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# Shadow-mask etching for data-display tubes

*The packing density of apertures in the high-resolution data-display tube's mask is three times that in the conventional entertainment tube's mask. RCA engineers overcame the formidable manufacturing challenges by making ingenious changes in the metallurgical specifications and in the etching process.*

Since the beginning of commercial color television in 1950, the shadow-mask color picture tube has been the overwhelming choice of receiver manufacturers as the display medium for transmitted TV signals. Over the years, color picture tubes have undergone many improvements. In the manufacture of the newly designed color picture tubes, the shadow mask itself has undergone a steady evolution to more complex designs that have kept pace with the ever-growing needs for improvements in tube contrast, beam convergence, and focus. These tube requirements have also necessitated significant equipment improvements involving capital investment of many millions of dollars to manufacture the new shadow-mask designs.

Initially,[1] masks used in 70° and 90° beam-deflection, delta-type tubes (tubes with masks having round apertures and dot screens) were etched so that the width of the steel strip was parallel to the observer. This is termed vertical etching. However, with the advent of precision inline tubes (tubes having slit type apertures and line screens), masks are etched so that the width of the strip is perpendicular to the observer. This horizontal etching process is necessary to prevent distortion of the slit, which occurs in vertical etching at the lower portions of the mask, due to the entrapment of ferric chloride etchant in the resist overhang. This entrapment does not occur with horizontal etching because the etchant is flushed through the aperture. As improvements have led to increased electron-beam deflection, from 70° to 110° tubes, the aperture geometry, formability of the metal, warpage, and magnetic coercivity of the mask material have all become more critical.

**Abstract:** *The masks for RCA Video Component and Display Division's high-resolution data-display tubes differ from the conventional entertainment-type masks in critical ways outlined in this article. Moreover, the manufacturing process had to be altered to meet the greater demands posed by this new mask. The authors cover metallurgical considerations, modifications to the etching process, geometric considerations and more, in an effort to compare the conventional manufacturing parameters and the newly developed parameters for the data-display-tube application.*


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**Table I.** *Comparison of typical critical dimensions for various delta-type masks (see Fig. 1).*

| Dimension | Mask type | | | |
|---|---|---|---|---|
| | Standard entertainment | Medium resolution | High resolution | Ultra-high resolution |
| A (mm) | 0.70 | 0.40 | 0.30 | 0.20 |
| B (mm) | 0.33 | 0.19 | 0.14 | 0.09 |

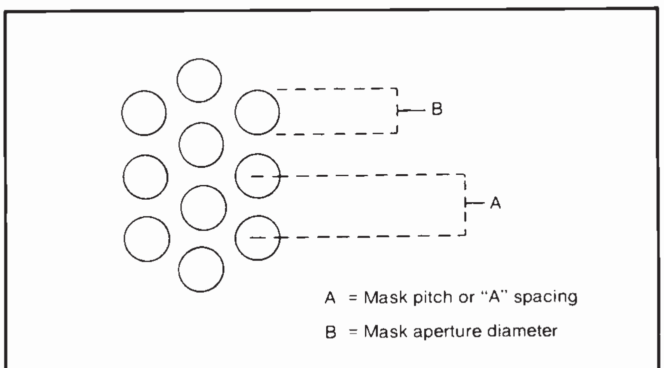
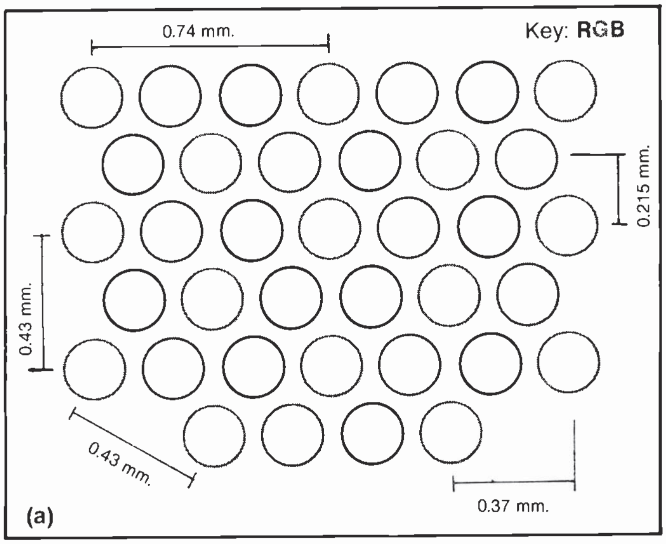



**Fig. 1.** *Critical dimensions for delta-type masks. Both the aperture spacing and the aperture size determine the degree of resolution in data-display cathode ray tubes.*

## Data-display tubes

Even with all these design- and material-related changes in entertainment-type tubes, there appeared on the horizon a new and



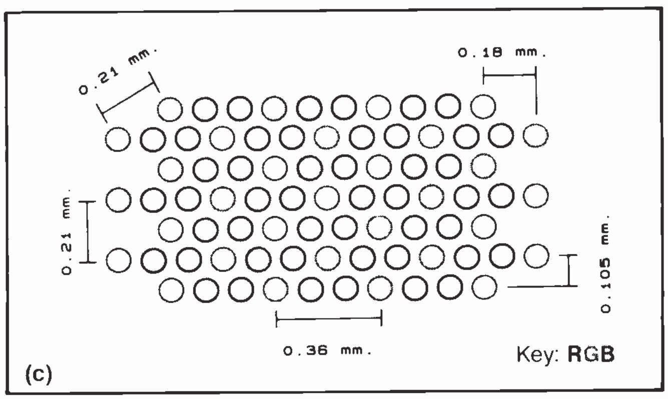
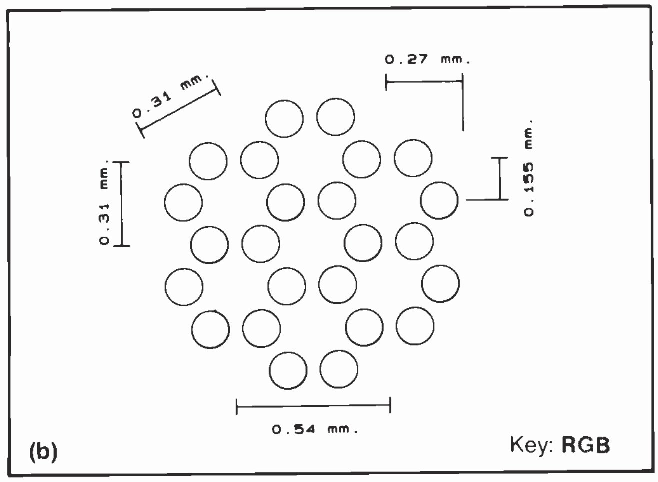




Fig. 2. *Comparison of typical screen structures for display tubes.* **(a)** *Typical medium resolution screen structure,* **(b)** *typical high resolution screen structure for RCA data displays, and* **(c)** *typical ultra-high resolution screen structure.*

even more challenging type of picture tube. Today, this tube has become a reality and we find ourselves in a new era of data-display color picture tubes. Data-display tubes are made in medium-, high-, and ultra-high-resolution versions. These tubes are used as the display medium for personal computers, arcade, and home games. The manufacturing of shadow masks for these tubes presents formidable challenges, which have been successfully undertaken by RCA Video Component and Display Division (VCDD).

Figure 1 and Table I show some critical dimensions for typical standard-, medium-, high-, and ultra-high-resolution dot masks as viewed from the gun side. Figure 2 shows the various illuminated screen structures obtained from the use of medium-, high-, and ultra-high-resolution masks.




A pictorial comparison from the screen side of an RCA 13V/90°COTY mask and an RCA 13V/90° high-resolution display mask is shown in Fig. 3. The packing density of apertures in the high-resolution mask is three times that of the conventional entertainment mask. Thus, it is obvious that artwork requirements and etching yields are severely tested by the increased number of mask apertures per unit surface area of the mask. Of course, the mask cannot have a single imperfection that would adversely affect the screen quality. Similarly, the visual uniformity must be acceptable in the flat and formed state. These are the basic manufacturing challenges that VCDD faced.

### *Metallurgy*

In the early phases of etching high-resolution data-display masks at RCA, it was found that the use of conventional rimmed steel (0.10 percent carbon, cold-rolled steel) resulted in masks with poor uniformity. Also, masks showed a further degradation in uniformity after the annealing and forming operations. A significant improvement in flat and formed mask uniformity was achieved when aluminum-killed (AK) cold-rolled steel was used in place of rimmed steel. Figure 4 shows a flat mask aperture made from rimmed steel and aluminum-killed steel respectively. It is obvious that the edge defining the aperture for the AK steel is superior to that of rimmed steel. The ragged apertures in rimmed steel partially account for the poor mask uniformity.

A comparison of the chemical compositions of rimmed and AK steels is shown in Table II. The impurity levels for the AK steel are somewhat lower than for rimmed steel. Further, the impurities in AK steel are uniformly distributed throughout the body of the material. In the case of rimmed steel, the carbon content is higher (0.10 percent) and there is an anisotropic distribution of all the impurities, giving rise to uneven etching and nonuniform stretching of the metal. Nonuniform stretching during the mask-forming operations can also be due to a metallurgi-

**Table II.** *Typical percent chemical composition of rimmed and aluminum-killed steels.**

| | C(%) | Si(%) | Mn(%) | P(%) | S(%) | Cr(%) | Cu(%) | Al(%) | Fe(%) |
|---|---|---|---|---|---|---|---|---|---|
| Rimmed steel | 0.10 | 0.10 | 0.25-0.50 | 0.040 | 0.050 | ** | ** | ** | † |
| Aluminum-killed steel | 0.006 | 0.05 | 0.25-0.50 | 0.020 | 0.020 | 0.05 | 0.08 | 0.02-0.08 | † |

* Single values are maximum allowed.

** Not detectable

† Remainder

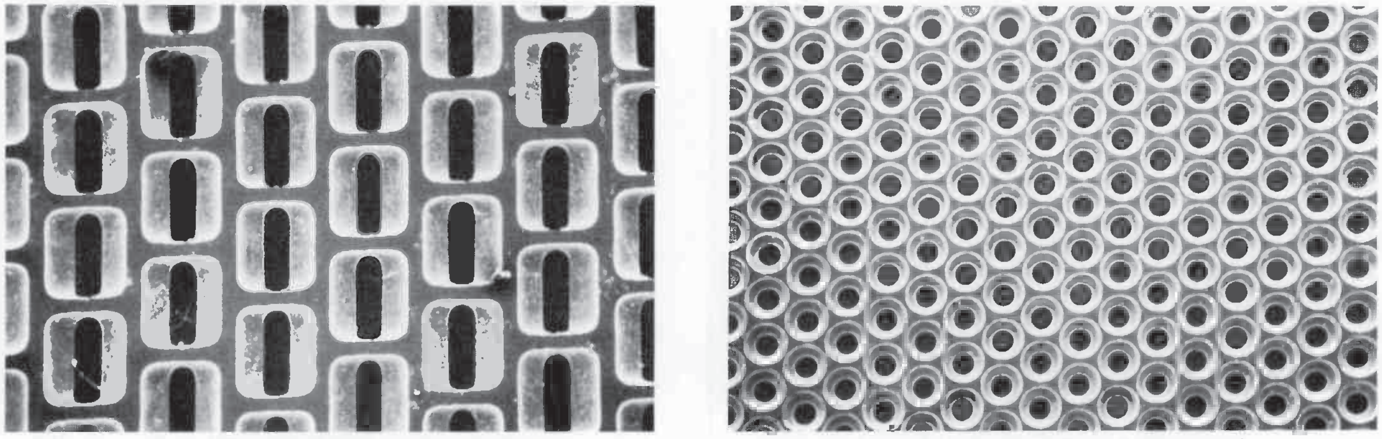



**Fig. 3.** *Comparison of equivalent areas for 13V/90° COTY and 13V/90° high-resolution display masks. The number of high-resolution display apertures is three times the number of apertures per unit area in entertainment-type masks.*

cal property termed yield-point elongation (YPE). Figures 5a and 5b show tensile plots of materials with and without YPE. A comparison of the information in Fig. 5 shows that AK steel can easily be annealed to remove YPE. This positive characteristic is another reason for selecting AK steel for data-display-tube shadow masks.

## Accommodating the new mask designs

### *Single-step data-display mask etching*

Other factors besides the metallurgical considerations can affect mask and aperture uniformity. Aperture visual and dimensional characteristics are also determined during etching by equipment configuration, process conditions, and artwork image-size design. For entertainment-type masks, these parameters are well established for efficient high-yield production. Extensive tests on pilot and manufacturing equipment have shown, however, that these entertainment-mask parameters must be modified to accommodate the small-aperture, fine-pitch, data-display mask designs. A comparison of the entertainment-mask aperture geometry versus the more demanding data-display mask aperture geometry leads to conclusions on the ideal etching processes for these new masks.

### *Entertainment-mask aperture geometry*

Figure 6a shows the typical finished aperture geometry for entertainment-type masks. This geometry provides good visual uniformity, process control, and acceptable electron-beam clearance. The critical features of the geometry in Fig. 6a are a large

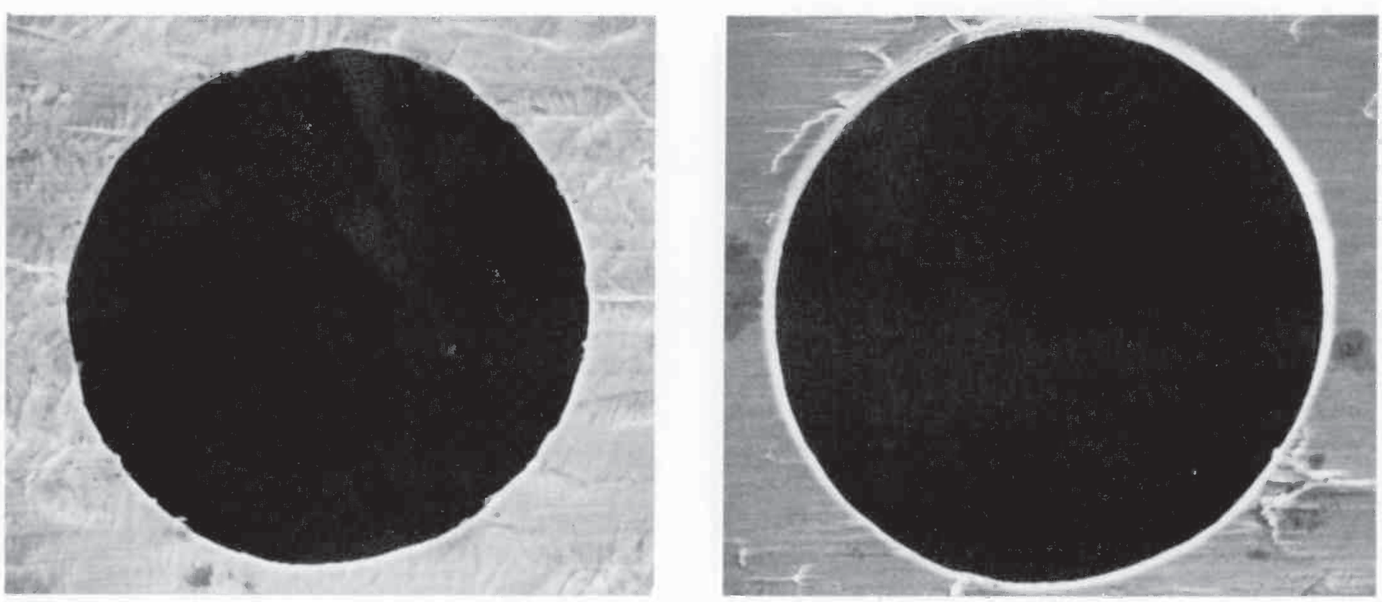



**Fig. 4.** *Comparison of rimmed steel and aluminum-killed steel display mask apertures.* **(a)** *Rimmed steel display aperture, and* **(b)** *aluminum-killed steel display aperture. The rimmed steel apertures are characterized by ragged edges. This condition is not present on aluminum-killed steel and produces better visual uniformity in the finished mask.*

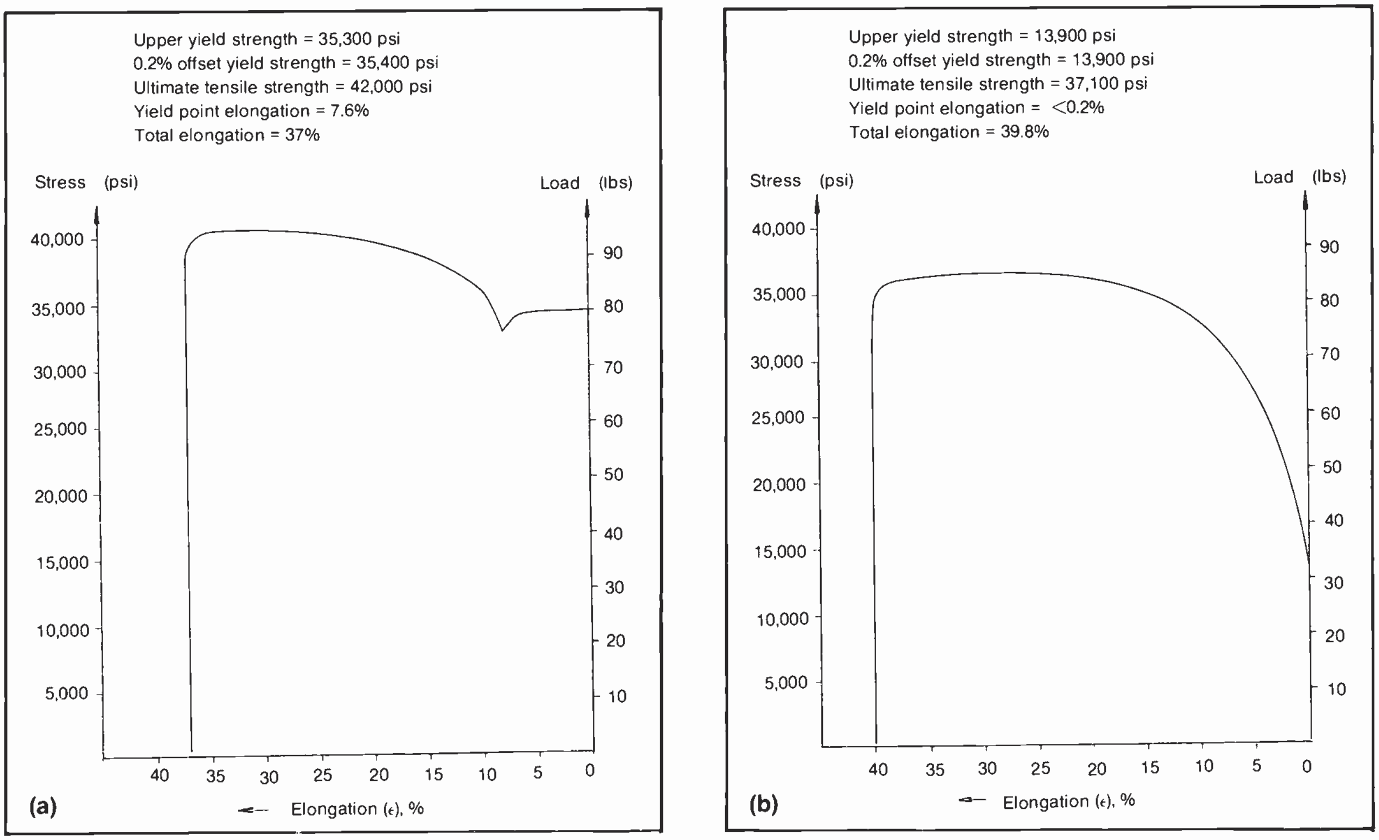



**Fig. 5.** *Comparison of the stress versus elongation curves (after annealing) for* **(a)** *rimmed and* **(b)** *aluminum-killed steel shows a discontinuous feature termed yield-point elongation (YPE) in the rimmed material that is not present in the aluminum-killed steel. YPE is a source of nonuniformity in the formed and blackened mask.*

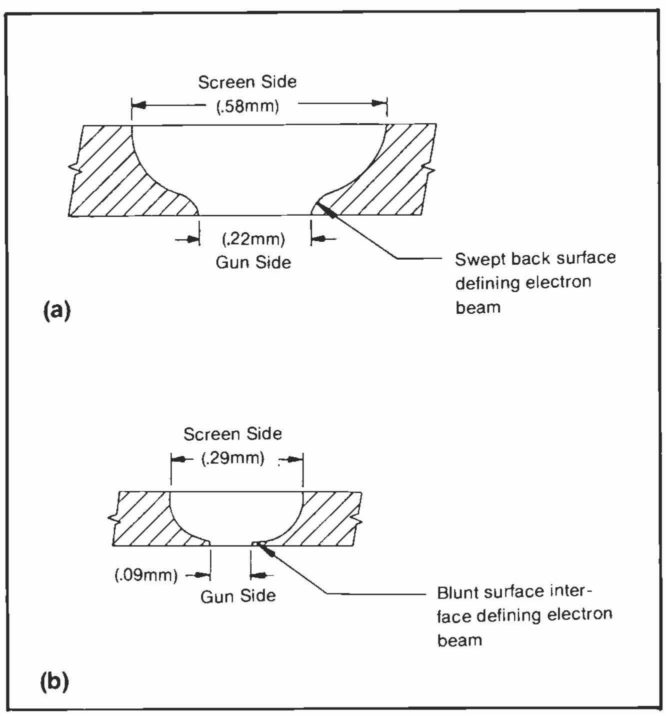



**Fig. 6.** *Comparison of aperture geometry for* **(a)** *entertainment and* **(b)** *data-display masks shows the data-display geometry has smaller screen size openings, more screen side etching depth, and more blunt surface interface defining the electron beam.*

screen-side aperture opening where 75 percent to 80 percent of the etching is done from the screen side, and a swept-back surface where the gun- and screen-side openings meet during etching. This aperture geometry provides slow-changing surfaces for good process control during etching. Good visual uniformity also results from the smoothed, swept-back opening that defines the electron beam. Aperture openings are large enough to prevent undesirable surface light reflections observed during mask inspections. Also the mask's finished aperture dimensions are such that the required artwork image sizes are well within state-of-the-art limitations.

### *Data-display mask-aperture geometry*

Initial attempts at etching data-display-type masks by use of the conventional entertainment-type manufacturing parameters met with failure, due to poor mask uniformity. Subsequent tests on pilot equipment showed that this poor uniformity was related to the data-display mask-aperture geometry. Specifically, the gun and screen openings, and the geometry of the intersecting surfaces where they meet during etching cause a nonuniform appearance in the finished mask. This condition is exaggerated by artwork-required image sizes that fall outside of current entertainment-mask state-of-the-art limits.

Figure 6b shows the empirically determined preferred aperture geometry for data-display-type masks. Critical features of this geometry that distinguish it from the entertainment-aperture configuration include the following: (1) screen-side openings are small because of the mask design pitch; (2) 85 to 90 percent of the etching is accomplished from the larger screen-side opening;

(3) a blunt surface where the gun- and screen-side openings meet defines the electron beam; and (4) the screen-side opening is "hollowed out" to minimize surface light reflections that could affect mask uniformity. These characteristics are necessary to achieve the best visual and dimensional quality for the data-display product with maximum process control.

### Etch modifications for data-display mask etching

The modifications to the conventional entertainment-type mask etching process, required to produce the data-display masks, were determined by two factors. One factor was the need for more screen-side etching, as shown in the optimum aperture geometry specified in Fig. 6b. This increased screen-side etching reduces surface reflections that affect uniformity, and provides the desired electron-beam clearance. The other factor identified for modification was the geometry and surface configuration of the gun- and screen-side surfaces where they intersect during etching. This point eventually defines the electron beam.

***Increased screen-side etching.*** It was determined that etch-machine equipment modifications would be the most effective method for achieving the increased screen-side etching. The most critical part of the etching process takes place before the gun- and screen-side surfaces meet, and "breakthrough" of the surfaces is achieved. After "breakthrough" occurs, the intersecting surfaces of the aperture are cleaned out and no more penetration from the screen side alone is possible. For this reason, modifications were made to the equipment to adjust the ratio of the gun-side to screen-side etching *before* "breakthrough" occurs.

On the manufacturing line, gun-side nozzles that dispense the etchant were changed to reduce the etchant flow rate. Extenders added to the spray manifolds of the screen-side nozzles, however, in effect moved the nozzles closer to the strip. Pressures on both sides of the strip were adjusted to obtain adequate, uniform coverage under this new set of conditions. Equipment and spray pressures after "breakthrough" were not changed. These modifications produced the desired increase in screen-side etching without unmanageable adverse effects.

***Modified openings.*** The need to modify the geometry and surface configuration of the gun- and screen-side openings where they meet during etching was approached in a slightly different way. A series of pilot etching tests, unrelated to data-display mask etching, was performed to determine the effect of etchant temperature and concentration on aperture geometry for entertainment-type masks. Visual and dimensional analysis of aperture geometry for these masks showed that the gun- and screen-side intersecting openings defining the aperture at particular temperatures and concentrations were similar to the desired configuration for data-display masks. Of course, these ranges were undesirable from an entertainment-mask production standpoint because current production rates would be significantly reduced. They were, however, judged to be acceptable for data-display mask production.

Laboratory tests were also run during this period to determine the effect of etchant temperature and concentration on steel surface roughness. These tests showed that the improved uniformity ranges found in the entertainment-mask aperture geometry tests correspond to the smooth etch regions defined in this testing. These results are shown in Fig. 7.

An optimum temperature/concentration combination for data-display mask etching was selected based on the pilot entertainment-mask aperture-geometry etch tests, and the curves in Fig. 7. As indicated previously, the intent in selecting this combination was to produce the optimum aperture geometry and surface configuration where the gun- and screen-side openings intersect and define the electron beam. Tests were run with these conditions, which confirmed that a more desirable data-display mask-aperture geometry with improved mask uniformity could be produced.

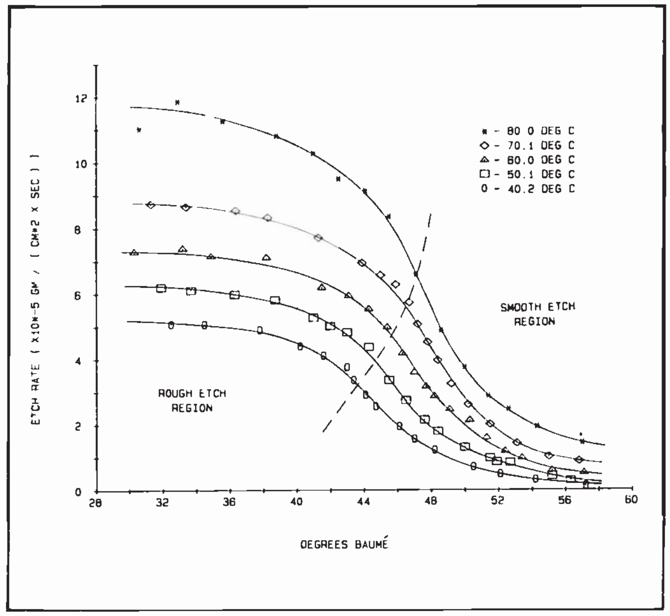



**Fig. 7.** *Baume and temperature-combination curves for smooth and rough etch. The sections of curves to the right of the dotted line define the regions where smooth etch and improved mask uniformity are obtained.*

Significant improvements have been made in RCA data-display mask uniformity with these equipment and process modifications. Work is continuing in this area to realize further improvements in the single-step data-display etching process. Another area of etching technology that may need to be utilized for data-display mask production involves two-step etching techniques. In addition to the single-step process described, RCA VCDD is exploring these two-step techniques.

### Two-step etching

A more theoretical examination of the mechanics of etching reveals why the etch process modifications to single-step etching, previously discussed, improve display-mask uniformity and aperture geometry. This examination also suggests other more complicated equipment and process modifications that could be used to produce high-quality data-display masks.

Several factors determine the minimum acceptable aperture opening that can be obtained in a given material thickness. First, there is a practical limitation to the minimum clearly defined, developed image size. This, of course, is directly related to the artwork image size. Also, etching unavoidably occurs laterally, under the resist opening, as the material is being etched to the required depth. Figure 8 shows progressive steps in the etching process. In actual practice, lateral etching increases at a rate of 60 to 80 percent compared to the rate of depth etching. Even after the two etched sides meet ("breakthrough"), it is necessary

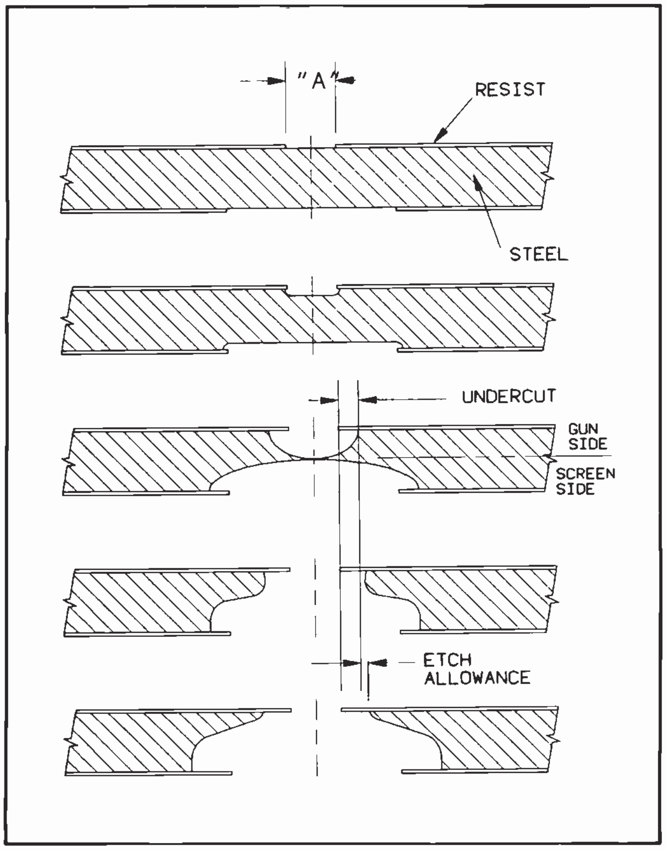



**Fig. 8.** *Progression of etching. The individual sections show idealized steps in achieving an etched aperture. Key features in establishing aperture geometry are undercut, etch depth, and etch allowance.*

to continue etching to produce the desired openings. This additional etching action further increases the size of the minimum obtainable well-defined etched aperture.

Etching that goes beyond the stencil opening is called "undercut"—as etching depth decreases, the undercut decreases. Therefore, a small minimum opening, whose shape and size closely approximates the stencil opening, can be obtained by etching to a minimum depth from the small-opening side of the material. This side of the mask faces the electron gun and defines the opening through which the electron beam passes. As previously indicated, this effect is accomplished in single-step etching by retarding the etching from the small side while simultaneously increasing the etching from the large side.

The minimum, clearly defined, opening size that can be obtained using single-step etching is equal to about 70 percent of the thickness of the material. If the minimum aperture size required is smaller than 70 percent of the material thickness, more complicated etching procedures must be employed.

### *Precision etching*

To solve this problem, posed by a minimum aperture size that is smaller than 70 percent of the material thickness, we designed and built a shield-like chamber within the overall etch chamber itself[2] (Fig. 9). This equipment allows for a two-step or precision etching process. The enclosure prevents the etchant from contacting the small-opening side until the large-opening side is etched to a predetermined depth. At this point, the material moves out of the protective enclosure, and the etching process is allowed to take place simultaneously from both sides of the material. But the etchant has been given a "headstart" on the large-opening side.

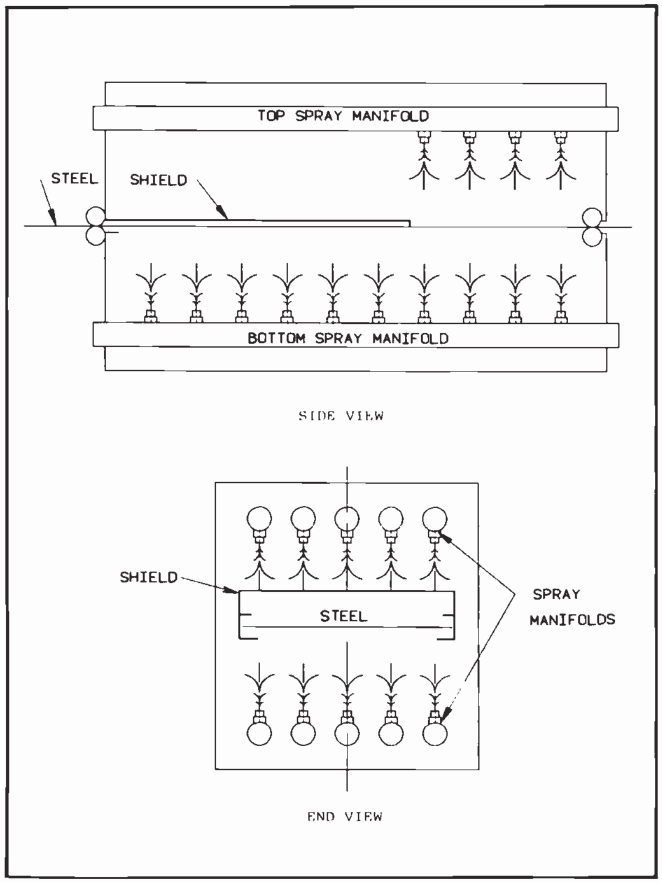



**Fig. 9.** *Precision etch equipment and process. The cross-sections show the use of a shield-type chamber to achieve very small apertures for ultra-high resolution masks. This relatively simple modification has been shown to be effective in producing good quality data-display masks.*

The prolonged etching of the large-opening side effectively reduces the material thickness so that only minimal etching of the small side occurs before the two sides meet one another. This etching procedure significantly reduces the undercut of the images on the small-image side.

There are special advantages to the RCA two-step etching process that cannot be achieved with one-step etching. Some of the advantages are:

1. Minimum undercut occurs on the small-image side of the strip.
2. Smaller etch allowance (Fig. 8) is needed.
3. The etched aperture more closely approximates the artwork image.
4. This continuous process does not require the application of an etch-resistant coating or other chemicals that retard etching.
5. Missing stencil defects on the small-image side are less critical due to the fact that the enlargement during etching is significantly less, compared to one-step etching.
6. Existing production equipment can be converted to two-step etching in a relatively short time at minimum expense.

Some of the disadvantages with two-step etching are:

1. The productivity for a given etch-chamber length is significantly less.
2. The large-size image undergoes a much greater undercut, which sometimes causes a problem in the separation of adjacent apertures.
3. There is a loss in production flexibility because production of entertainment-type shadow masks with a two-step etching process is not economically practical.

Thus, it is obvious that a two-step etching process will be employed in production *only when there is a sufficient demand to justify the increased cost* for such a sophisticated shadow mask.

## Summary

RCA Video Component and Display Division has made significant advances in shadow mask manufacturing technology, to meet the challenges related to the production of shadow masks for data-display tubes. Key factors in this progress have been a better understanding of the etching process, the use of aluminum-killed steel instead of rimmed steel, and relatively minor modifications to existing etching equipment. For very high resolution masks, a novel etch-tank modification is used, which employs a shield-type chamber to reduce the amount of etching on the small-aperture side of the mask.

Even with all of the present and past innovations in processes and equipment to produce color picture tube shadow masks, there undoubtedly will be future challenges associated with the introduction of high-definition television (HDTV) in the years ahead. Currently, color data-display tubes represent a promising business opportunity for VCDD. As this market expands in 1985 and beyond, VCDD plans to capture a sizable market share of this high-technology product.

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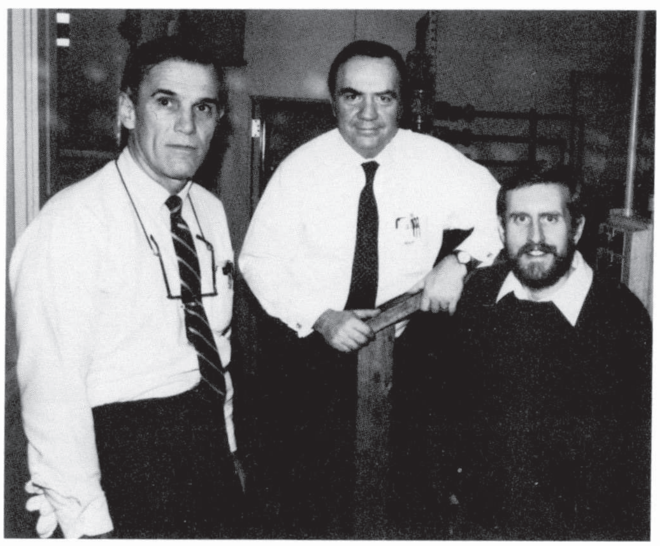

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In 1979 Don transferred to the Mask Technology/TTL group in Lancaster and is presently a Senior Member Technical Staff. He is responsible for advanced development and coordination of studies relative to improved processes for new mask designs.
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Since 1979, Jack has been Manager of the Mask Technology group of the Lancaster Technology Transfer Laboratory, and Leader Technical Staff of the Materials and Process Mask group.
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**Ernie Doerschuk** joined the RCA Color Picture Tube Division in 1973 after receiving a BA in Chemistry from Millersville University. He has been involved since that time in the area of materials and process development for color picture tube shadow mask manufacturing. Ernie has helped in the solution of a broad range of problems including casein-resist development, production start-up of horizontal processing equipment in Barceloneta, Puerto Rico, and development of data-display, full-square, and square-planar mask types for production. He is currently Member Technical Staff, Mask Materials and Process Engineering, Video Component and Display Division.
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