Economic Mass Producible Mirror Panels for Solar Concentrators

G Johnston, G. Burgess, K. Lovegrove and A. Luzzi
Centre for Sustainable Energy Systems
Australian National University, Canberra 0200
Australia
E-mail: Glen@faceng.anu.edu.au

Abstract

The Centre for Sustainable Energy Systems at the Australian National University is working on the development of low cost durable mirrors for large paraboloidal dish concentrators and for smaller trough concentrators photovoltaic systems. Both concepts utilize a robust Glass on Metal Laminate (GOML) technology for the mirror surface. The dish mirror panels use the GOML material in a sandwich construction with a foam core and a back sheet of steel. This provides a cost effective structurally strong composite panel. For the troughs the smaller focal length and one dimensional curvature, lead to a design that holds the GOML mirrors in place with a rib system. Both concepts have demonstrated good optical performance and durability under accelerated lifetime testing.

1. INTRODUCTION

The ANU has a long history in solar concentrator development. Beginning with the White Cliffs solar thermal power station in the early 1980's, followed by the 400 m^2 large dish concentrator completed in 1994, work on large area dishes has continued to the present. In recent years this work has been complemented by development of trough concentrators for PV applications.

Central to the success of all solar concentrators of this nature are cost effective and durable mirror panel components. This paper reports on progress made with mirror construction for both dish and trough concentrators.

The development path for dish based solar thermal stations is expected to progress from a demonstration system of 10 – 20 dishes, to a first fully commercial plant incorporating approximately 200 dishes. Support from the NSW Office of Energy has allowed a mirror panel design to be investigated which would be suitable for the mass production of reflective panels for such plants. The ANU dish prototype has 54 triangular mirror panels, each having a side-length of approximately 4.4 m. Optical studies have indicated that if the side-length was halved, such that each 4.2 m triangle was divided into four, 2.2 m triangular panels (giving 216 panels per dish), then these smaller panels could all be made identically and still give acceptable optical performance. This would allow for a production run of approximately 40,000 panels (200 dishes), and so help to justify investment in sophisticated tooling.

A panel design has been developed for this purpose. It incorporates a foam core bonded between two sheet-metal skins, with a thin-glass mirror bonded onto the concave side of the panel. A photograph of a panel prototype is shown in Figure 2 (below). Both focal region performance measurements and close-range photogrammetry characterisations indicate surface slope errors in the order of 3-4 milliradian for the panel prototypes developed to date.

The Centre for Sustainable Energy Systems at the ANU has also been developing thin mirrored glass-on-metal-laminate (GOML) technology since 1997, and this technology is used to fabricate trough concentrators for concentrating photovoltaic and solar thermal applications. This application does not use core-filler material to maintain the required parabolic shape of the troughs, but instead shape is maintained by both the depth of the cylindrical structure of the trough, and profiled support ribs at either end of the trough. Figure 1 shows a GOML trough concentrator unit used for concentrating PV applications.

Surface and focal region characterisations indicate slope errors in the order of 3-4 milliradian for this type of concentrator.

Figure 1. Glass-On-Metal-Laminate (GOML) trough concentrator for concentrating photovoltaic power generation.

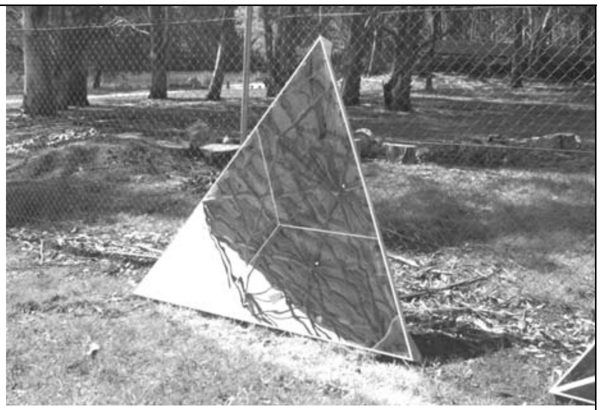

Figure 2. Foam-cored mirror panel developed for large area solar dish applications.

2. DEVELOPMENT AND CHARACTERISTICS OF GOML TECHNOLOGY

Figure 3 shows the basic construction of a Glass-On-Metal-Laminate (GOML) structure, consisting of a metal substrate bonded to a thin mirror-backed glass reflector via an adhesive layer. Creation of such a composite system develops structural characteristics within the glass that gives it significantly increased resistance to fracture than a free-standing glass sheet. This allows the GOML sheet to be flexed and curved to much shorter radii of curvature than would normally be possible for a glass sheet having the same thickness, and also imparts a greatly increased resistance to impact damage.

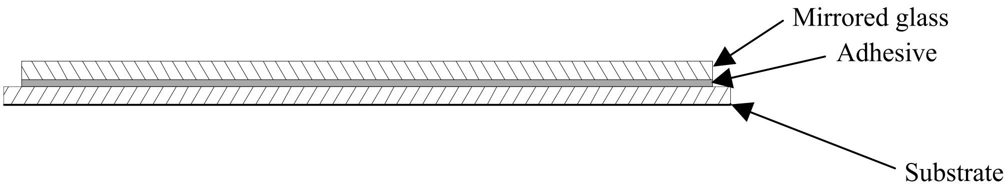

Figure 3. Basic construction of a glass-on-metal-laminate (GOML) structure.

2.1 GOML Trough Concentrators

The basic GOML structure exhibits a significant level of flexibility, and requires shape-holding structures to be applied either to its surfaces, and/or around its perimeters. Curving the GOML sheet into a cylindrical form to create parabolic trough concentrators has been most simply accomplished by applying appropriately shaped ribs to either end of the trough structure, and longitudinal stiffening ribs along the peripheral sides of the trough to provide linear support along the long-axis of the trough, as shown in Figure 1.

2.2 Three-dimensionally Shaped Mirror Panels

Fabricating reflecting elements having a 3-dimensional profile using GOML technology requires a different approach from the edge-mounted shape support concept, because the application of shaping devices at the edge of a 3-dimensionally curved panel has been found to show poor penetration of the desired shape into the central regions of the panel. Good shape conformance instead requires a contiguous, self-supporting shape structure applied across the whole surface of the reflector. A structure using a core material, such as a polymer foam, bonded between two sheet-metal skins, with thin mirror-backed glass bonded to one of the metal skins to form a composite sandwich device has been found to provide high structural rigidity, reasonably low areal weight, high optical quality for solar concentrator applications, and offers low cost material and fabrication regimes. Figure 4 shows a profile through a basic GOML reflector bonded to a foam core material, such that the GOML forms the front skin of the composite panel, and a simple metal sheet forms the rear skin. A prototype using such a construction is shown in Figure 2.

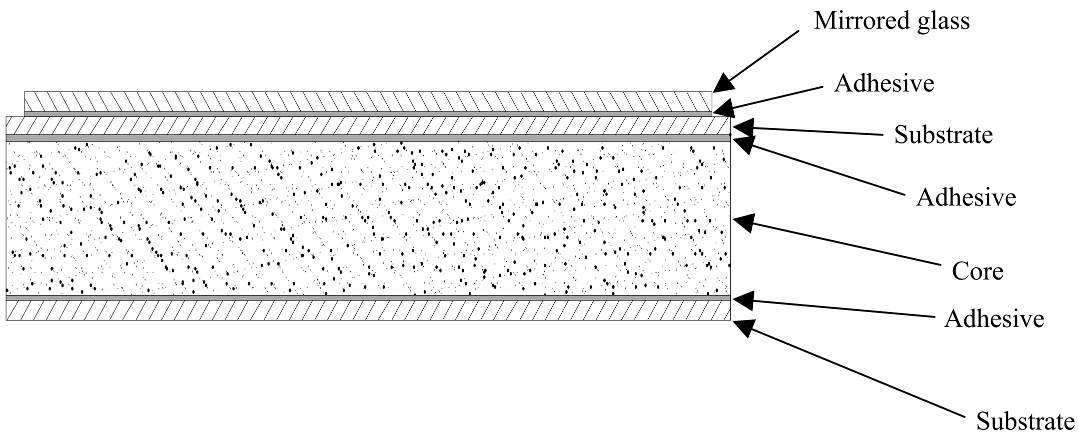

Figure 4. Basic construction of a foam-cored composite sandwich structure used for fabricating 3-dimensionally curved, self-shape-holding mirror panels or facets.

3. REFLECTOR PERFORMANCE

3.1 GOML Trough Concentrators

Composite flux maps have been undertaken on the GOML trough concentrators produced at the Centre for Sustainable Energy Systems. Figure 5 shows such a flux map for one of the trough concentrators.

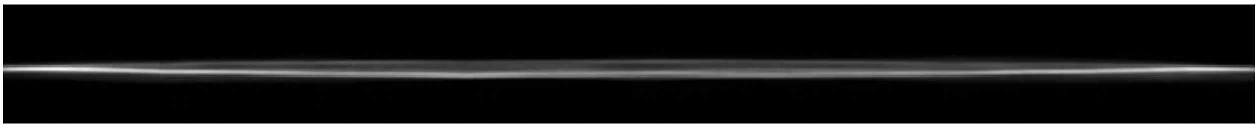

Figure 5. Composite image of the focal region flux distribution at the focus of a GOML trough concentrator. The image extent represents an area measuring 150 mm wide x 1600 mm long.

Figure 6 shows a mean profile of the focal line (averaged along the length of the distribution shown in Figure 5).

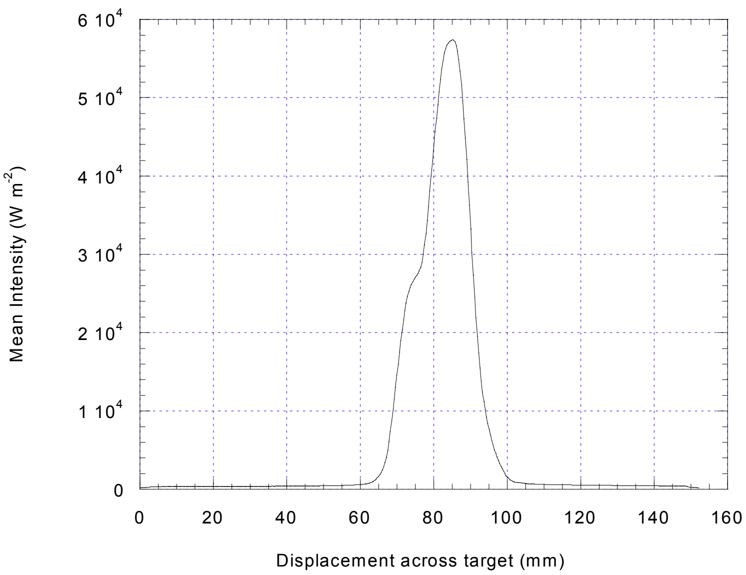

Figure 6. Mean flux profile for the flux line shown in Figure 5.

The trough concentrators have been developed specifically for photovoltaic concentrator applications, and radiation capture has been optimised for a 38 mm wide PV receiver geometry. Assessment of the focal region performance of the GOML trough concentrators has been undertaken by scanning a simulated PV cell array across the width of the focal line, and calculating the proportion of light captured on the cell array as a ratio of the total radiation intercepted on the flux target. Figure 7 shows the results of such a scan across the flux distribution shown in Figure 5.

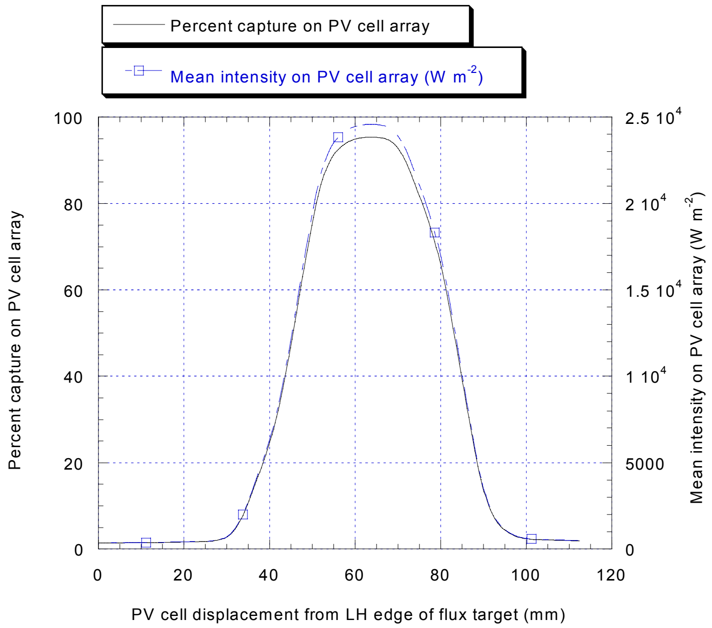

Figure 7. Both mean cell array intensity, and percentage radiation capture on a 38 mm wide x 1600 mm long PV cell array scanned across the flux line shown in Figure 5.

Examination of Figure 6 indicates that the flux image has an approximate width of 35 mm, while Figure 7 shows that a radiation capture of approximately 95% can be expected on the 38 mm wide PV cell array placed at an optimal position along the flux line.

3.2 Three-Dimensionally Curved Mirror Panel

Flux distribution studies have been conducted on the prototype mirror panels constructed at the Centre. Figure 8 shows a square mirror panel that was used for flux measurement studies, while Figure 9 shows the flux distribution that was produced on a 900x900 mm target placed 13.8 m from the mirror panel.

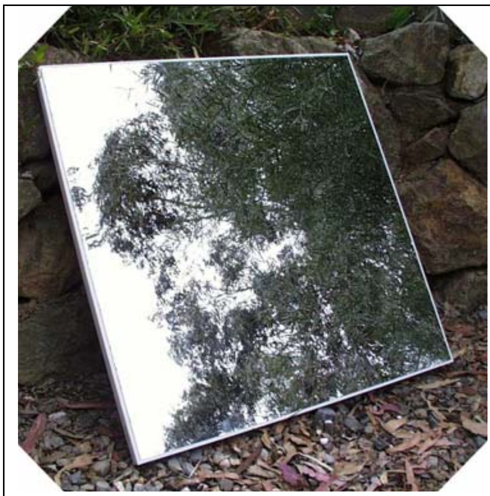

Figure 8. Square mirror panel (1.1x1.1 m.) used for flux measurement studies.

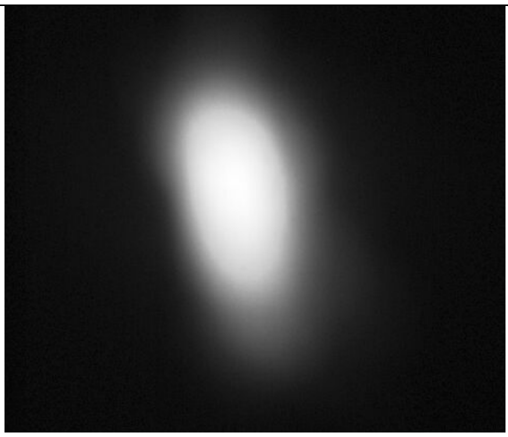

Figure 9. Flux distribution for the square mirror panel shown in Figure 8. Panel-target distance = 13.8 m. Target dimensions = 900x900 mm.

Figure 10 shows a plot of cross-sections through the x and y-dimensions of the flux distribution of Figure 9. Figure 11 shows a percent-power-in-radius plot for the distribution, where power capture as a percentage of the total intercepted power on the target is plotted as a function of radial distance from the centroid of the flux distribution.

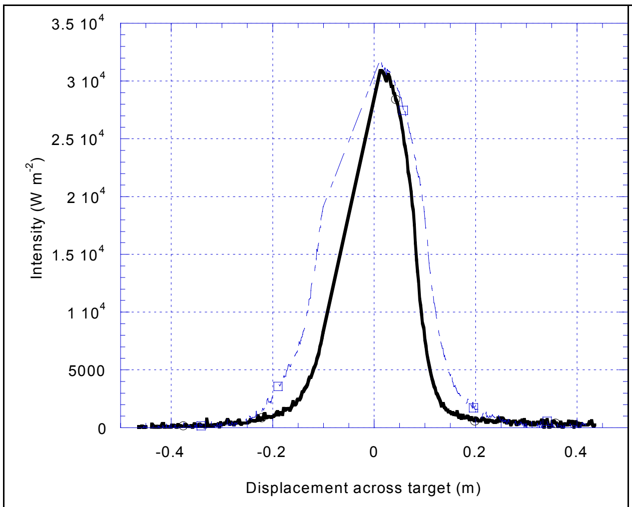

Figure 10. Intensity cross-sections through x- and y-dimensions of the flux distribution shown in Figure 9.

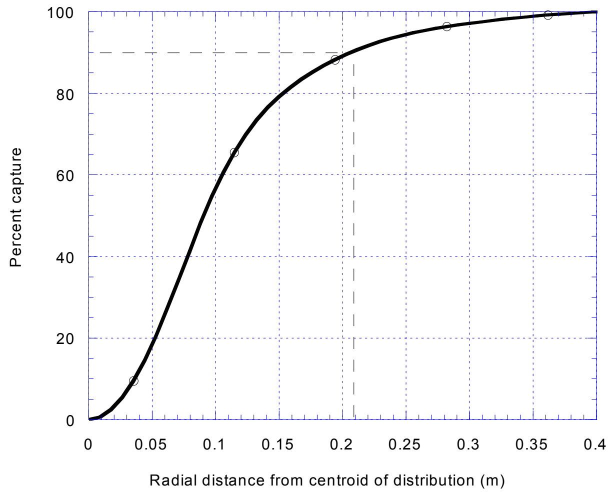

Figure 11. Percent power in radius plot for the flux distribution shown in Figure 9.

Inspection of Figure 10 and Figure 11 shows that although the plot shows some asymmetry, peak concentration ratios in the order of 31 suns, and a 90% power capture ratio of 0.21 m are apparent. Previous experience indicates that such concentration ratios and distribution extents are commensurate with reflector surfaces having between 3-4 milliradian of slope error.

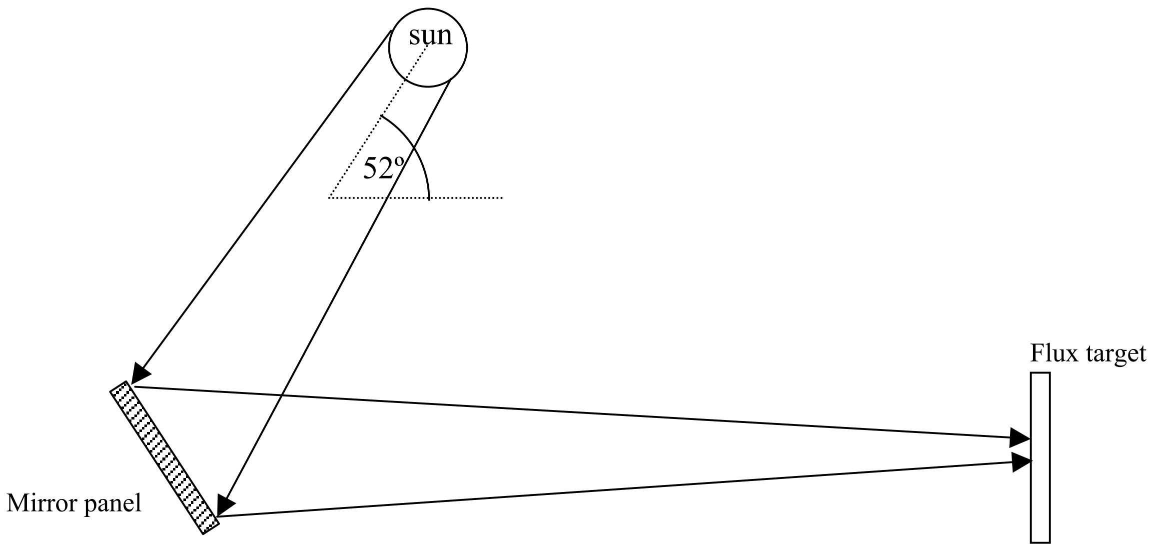

Figure 12. Arrangement of mirror panel and flux target for flux map measurement.

4. CONCLUSIONS

The present studies indicate that glass-on-metal-laminate (GOML) reflector elements are showing good optical performance characteristics for both trough and dish type solar concentrator systems. The trough concentrator used in this study shows 95% capture on a 38 mm wide x 1600 mm long receiver. Other studies indicate an overall surface slope error of approximately 3-4 milliradian exists on this concentrator.

The dish mirror panel reflector shows peak fluxes in the order of 31 kW m^{-2}, with a 90% capture radius of some 0.21 m. Considering a convergence of flux from 216 panels having similar performance characteristics, such as could be used on a 400 m^2 dish, indicates that a peak flux of some 6000 suns could be expected. Such a figure is commensurate with overall surface slope errors of approximately 3 to 4 milliradian.

Overall, developments in both trough and dish type reflector elements at the Centre for Sustainable Energy Systems at the ANU are producing solar concentrator components having the following features:

- high optical qualities, in the order of 3-4 milliradian of slope error;
- high flexural rigidity;
- relatively simple manufacturing requirements;
- low cost componentry and processing;
- high resistance to environmental degradation