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Obtaining Gas Panel Metallization Patterns by Vacuum Deposition Through Rib-supported Mask Structures

Abstract: Gas discharge display panel metallization patterns have been obtained directly in a single vacuum deposition step through rib-supported mask structures. This approach provides a simple alternative to screening or photoetching. The rib-supported structures were developed to solve problems of fabricating masks containing long and narrow closely spaced apertures, poorly supported cantilever sections, and free-standing islands. The design of these structures minimizes shadowing from support ribs by using non-line-of-sight deposition techniques. Made out of graphite to avoid chemical attack during cleaning operations and fabricated by air abrasion machining, the self-supported masks are held in intimate mask-to-substrate contact during vacuum deposition by an electrostatic hold-down technique.

Introduction

The large metallization patterns required in gas discharge display panels consist of long (≥ 10 cm) and narrow (≥ 50-μm-wide) lines closely spaced in approximately 5 cm × 20 cm active display areas. Future displays may cover areas larger than 30 cm × 30 cm. At present, patterned metallurgy is obtained either by screen printing and firing of conducting pastes or by photolithographic/subtractive etching of deposited films.

An alternative approach has been reported [1] that relies on vacuum depositing metallization patterns through rib-supported mask structures. This method promises to be less costly, should improve yields, and is extendable to larger areas. The rib-supported structures solve problems of fabricating masks containing long and narrow closely spaced apertures, poorly supported cantilever sections, and free-standing islands. This paper describes improvements obtained over previously reported methods of fabricating these reusable masks by air abrasion machining [1], using bonded metal foils. Additional experimental results are given, and an electrostatic hold-down technique is described.

Initial investigations

Graphite is an ideal material for economically fabricating vacuum deposition masks [2] and has been used in all the masks fabricated in our work because of the following considerations. It is a fine-grain, dense, isotropic material, readily available commercially [3]. In addition, it is particularly suited for this application since

1. High purity graphite does not outgas, and being chemically inert to most corrosives it resists attack during mask cleaning.
2. The material combines light weight and high strength (72.5×10^6 Pa flexural strength).
3. Very thin sections can be machined to close tolerance without breakout.
4. It has a relatively low thermal expansion coefficient ($8\text{–}9 \times 10^{-6}$/°C), so distortion due to thermal cycling is negligible.

Since chemically inert graphite cannot be etched, it must be mechanically machined. Using either a high speed dicing wheel or ganged cutting blades, tests were made by cutting slots of various width and center-to-center spacings in 125-μm-thick sheets of this material. These tests showed that slots could be cut ≥ 50 μm wide with linewidth variations less than 8 μm. However, there would be severe problems in maintaining correct center-to-center spacings for slots much over 1 cm long, due to flexibility of the narrow separating ribs. This problem would be crucial in masks where line patterns may be as long as 30 cm, and it emphasizes the need for supported mask structures.

Rib-supported mask structures

Rib-supported structures are fabricated with narrow ribs arranged above and perpendicular to the line pattern mask. Since use of a line-of-sight deposition technique,

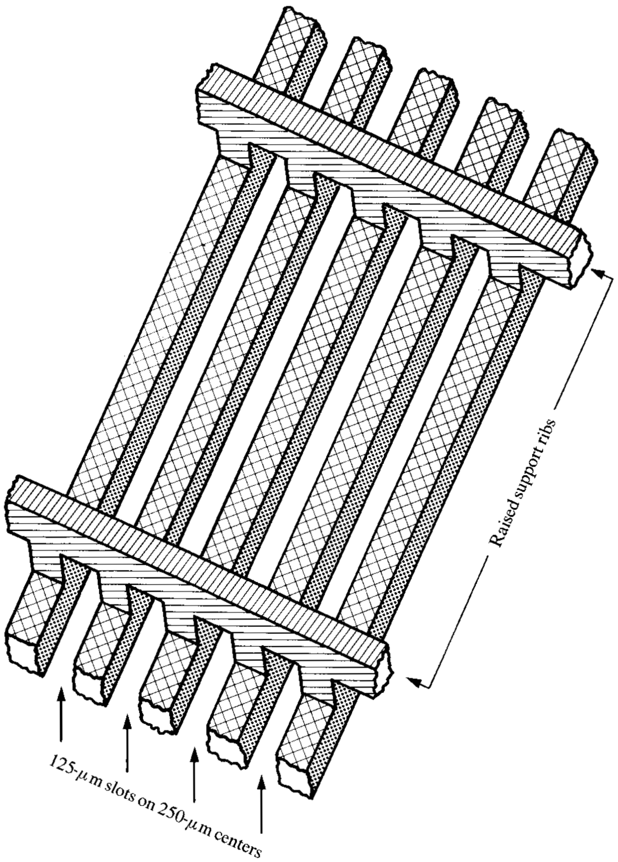


Figure 1 Section of one piece graphite rib-supported mask fabricated using machine shop techniques.

such as e-beam evaporation, would result in total shadowing from support ribs, non-line-of-sight techniques, e.g., ion-plating or sputtering, are required. To minimize further shadowing effects, the masks are fabricated with support ribs raised up from the line pattern mask.

Shown schematically in Fig. 1 is a section of a rib-supported mask, which was fabricated in the following way. From the top surface of a 380-μm-thick graphite sheet, 3-mm-wide regions were milled out to a depth of ≈ 250 μm and spaced to leave narrow ribs remaining. (To assess the effect of rib width on shadowing, this mask was fabricated with support ribs of various widths, from approximately 100 to 475 μm wide.) Next, a line pattern mask of 50 slots 125 μm wide on 250-μm centers was cut into the bottom surface (also to a 250-μm depth) using ganged cutting blades.

Deposition results

Using such a mask, the effect of rib width on shadowing was assessed by observing the variations in both film thickness and linewidth of the metal films deposited under the support ribs. A reduction in film thickness with increasing rib width was previously reported [1]. Thickness data obtained by Talysurf measurements of Al and Cu films, both ion plated and sputter gun deposited through the mask onto glass slides, are shown in Fig. 2, where film thickness is plotted versus rib width. Shadowing from the narrowest rib causes about a 25% reduction in thickness of sputtered films, whereas a reduction of 31–44% is observed for ion plated films. A comparison of these two techniques cannot be made based on these results, since no attempt was made to optimize either approach. Furthermore, linewidth measurements by optical comparator showed 12- and 25-μm narrowing in the regions of the 350- and 480-μm-wide support ribs, respectively. No narrowing was found for support ribs 230 μm or less in width.

To assess the relationship between shadowing and support rib height, a series of masks were cut from graphite sheets of different thicknesses (380 μm to 650 μm) to give a range of rib heights. One such mask, fabricated with 24 slots 125 μm wide and > 8 cm long cut on 500-μm centers, is shown in Fig. 3(a). Shown in Fig. 3(b) is a glass plate obtained by sputter depositing Al through such a mask. Plotted as a function of rib height in Fig. 4 are the normalized film thickness data of metal lines sputter deposited under support ribs and in open regions of the mask. The data are normalized to thickness measurements taken at the short 500-μm-wide lines connecting the ends of the patterns shown in Fig. 3(b) or to measurements of test slides deposited simultaneously with the masked deposits. These measurements show a uniform level of shadowing of approximately 38% for films deposited through the open 138 to 150-μm-thick mask regions. The shadowing due to support ribs was approximately an additional 15% for ribs > 250 μm high and increased with decreasing rib height, as would be expected.

Air abrasion machining

To provide a versatile fabrication technique, which allows cutting in any direction, an air abrasion machining technique had been developed [1]. This method allows for oblique cuts at varying angles as is required in certain masks for fan-out to contact pads, etc., in comparison to the previous work where ganged cutting blades provided only parallel cuts.

Air abrasion machining has been used in the past for such well established, large volume applications as Si wafer dicing [4], crystal resonant frequency trimming [5], and trimming of thick-film resistors [6, 7]. The capability of machining fine geometries to close tolerances is used in the present work to fabricate mask apertures.

In this technique, a gas-propelled stream of fine abrasive particles (25-μm Al_2O_3) is used to machine the mask pattern. The basic arrangement used is shown in Fig. 5. After the narrow ribs have been machined into the top surface, the graphite sheet is turned over and the mask

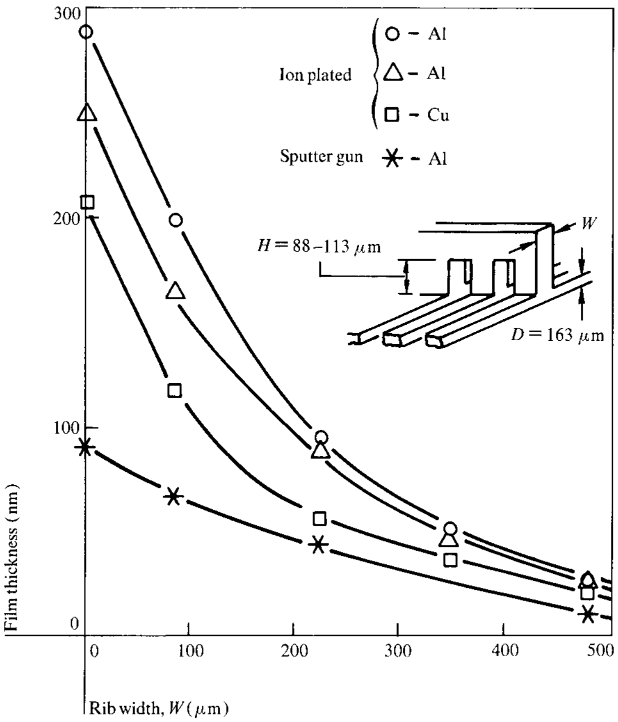


Figure 2 Effect of support rib width on film thickness of 125-μm-wide metal lines. Other mask dimensions are given in insert. Data points at $W = 0$ are from measurements in open mask regions. Plot taken from [1].

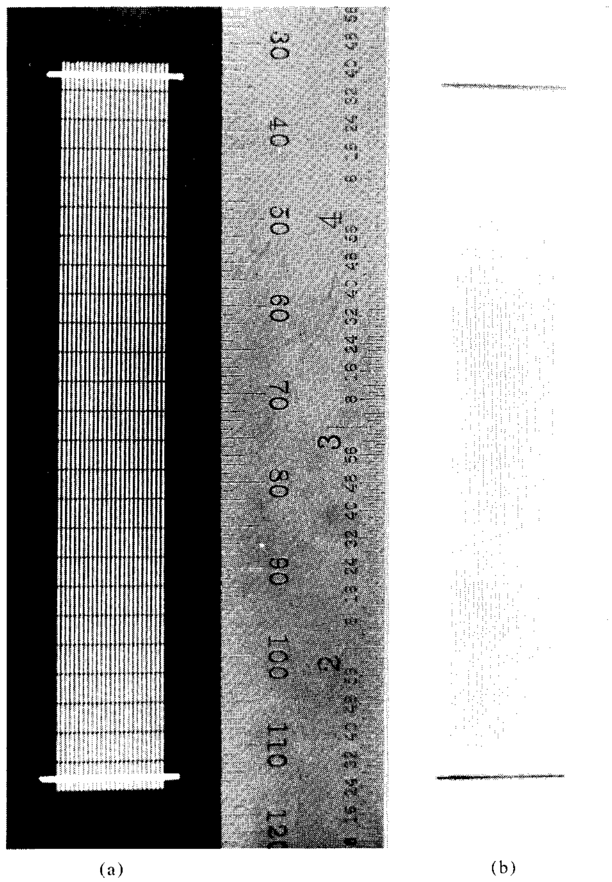


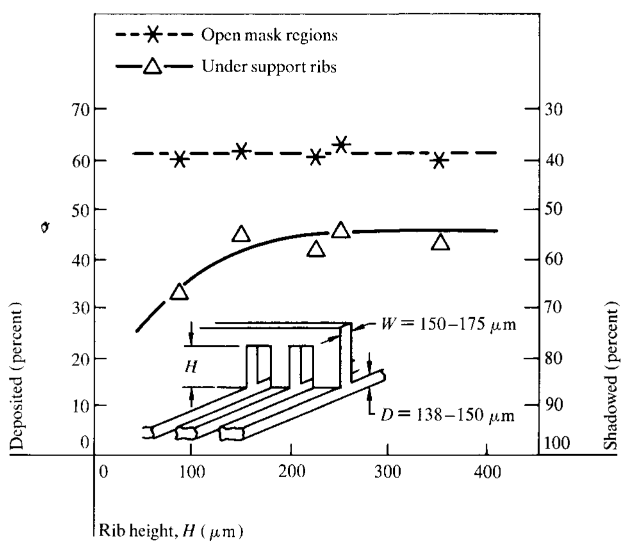
Figure 3 Large pattern configuration of 125-μm slots, ≈ 8 cm long on 500-μm centers. (a) Mask is shown with support ribs visible. (b) Corresponding metallized glass plate has no observable shadowing. Aluminum was sputter deposited at 15 μm, 350 watts.

pattern machined into the bottom surface by use of a fine jet of abrasive powder directed normal to the graphite surface. A honeycomb structure supports the graphite while allowing clear passage of the abrasive grit to an exhaust system below. Careful control of propellant pressure and abrasive feed by a commercial abrasive delivery system [8] limits the depth of cut to prevent completely cutting through the support ribs.

To define the area in which cutting action occurs, two techniques have been tried. In one a metal mask bonded to the graphite limits the area over which abrasion occurs, while in the other the width of the cut is determined directly by the dimensions of the orifice used. The latter approach is shown in Fig. 5. The narrowest cuts obtained in this way, using commercially available jets (having an approximately 100 × 530-μm orifice), were typically 112 μm wide. By rotation of the jet 90° relative to direction of travel, cuts up to 550 μm wide were made.

Using a numerically controlled (N/C) milling machine table, and by rotation of the jet where required, the rib-supported mask shown in Fig. 6 was fabricated by this approach. Appropriate on-off commands to the abrasive delivery system were included in the program written to direct movement of the N/C machine. Shown in Fig. 6(a) is a portion of a 650-μm-thick graphite sheet in which

Figure 4 Effect of support rib height on film thickness.



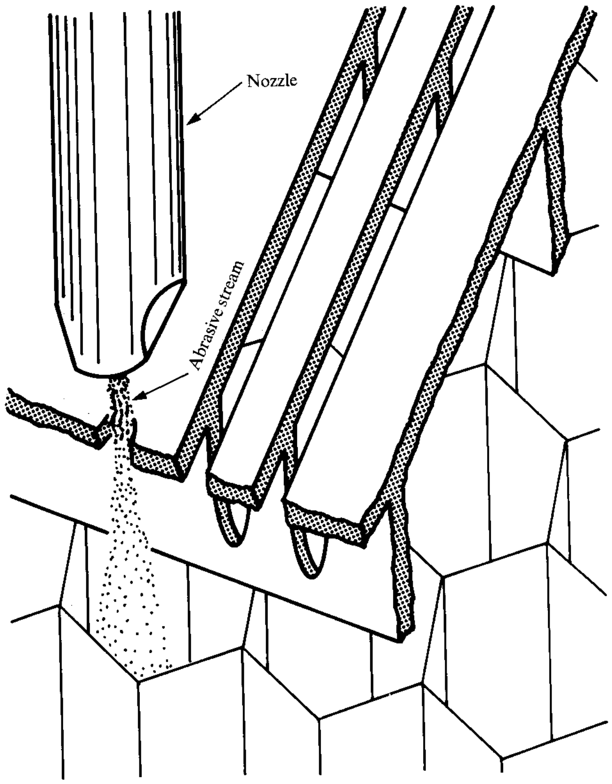


Figure 5 Configuration used for air abrasion machining of rib-supported graphite masks.

125-μm-wide support ribs were fabricated on about 2.5-mm centers (also by N/C machining). The mask, completed by air abrasion machining, is shown in Fig. 6(b). It has 23 slots about 110 μm wide on 350-μm centers, with fan-out to about 500-μm-wide contact pads, obtained by rotating the jet. The 125-μm-wide support ribs are intact throughout the mask even over the 500-μm-wide cuts.

In order to show that the technique can be extended and larger masks fabricated, a rib-supported mask was cut out of a 13-cm × 30-cm graphite sheet 650 μm thick, which had support ribs machined over a 10-cm × 23-cm area. The mask, shown in Fig. 7(a), was cut to approximate a 240-character gas panel top plate configuration. The pattern, measuring approximately 10 cm × 20 cm, contains 360 lines, approximately 140 μm wide on 500-μm centers, representing 3200 cm of cutting. The support ribs can be seen intact throughout the mask. Of the approximately 9100 places where the support ribs cross over slots, they were intact in all but 20 places—indicative of the degree of control available over cutting parameters. Shown in Fig. 7(b) is a glass plate obtained by sputter gun depositing Cu 10% Al through the mask.

Masks such as these demonstrate a capability for fabricating complicated masks, with patterns of varying linewidth between about 100 and 500 μm. The technique, however, is limited by the orifice geometries available and by the fact that optical comparator measurements of metal lines obtained by sputter gun deposition through such masks typically are 25–38 μm wider than the apparent width of the slots. This increase in width is due to rounding of the bottom edges of the mask during the air abrasion operation. To overcome these shortcomings a second air abrasion machining technique has been tried.

In studies of erosion phenomena [9, 10] it has been found that for soft and ductile materials the erosion rate is maximum at low impact angles (approximately 15°), whereas hard and brittle materials show a maximum at higher impact angles (approximately 90°). In machining graphite, advantage can be taken of this difference in erosion rates in the following way. A thin, ductile metal foil is bonded to a graphite sheet by use of a laminating press and epoxy adhesive. The required circuit pattern is etched with open foil areas corresponding to regions which are to be machined by air abrasion.

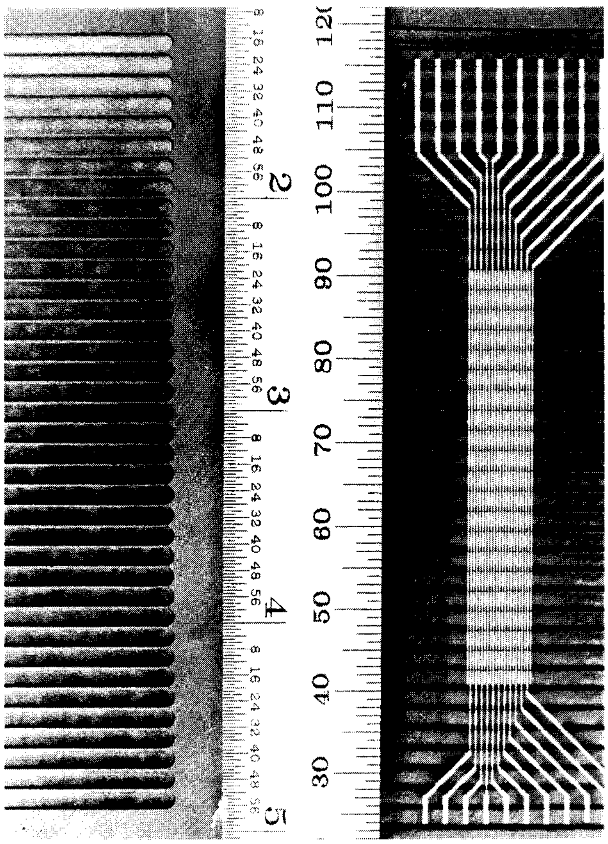
At the normal angle of incidence used here for air abrasion machining, the high material removal rate of graphite, compared to that for the metal foil, allows use of thin foils (25 to 50 μm) to define mask apertures with geometries finer than those obtained with the earlier technique using a jet alone. Furthermore, after removal of the foil, much sharper corners are obtained at the bottom surface of the mask, since these corners are protected by the foil during machining (Fig. 8).

When this approach was tested it was found possible to fabricate small masks with slots 1.2 cm long, < 100 μm wide on 175-μm centers, by air abrading through a bonded 25-μm BeCu foil, with a large 500-μm diameter jet. However, when larger masks (approximately 5 cm × 10 cm) were attempted with long slots (about 6.5 cm) 100 μm wide on 500-μm centers, a bowing problem resulted. This was due to peening of the metal foil lying between slots.

This problem (which appears to be less severe when 25-μm stainless steel foil is used) was minimized by eliminating peening over most of the foil; i.e., a smaller jet was used which was programmed (under N/C) to follow only the open area of the foil. In this way an additional 240-character-gas-panel-size, rib-supported mask was cut, with the same jet (100 × 530-μm orifice) as was used to cut the mask shown in Fig. 7(a); however, instead of slots ≈ 140 μm wide obtained originally, slots about 104 μm wide were obtained. Optical comparator measurements of the metal lines obtained through this mask show that this approach has reduced the linewidth down to 115 μm, instead of lines about 175 μm wide obtained from the mask fabricated using the jet directly.

Mask hold-down technique

As larger masks are made the usual methods of holding mask and substrate in close contact by mechanical perim-



(a) (b)

Figure 6 (a) Graphite mask after machining support ribs in top surface. (b) Completed mask with intact support ribs over line pattern formed by air abrasion.

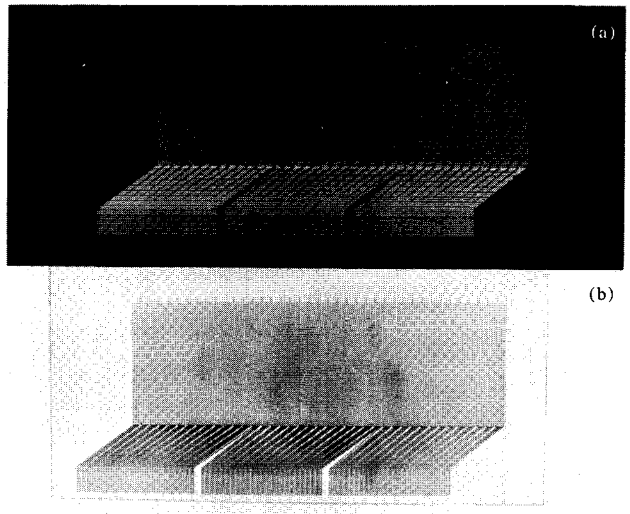


Figure 7 (a) Very large rib-supported mask fabricated in a 240-character gas panel configuration. (b) Corresponding metallized glass plate obtained by sputter gun depositing Cu 10% Al through the mask.

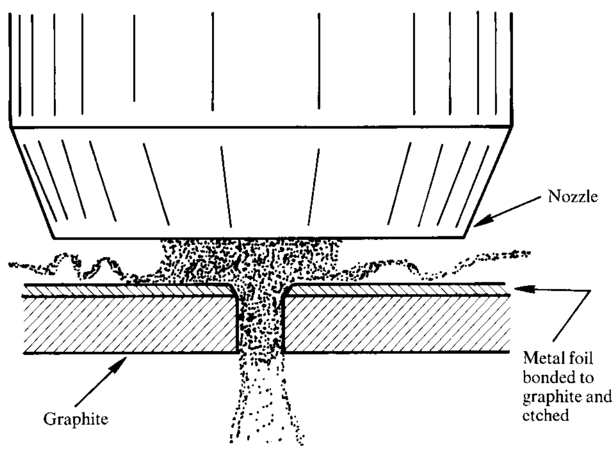


Figure 8 Configuration used for air abrasion machining of fine geometries with a large orifice through a bonded and etched metal foil.

eter clamping become less reliable, especially when non-line-of-sight deposition techniques are used. For evaporation masks, some mask-to-substrate spacing is tolerable (often required to allow lateral movement of mask and substrate relative to each other during registration) without causing excessive lateral spreading of the evaporant under the mask. However, for non-line-of-sight deposition techniques (which are required when rib-supported masks are used), more intimate contact between mask and substrate is needed to prevent off-axis material from depositing under mask edges.

To provide this contact, an electrostatic hold-down arrangement has been developed. This approach makes use of the attractive Coulombic forces that arise between electrodes of a capacitor with a voltage impressed across it. In the past, similar use has been made of these forces to maintain surfaces of silicon wafers in image planes during electron-beam microfabrication, using electrostatic chucks driven by special square-wave sources of high voltage and power [11].

In the present work a capacitor structure was similarly used; however, only a simple dc voltage source was required. The graphite mask was used as one electrode, electrically grounded and positioned over the glass substrate, while a metal plate under the substrate provided the second electrode. Observations made by optical microscope showed that raising the dc potential applied to the metal electrode to approximately 1500 V caused the mask of Fig. 3(a) to be pulled into contact with the substrate throughout. Also, a reduction of this potential to approximately 300 V was then sufficient to maintain physical contact.

During *in situ* tests, conducted by sputter depositing (300 nm of Al) through the mask, the metal electrode was supported by a Teflon block, while a metal cover provided the mask ground and also prevented deposit from shorting the capacitor structure. To show that clamping action was being maintained during deposition, the mask was deliberately raised up from the glass by 125-μm shims placed under each end of the mask. When a 400-V bias was maintained during a deposition, the correct metal linewidths of 125 μm were obtained only at the center of the metal pattern, increasing to wide (250 to 340 μm), poorly defined lines at the raised mask ends. In a deposition made with a shimmed mask and bias off, the wide lines were obtained throughout the metal pattern. Finally, in a deposition made with shims removed and bias applied, 125-μm-wide lines with good definition were obtained throughout. In latter depositions done through the large 240-character-size mask, a 5000-V bias was applied during deposition.

Summary

Gas panel metallization patterns have been obtained simply and directly by vacuum depositing through reusable masks. This approach is now possible as a result of the development of rib-supported mask structures. These structures allow fabricating masks with patterns which have in the past been very difficult if not impossible to make due to stability problems. Now, large masks have been fabricated with long and narrow closely spaced parallel slots, thin cantilever sections, and regions which would normally be unsupported free-standing islands.

The masks, fabricated out of graphite, may be reused until the accumulated deposit becomes sufficient to affect the accuracy of subsequent deposited film patterns. It appears that 15 to 20 deposits may be obtained before design tolerances are exceeded. And since graphite is inert, periodic removal of accumulated deposit is possible by chemical etching. Intimate mask-to-substrate contact during vacuum deposition is maintained by a simple electrostatic hold-down technique.

Mechanical machining is used for fabricating mask patterns. For straight parallel slots, dicing wheels or ganged cutting blades are used. For more complicated masks requiring oblique cuts, air abrasion techniques have been developed. It has been shown that air abrasion machining through bonded foil masks produces masks with sharper detail and finer geometry.

Acknowledgments

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