into vogue in various parts of the ancient world. Low-tin bronze consists of the coppery-toned solid solution of tin in copper, known as the alpha phase, which enhances its strength. However, it has limited reflectivity, whereas cast bronze with higher amounts of tin has increasingly higher reflectivity. This is due to the formation upon cooling of higher tin bronze of an alpha plus delta eutectoid phase; i.e. a fine mixture of two solid components, the alpha phase and the delta phase which a silvery white intermetallic compound of copper and tin. However, since this delta phase component is also highly embrittling, as-cast higher tin bronze mirrors were usually leaded. Such examples of cast bronze mirrors with 20–25% tin and 5–10% lead are widely found from Han China and the Roman world from the Christian era (Meeks 1993). Bronze mirrors have been one of the most prolific and exotic of Chinese *objets d'art*. The addition of lead improves castability, but lead is an opaque material that is not soluble in copper and may have compromised the reflectivity.

At the village of Aranmula in Kerala in southern India, a unique mirror making tradition survives. Here, a cast high-tin bronze mirror of 33% tin of highly specular or reflective properties is made which is comparable to, if not better than, modern mercury glass coated mirrors (Fig. 1). This is done by optimising the presence of the brittle silvery-white delta phase of bronze while eschewing the use of lead. In an anthropological study, Mukherjee (1978) briefly mentioned the craft of making metal mirrors at Aranmula, while studies were also made by Thomas 1991, Srinivasan and Pillai et al. (1992). The author documented the making of metal mirrors from Aranmula in 1991, followed by detailed technical and micro-structural studies on equipment purchased in early 1992 by Dr. Ian Glover from mirror makers hailing from Malakkara, also in Kerala (Srinivasan and Glover 1995, 1997, 1998). These comprehensive metallurgical investigations on fragments of the mirror alloys established that uniquely, these were made of a binary alloy of copper with 33% tin. This may be described as a high-tin delta bronze due to its close match with the composition of the pure delta phase of bronze, an intermetallic compound ($Cu_{31}Sn_8$) of 32.6% tin and the rest copper. It is this composition, approximating to a pure delta phase, which yields properties ideally suited for a mirror, since it is a hard, stable and silvery compound, which can be polished with great reflectance. The entire mirror manufacturing process seems geared to optimising the presence of this delta phase, which the copper-tin phase diagram indicates forms only within a narrow composition range of bronze of 32–34% tin at non-equilibrium room temperatures (Scott 1991: 95). While this silvery metallic alloy shatters quite easily like glass, this brittleness is offset not by adding lead but by casting a very thin blank, no more than 3-mm thick, which would thus cool quickly with fewer heterogeneities. Then the



Mirrors: Metal Mirrors from India. Fig. 1 Traditional metal mirror of cast high-tin delta bronze (33% tin) made at Aranmula, Kerala.

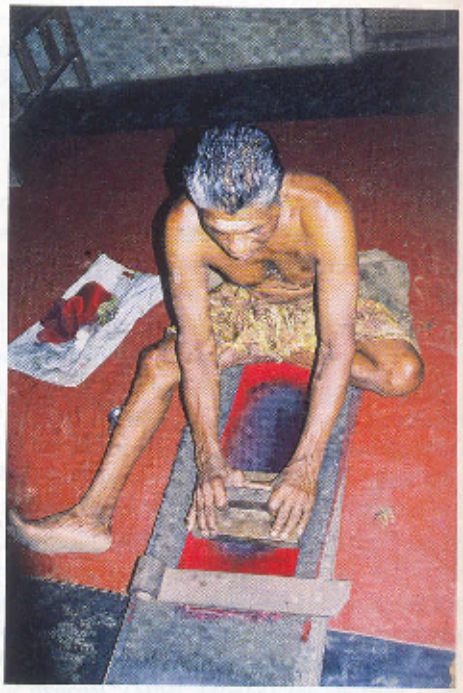
Mirrors: Metal Mirrors from India. Fig. 2 Cast oval mirror blank of silvery delta bronze mounted on wooden polishing board.

Mirrors: Metal Mirrors from India. Fig. 3 Heating of crucible-cum-mould in a hearth fuelled by coconut husks.

blank is reinforced by mounting it with resin on a wooden mount for the polishing process (Fig. 2). A finished mirror from Aranmula consisted of 32.5% tin, approximating the composition of the pure delta compound of 32.6% tin. Thus, it is remarkable that merely by using traditional 'low-tech' methods and materials a rather sophisticated 'high-tech' metallurgical end product is achieved.

At the workshop of Janardhan Achari of Aranmula, a cleverly made jug-shaped crucible-cum-mould of clay is used for the casting process. The lower portion consists of a two-piece clay mould which is connected to the neck, consisting of a hollow cup wherein the metal pieces to be cast are placed and sealed with clay. Then this closed clay crucible-cum-mould is heated neck down on a hearth (Figs. 3 and 4), whereby the metal melts in the neck, and then the jug-shaped crucible-cum-mould is tipped over so that the molten metal flows into the narrow gap between the oval two-piece mould so that it solidifies into a thin 3 mm oval metal blank. The cast blank, which is retrieved by breaking the mould, is mounted onto a wooden handle and polished over several days with hessian and velvet

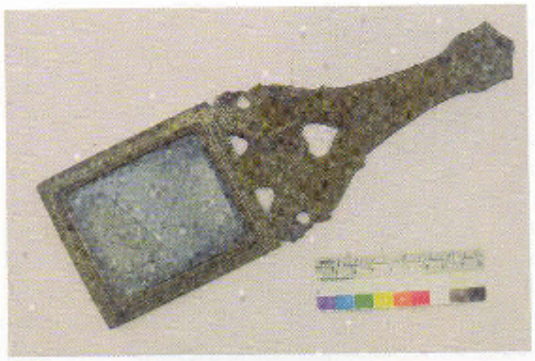
Mirrors: Metal Mirrors from India. Fig. 4 Heated inverted crucible-cum-mould being removed from hearth with the lower part containing the metal to be cast. When the jug-shaped crucible-cum-mould is tipped over the molten metal flows into a narrow hollow space for the blank created by two flat disc moulds.



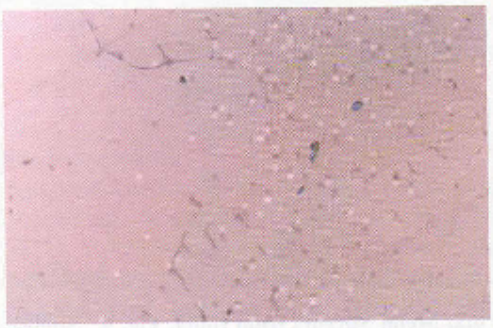
Mirrors: Metal Mirrors from India. Fig. 5 Polishing of cast blank on hessian cloth using the powdered brittle mirror alloy itself for polishing.

cloth to get a mirror finish (Fig. 5). The hardness of the delta bronze alloy was found to be between 500–540 VPN, which is harder than normal steel, and thus the thin mirror blank could be polished almost entirely free of distortion. Ingeniously, the hard mirror alloy is itself used to give the mirror a final polish since it can be easily powdered, as it is highly brittle. This would usefully serve to smooth out and fill in any defects in the cast blank with the same alloy to give the best

Mirrors: Metal Mirrors from India. Fig. 6 Micro-structure of as-cast 33.4% tin-bronze mirror fragment from Malakkara showing a matrix of silvery-white delta phase with a fine network of bluish alpha plus delta eutectoid (1000X).



Mirrors: Metal Mirrors from India. Fig. 7 Old metal mirror from Kerala showing insignia of the Royal family (seventeenth and eighteenth centuries).



Mirrors: Metal Mirrors from India. Fig. 8 Microstructure of fragment of above old mirror showing that it consists almost of pure delta phase crystals with very little inter-granular bluish eutectoid phase (940 X).

possible mirror finish. The microstructure of an as-cast mirror fragment recently made at Malakkara with 33.4% tin showed a structure consisting predominantly of a matrix of whitish delta phase interspersed with a bluish network of the alpha plus delta eutectoid (Fig. 6).

Such mirrors yield a precise point image, as they do not suffer from blurring due to refraction through glass encountered in standard glass mirrors. The colours seem to be reflected even more brilliantly. For many high-tech applications, the type of refraction that occurs through glass mirrors is unacceptable and 'front-facing mirrors' are used, such as those, which consist of a layer of softer reflective aluminium under a thin protective quartz material. However, as pointed out by T. Poston, the hard Aranmula mirror alloy has comparable reflectivity to these front-facing mirrors and does not scratch easily; unlike a layered surface, it can be repolished. Although the mirrors made these days have a blank which is no more than 7–10 cm along its oval length, in 1998 the elderly Janardhan Achari, perhaps one of the last of the meticulously traditional practitioners, showed a metal mirror with a 30-cm long blank made in his heyday. (Large modern front-facing mirrors are a major challenge to make by the deposition technology).

Fig. 7 shows an old metal mirror from Kerala with the insignia of the Travancore Royal family of Kerala, which may date to the seventeenth and eighteenth century. Metallurgical investigations on tiny fragments of the mirror undertaken by the author at the Department of Conservation and Scientific Research, Freer Gallery of Art, Smithsonian Institution in 1998 indicated that the mirror consisted of almost pure crystals of silvery white delta phase (32.6% tin bronze) (Fig. 8) with practically no eutectoid [as agreed by T. Chase, personal communication]. The absence of the eutectoid suggests that the blank may have been rapidly cooled. This indicates the high level of technological accomplishment in isolating the reflective intermetallic delta compound. This is no small feat even in modern metallurgical terms. The structure of the delta phase is that of gamma brass and contains icosahedral clusters; the icosahedron being the most symmetric of all objects (Srinivasan and Ranganathan in press). Metaphorically speaking, it is as if the inner beauty of the intermetallic compound mirror stares back at the onlooker gazing into it (Fig. 9). The shadowy whitish patterns in that image (Fig. 9) are in fact the crystals of the predominant delta phase.

This waning handicraft tradition of Aranmula has not only technological significance but also considerable sacred meaning. The Aranmula mirror (*valkannadi* in Tamil and Malayalam), was one of the eight auspicious articles or *ashtamangalyam* set that traditionally made up a bride's wedding trousseau from the Nair and Namburthri communities (Thurston and Rangachari 1909). A Kushan period Jain votive tablet (first and second century CE) (illustrated in Czuma 1985) depicts a mirror as part of the *ashtamangalyam* set. Fig. 10 shows a celebrated sculptural bracket figure of a *madanika* or temple dancer holding a mirror in the steatite temple of Belur, Karnataka of the Hoysala period (twelfth century), and such depictions are also found in the eleventh and twelfth centuries sandstone temples of Khajuraho. [Such mirrors uncannily resemble the thick

Mirrors: Metal Mirrors from India. Fig. 9 Srinivasan demonstrating image reflected in Aranmula mirror with whitish crystals of predominant delta phase being seen in the background.

Mirrors: Metal Mirrors from India. Fig. 10 Sculptural bracket figure from Belur, Karnataka showing *madanika* or dancer with mirror which resembles the Aranmula wooden mount for polishing mirror blanks.

wooden polishing board with a rear handle from Aranmula onto which the mirror blank is fixed with resin for polishing. Indeed, one might speculate that this could have itself been used as a finished mirror as an alternative to the current traditional practice of mounting the mirror blank into a tanged brass frame]. Metal mirrors are also worshipped in Kerala, where they are known as *kannadi bimba*. In a subsidiary shrine at a temple complex dedicated to the Goddess Bhagavati in Ernakulam, Kerala, an old large metal mirror is worshipped as a form of the goddess.

The manufacture of the Aranmula kannadi has been a zealously guarded secret of all but a handful of surviving master craftsmen known as *acharis*. Discussions with them indicate that they believe the craft has an indigenous origin. Local legends link the history of the Aranmula mirror to the Parthasarathy temple to Krishna at Aranmula, one of Kerala's five most sacred shrines. One lively story of the origins of the Aranmula metal mirror was reported in 1992 to Glover by mirror maker Janardhanan Achari (Srinivasan and Glover 1995). Some bronze craftsmen are said to have originally migrated from Tamil Nadu to make artefacts for the Parthasarathy temple. The Raja of Aranmula had threatened to evict, since they had grown fat and lazy. A widow, Parvati Ammal, came to their rescue as she dreamt that Lord Parthasarathy or Krishna had revealed the secret of making an unusual reflecting metal. In an interesting twist, not only was the king placated by the crown made of this material but he also exhorted the artisans to make mirrors for the auspicious *ashtamangalyam* wedding sets of brides-to-be from this alloy dreamt up by the widow.

As indicated before, the unleaded delta bronze mirrors of Aranmula are technologically distinct from mirrors elsewhere, such as the leaded specular bronze mirrors which were common in China. Rather, the Aranmula high-tin delta metal mirror seems to draw from longstanding Indian familiarity with making artefacts of unleaded binary high-tin bronze which had previously been little recognised. Metallurgical investigations were made by the author on vessels from Iron Age burials and megaliths such as from the Nilgiris and Adichanallur in Tamil Nadu, datable to the early to mid first millennium BCE (Srinivasan 1994; Srinivasan and Glover 1995, 1997) and one from Adichanallur by Paramasivan (1941). These were to be wrought and quenched high-tin beta bronze with around 23% tin, ranking amongst the earliest and most finely wrought and elegant examples known in the world, with some having rim thicknesses of no more than 0.2 mm and with a range of decorations from

fluted or carinated (shaped like the keel or prow of a ship) shapes, or ringed and floral motifs. Due to the formation at high temperatures of a plastic beta intermetallic compound phase of a composition of 22.8% tin (and the rest copper), these specialised alloys can be hot forged considerably between 600–700°C. Thereafter, quenching in water results in the retention of the high-temperature beta phase in a rapid martensitic transformation, akin to that found in steel, which is characteristic by needle-like structures in the metallic microstructure as seen the quenched structure of an Iron age bowl from Adichanallur. This yields improved properties of golden lustre, musicality, toughness and corrosion resistance. Also, quenching prevents the formation of the low-temperature alpha plus delta eutectoid phase which due to its embrittling effect was undesirable in this case.

Vessels and cymbals of wrought and quenched high-tin beta bronze are still made in Kerala, bearing similarities in design to the megalithic vessels documented by the author in 1991 and with Glover in 1998. Mirrors were amongst the collections from the Nilgiri cairns (of about 40 vessels each in the British Museum and the Government Museum, Chennai) and Adichanallur burials from Tamil Nadu of the early to mid first millennium BCE. One such sample of unleaded 30% tin bronze was reported from the Nilgiri cairns by Breeks (1873: 63, 156). From Sonepur in eastern India an early historic period metallic specimen of 32.4% tin-bronze was reported (Biswas 1996: 187). Minor occurrences of tin have been reported in parts of India such as Hazaribagh in east-central India and in Karnataka in southern India, while the author reported old slags from co-smelting copper and tin ores from the Karnataka region (Srinivasan 1997) which might suggest that minor local tin reserves could have been exploited in southern antiquity. Indeed, Maloney (1975: 26) suggests that tin was one of the items of export from the Karnataka coast by Solomon's army along with peacocks, iron, ivory, apes, gold and silver. Two unleaded bronze samples of 22% and 26% tin were reported from the Indus Valley site of Mohenjodaro (ca. 2500 BCE) (Mackay 1938: 480–81), although without a metallographic study it is not possible to conclude if these were intentionally quenched beta bronzes. From the Bhir mound in Taxila in Pakistan, a binary high-tin bronze mirror of 25% tin was uncovered (Marshall 1951: 567–9). A vessel examined by the author from the Vidarbha megaliths of Maharashtra, carbon dated to about the eighth century BCE, was a quenched high-tin bronze with 21% tin, as was another with 24% tin from the Gandharan Grave Culture of Pakistan of the early first millennium BCE. Rich finds of high-tin beta bronze vessels and bracelets have been found from Ban Don Ta Thailand, fourth century BCE (Rajpitak and Seeley 1979; Bennett and Glover 1992). These show similarities with the Nilgiri and Adichanallur vessels in the ringed and knob-based decorations, although metallurgical comparisons indicate that the south Indian bowls were much more extensively hot forged prior to quenching. While trace element comparisons do not suggest common metal sources, it is possible that Indianised stylistic influences were common to southeast Asia together with other cultural influences such as Buddhism in the latter first millennium BCE. In the medieval Tamil text, *Arrichantira Puranam*, *kanjanam* is used to describe a shining mirror whilst this word is also used to describe cymbals (Tamil Lexicon), conveying the metallic lustre of high-tin bronzes. Thus, it is probable that the Aranmula mirror making process evolved out of longstanding metallurgical traditions prevalent in the Indian subcontinent for the use of bronzes of a high tin content. Significantly, in recent years this skilled and quaint mirror craft from Aranmula has been awarded a Geographical Indicator (GI) patent in India.

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