Selective Anodising Technologies for Obtaining Translucent Micro Structures

H.N. Hansen[1], P. Møller[1], C. Jarnov[1], J.Staun[1], J.P. Prichystal[2]
[1]Department of Manufacturing Engineering and Management, Technical University of Denmark,
[2]Bang & Olufsen Operations a/s

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Abstract

Anodising of aluminium is a well-known technology usually applied to surface treatment. With this technology a transparent layer of oxide is established on the surface of a workpiece. For the establishment of components in aluminium with certain light transmitting areas anodising was investigated. A process sequence involving application of photoresist, lithography using UV light, development of photoresist and subsequent anodising was established and investigated. The effect of various process parameters, material composition as well as pattern layout on the final component quality was investigated. It was found that with this technology it is possible to create light transmitting areas on aluminium workpieces consisting of either dot-like structures or continuous patterns.

1 Background

Information displays became invisible in inactive state when placed behind transparent or semi-transparent materials such as plastic or glass. Different technologies for obtaining such displays are commercially available including metallisation of plastic or glass in order to render the impression of a metal surface. However, if the bulk material were to be all metal very few known solutions exist. This has to do with the fact that extremely thin metal layers are required for light to penetrate. Theroretical models will result in transmission curves as illustrated in figure 1. It is obvious that obtaining metal layer thicknesses of the order of 10-40 nm is far from trivial using any technologies available today. Furthermore, regions with a wall thickness of this magnitude most probably will not be able to withstand any forces.The present paper adresses methods for obtaining such nano sized structures in bulk aluminium, in particular selective anodising.

Methods for obtaining translucent areas in bulk metal have so far all been based on material removal processes (ref. 1). Succesfull application of femto second laser machining combined with an advanced detection and process control loop has rendered good results as presented in ref. 2.

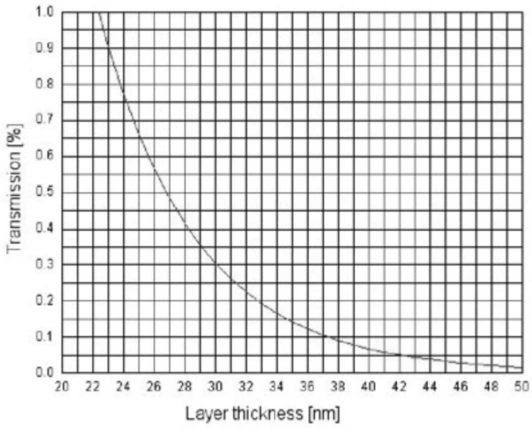

Fig. 1. Light transmission in metals (ref. 2).

Material removal processes applied to bulk aluminium displays result in a matrix of holes as illustrated in figure 2. In each hole the bottom aluminium layer has to be controlled precisely not to jeopardise light transmittance. Therefore a new process is suggested and tested that involves material transformation instead of material removal. This new process, selective anodising, is based on the fact that aluminium can be transformed into translucent aluminiumoxide by means of an anodising process. By applying the anodising process selectively a matrix of light transmitting pixels is created. Figure 3 illustrates the principle.

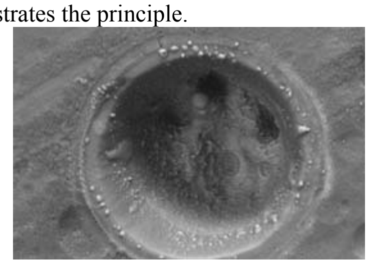

Fig. 2. SEM micrograph of hole obtained using femtosecond laser. Diameter approximately 40 µm (ref. 2).

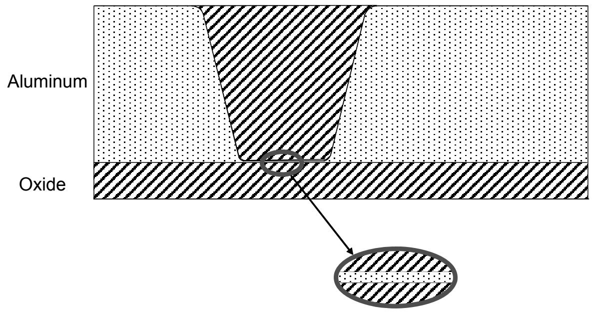

Fig.3. Principle of creating translucent areas in aluminium by selective anodising.

2. Selective anodising

Anodising of aluminium is a well-known technology usually applied to surface treatment. With this technology a transparent layer of oxide is established on the surface of a workpiece. The oxide layer (or coating) can be obtained on aluminium by using a wide variety of electrolytes with AC, DC or a combination of both voltage types (ref. 3). In order to generate an anodic layer the aluminium workpiece acts as the anode and another suitable metal or alloy acts as the cathode (ref. 4).

A new variant of the anodising process is proposed. A pre-machined workpiece in bulk aluminium is exposed to photolithography in this way covering defined regions of the surface with a polymer. Upon development of the photoresist, anodising is performed. Only those areas not protected by the polymer are subject to the anodising process, and in this way aluminium is transformed into translucent aluminiumoxide in selected areas only. The principle is illustrated in figure 4.

The process is heavily inspired by traditional microelectronics processes, where photolithography is used intensively in combination with both etching and electrodeposition (ref. 5). The new aspect is found in the fact that aluminium is a polycrystalline material (in contrast to silicon) and that the process control of the anodising process is less predictable than etching of semiconductors. Due to the nature of the anodising process, there is a limit as to how thick the bulk material can be. Operational experience shows that the thickness preferably has to be less than 0.5 mm if all aluminium is to be transformed into transparent aluminiumoxide. Therefore some kind of pre-machining is necessary. The four criteria initially set up to evaluate the selective anodising process are:

1. Translucency in aluminium. Can the desired translucent effect be obtained with the same result as proven with material removal proceeses?

2. Selectivity. Can the selectivity of the process be controlled in a sufficiently precise manner?

3. Mechanical stability. Can the microstructures obtained using selective anodising be imcluded into assemblies?

4. Invisibility. Can the symbols be identified when the display is turned off?

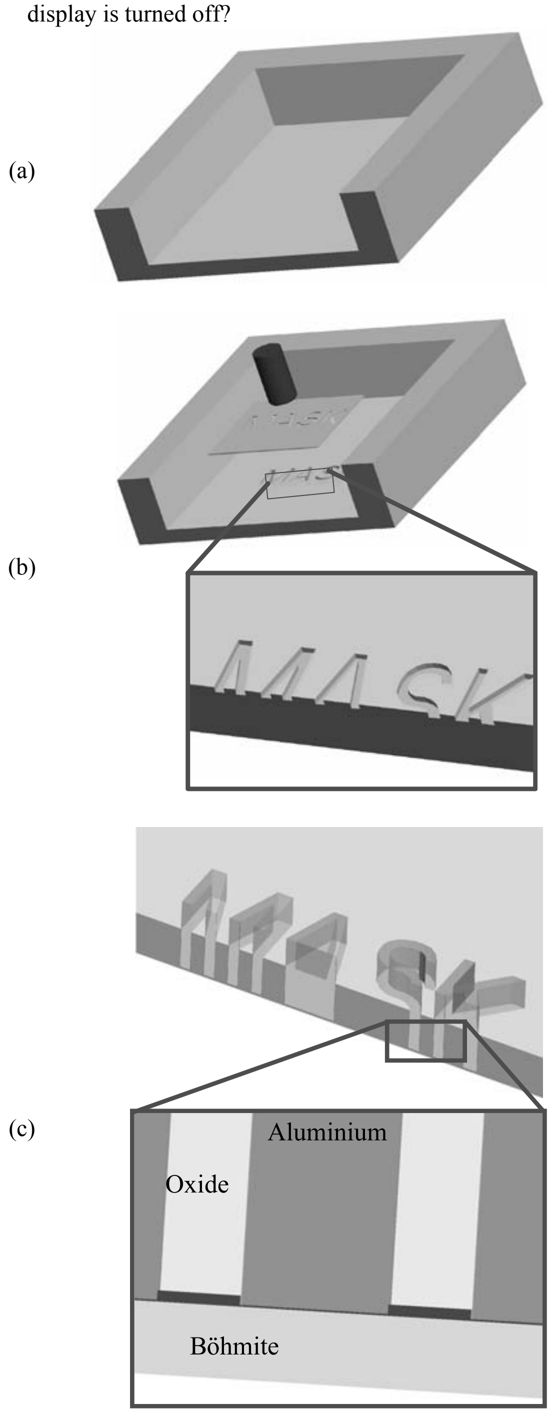

Fig. 4. Main steps of selective anodising: (a) Pre-machining, (b) lithography including development of resist, (c) anodising.

2.1 Translucency in aluminium

Three different aluminium foils were investigated with respect to the possibility of obtaining translucency through anodising (A: 90 μm foil, 1000 alloy. B: 300 μm plate, 5000 alloy. C: 11 μm foil, 8111 alloy). Initial experiments confirmed the hypothesis that translucency in aluminium can be obtained by anodising using the above mentioned types of materials. For foil C conventional DC anodising could be used whereas pulsed anodising was necessary for the thicker foils and plate.

2.2 Selectivity

The first approach to selectivity was based on simple shadow masking using chemically resistant tape. This method of course was not able to render satisfactory resolutions so subsequently selectiveness was performed with UV-photolithography using a positive resist and a mask. By exposing the resist with a UV lamp through a mask it was possible to produce consistent structures with a diameter of 66 μm and a center-to-center distance of 200 μm. If dedicated lithography equipment were used, resolutions down to or even below 1 μm is expected. The resist needs to be able to withstand sulphoric acid for a relatively long time (>10 minutes). Practical experiments showed that this particular requirement was hard to fulfill with the resist and lithography method used in the present investigation (figure 5).

Masks with varying pixel diameters from 50 μm to 1000 μm were produced and tested. Besides the pixel size also the total area exposed to the electrolyte had to be considered because the current density is one of the key process parameters. Figure 6 shows a 3D scan of the resist after development obtained using an optical profilometer. As expected, the resist is very uniform and the exposed areas of the aluminium is very close to the nominal dimensions of the mask.

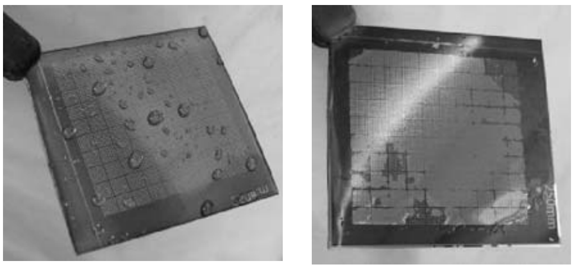

Fig. 5. Examples of resist adhesion in sulphuric acid. Left: good adhesion. Right: poor adhesion.

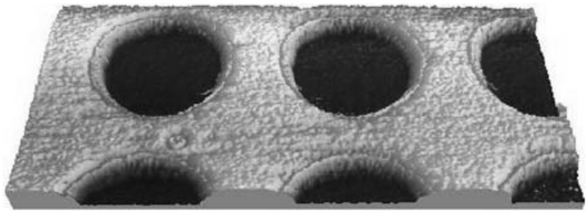

Fig. 6. 3D visualisation of photoresist on aluminium. Pixel size Ø 500 μm with a center distance of 1000 μm. Thickness of the resist approximately 2.5 μm.

The subsequent anodising process is another key step in obtaining translucency. Investigation of conventional DC anodising revealed that it was not possible to obtain translucency for the 90 μm foil even with very long process times. However, for pulsed anodising translucency was obtained after approximately 60 minutes. After this period of time the oxide was observed to break down at the same rate at which it was formed. The anodising process requires electrical contact to the aluminium areas to be transformed. If the process is not entirely uniform, oxide may be formed at different speeds in different areas resulting in isolated "islands" of aluminium without electrical contact to the remaining aluminium. If this situation occurs the anodising process will stop locally and "islands" of non-translucent material may be observed in otherwhise translucent oxide. This effect was primarily observed for pixel diameters larger than 500 μm. Figure 7 shows translucency of anodised aluminium foil (type A) as observed in a light optical microscope using back light. No translucency has been achieved for the 125 μm pixels. Furthermore islands of aluminium are observed in the 2000 μm pixels. Figure 8 shows cross sections of 90 μm anodised foils. Translucency is clearly observed because of the transparent oxide regions.

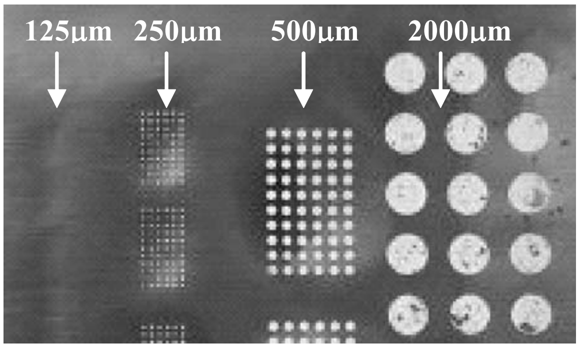

Fig. 7. Translucency obtained in 90 μm aluminium foil. Numbers indicate nominal pixel diameters.

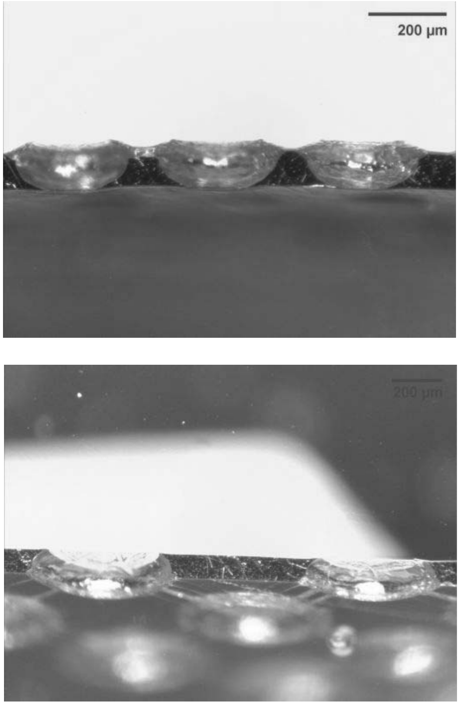

Fig. 8. Light optical microscope pictures of Ø 250 µm (top) and Ø 500 µm (bottom) pixels.

Figure 8 also illustrates that the oxide has a different crystal structure, and therefore it expands relatively to the aluminium. This results in local compressive stresses in the aluminium. Due to this fact different anodising strategies were investigated. First a process where the front side of the workpiece was anodised and sealed as in conventional anodising. This treatment was then followed by a selective anodising process from the back side. The result is illustrated in figure 9. The larger volume of the oxide is clearly seen. If the workpiece was anodised simultaneously from both sides, the result is seen in figure 10. Here the process has reached the phase where oxide is created and broken down at the same speed.

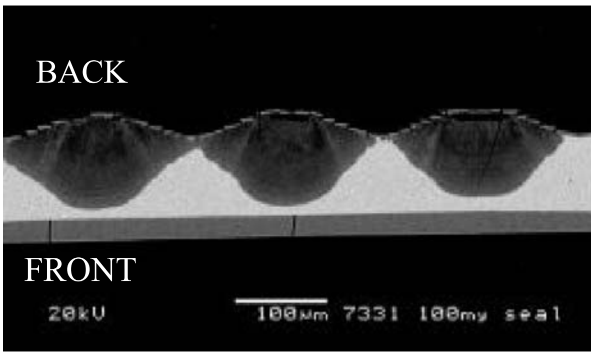

Fig. 9. SEM micrograph of cross section of selectively anodised aluminium. Initial thickness 90 µm. Anodised from backside only. Frontside sealed. Dark material indicates oxide.

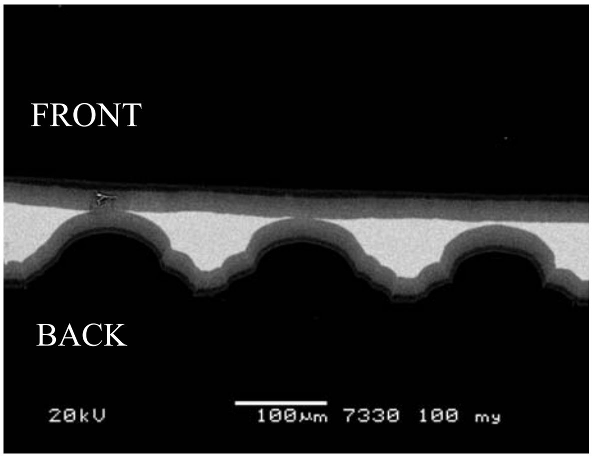

Fig. 10. SEM micrograph of cross section of selectively anodised aluminium. Initial thickness 90 µm. Anodised from both sides simultaneuosly. Dark material indicates oxide.

2.3 Mechanical stability

Anodizing the whole way through from the rear side to the front can result in bulging areas on the front. Anodizing from the front in areas covering the bounded areas can reduce bulging. This is closely related to the discussion about oxide and aluminium volume. Figure 11 shows the effect of bulging on a 50 mm * 50 mm plate of 90 µm thickness. The amount of supporting aluminium not active in the anodising process is critical to the mechanical stability of the final product. Finite element simulations showed that the deformation could be significantly minimized by increasing the centre-to-center distance of the pixels. Furthermore, the thickness of the supporting oxide layer on the front side (e.g. figure 9) has a direct correlation to the mechanical stability of the workpiece.

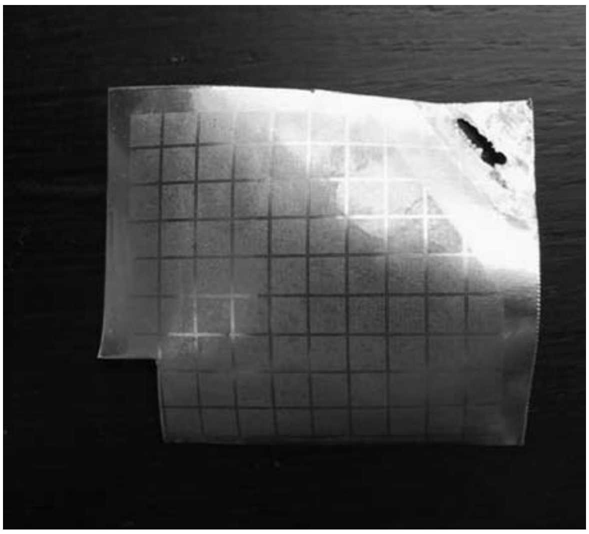

Fig. 11. Bulging as a result of selective anodising.

2.4 Invisibility

In order for the pixels to be invisible at the front side there needs to be a nanometer thin aluminium leyer left or the transparent oxide "channels" need to be smaller than the resolution of the human eye (i.e. < 20 µm). Invisibility was not fully achieved since some of the oxide channels and local deformations were visible to the viewer. Furthermore the macroscopic bulging of the thin foils clearly is a problem even though the single pixels might be invisible. Figure 12 illustrates the front side of the aluminium workpiece without and with backlight.

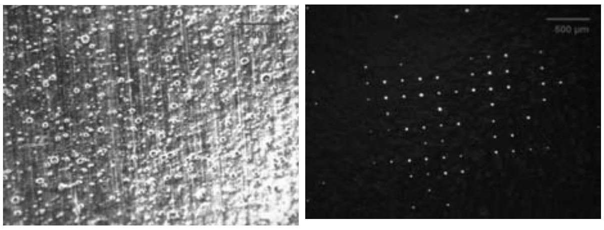

Fig. 12. Front side of selectively anodised workpiece. Anodised from back side only. Scale indicates 500 µm. Left: front side as seen in microscope. Right: front side with backlight illumination.

3. Conclusion

For the establishment of components in aluminium with certain light transmitting areas selective anodising was investigated. A process sequence involving application of photoresist, lithography using UV light, development of photoresist and subsequent anodising was established and investigated. In particular the structures created in this way varied in size from Ø 60 µm to Ø 400 µm with varying centre distances. The effect of various process parameters, material composition as well as pattern layout on the final component quality was investigated. It was found that with this technology it is possible to create light transmitting areas on aluminium workpieces consisting of either dot-like structures or continuous patterns. The structure of the anodised layer before sealing is nano-scale and can be controlled by controlling parameters in the anodising process. With this technology it is possible to establish microstructures directly in an aluminium matrix consisting of a different material with different material properties. In this case the light transmittance was the desired property, but other effects may be achieved. The up-scaling of the technology to industrial production schemes is relatively easy.

4 References

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