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Increasing the Brightness-Voltage Nonlinearity of Electroluminescent Devices

The brightness of an electroluminescent cell has a nonlinear relationship to applied voltage. For certain applications, however, this sensitivity is not sufficiently nonlinear. For example, it is desirable that the brightness-voltage nonlinearity as well as the discrimination ratio[1] of electroluminescent elements (EL) in *x-y* displays and photologic devices be increased at practical emission levels, i.e., between 1 and 10 ft-L.

This note describes one practical approach to the problem of increasing EL *B-V* nonlinearity. The *x-y* panel was chosen as a working vehicle. In such panels made with conventional EL alone, maximum discrimination ratios on the order of 30 to 60 are obtained, depending on the type of phosphor used. The familiar "crosstalk" is consequently observed at practical emission levels.

When a silicon carbide nonlinear resistive layer was deposited in series with the EL elements, marked alteration in *B-V* nonlinearity and discrimination ratios greater than 10^4 were obtained at usable light levels and operating voltages. The inclusion of the SiC layer likewise resulted in the elimination or marked suppression of "crosstalk," affording improved contrast in light emission from the EL elements.

The use of SiC, a well-known nonlinear resistive material, is by no means the only method of obtaining these results. A number of nonlinear elements have been suggested, e.g., other symmetrical varistors, CdS, As_2S_3,[2,3] ferroelectrics,[2,4] photoconductors,[5] and polaristors.[2,6] The authors have obtained equivalent results by using double diodes back-to-back.

While the present note in no way indicates the maximal characteristics obtainable by this technique, it is intended to indicate an approach to improved device design.

The *x-y* panel

In an *x-y* panel, information is displayed by lighting an EL "bit" located at the intersection of selected *x* and *y* drive lines. A schematic diagram for a 4 x 4 matrix is shown in Fig. 1. An equivalent circuit analysis has been given by Orthuber et al[2] and Matarese and Wasserman.[3] Considering the voltage division in the circuit, it may be shown that for matrices of large order, full voltage is applied to the selected intersection, while half-voltage is applied to all elements lying along selected *x* and *y* lines. This sort of voltage division manifests itself in the undesirable "crosstalk," previously alluded to, which is observed in panels made with EL layers alone.

Experimental procedure

A basic 4 x 4 element, *x-y* matrix pattern was chosen for test purposes.[7] A schematic showing cell fabrication is given in Fig. 2. The glass substrate had a pattern of parallel, semitransparent tin oxide electrodes formed by sandblasting a glass sheet with a continuous coating of tin oxide. A layer of EL phosphor in dielectric was

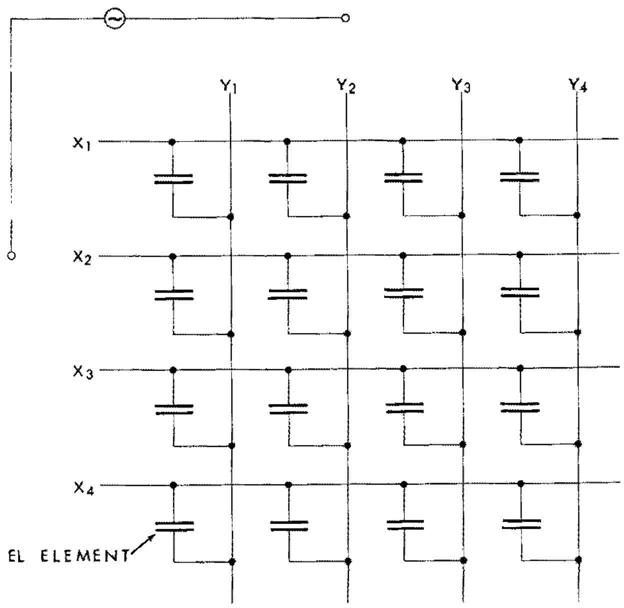


Figure 1 **Schematic diagram of x-y EL panel.** *The El elements are arrayed at the intersections of mutually perpendicular electrodes (x_i and y_i). The application of an alternating voltage to given x and y electrodes lights the EL element at their intersection.*

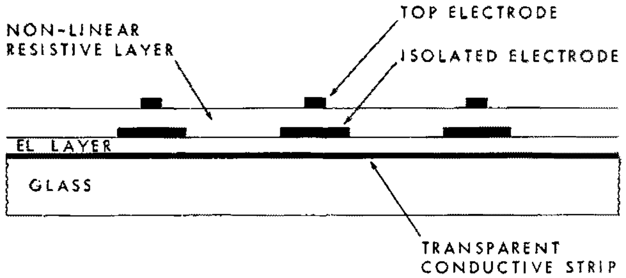


Figure 2 **x-y panel, transverse section.**

applied to the glass. Isolated electrodes of aluminum or silver were next vacuum deposited on the EL layer. The isolated electrodes were found necessary in the design in order to insure a defined impedance in the EL areas, facilitate contact between EL and SiC layers, and improve EL definition and brightness uniformity. In all cases they were square, with linear dimensions equal to the width of the transparent electrodes.

A layer consisting of a mixture of SiC powder in a suitable binder was applied over the isolated electrodes. Parallel top electrodes were applied to the SiC layer, orthogonal to the transparent electrodes. Variations were made in electrode width and spacing as well as in SiC layer thickness and SiC-powder-to-binder ratio.

For each sample, before and after application of the SiC layer, the B-V characteristics of specific EL areas were determined. Brightness measurements were made on a Photovolt Photomultiplier Photometer calibrated against a Spectra Spot Brightness Meter. Throughout the investigation, a green, N. V. Philips EL phosphor and Carborundum 600 grit, low resistivity SiC powder were used. Plastic and low-melting glass embedment materials were employed.

Results

- *Influence of SiC concentration and thickness*

Typical effects of variations in SiC-powder-to-binder ratio on B-V curves are shown in Fig. 3. The addition of a SiC layer altered the B-V nonlinearity by displacing, along the voltage axis, the voltage at which EL emission commences. We shall henceforth refer to this difference as the displacement voltage, V_d.

Increased concentration of SiC over the range of 40-46% by volume[9] decreased V_d and resulted in increased emission at any given voltage. In general, for constant SiC layer thickness, decreased SiC concentration over the same range made for higher maximum discrimination ratios at higher light levels, although at the cost of higher operating voltages.[8]

Both increased V_d and maximum discrimination ratio at increased light output resulted from increased SiC

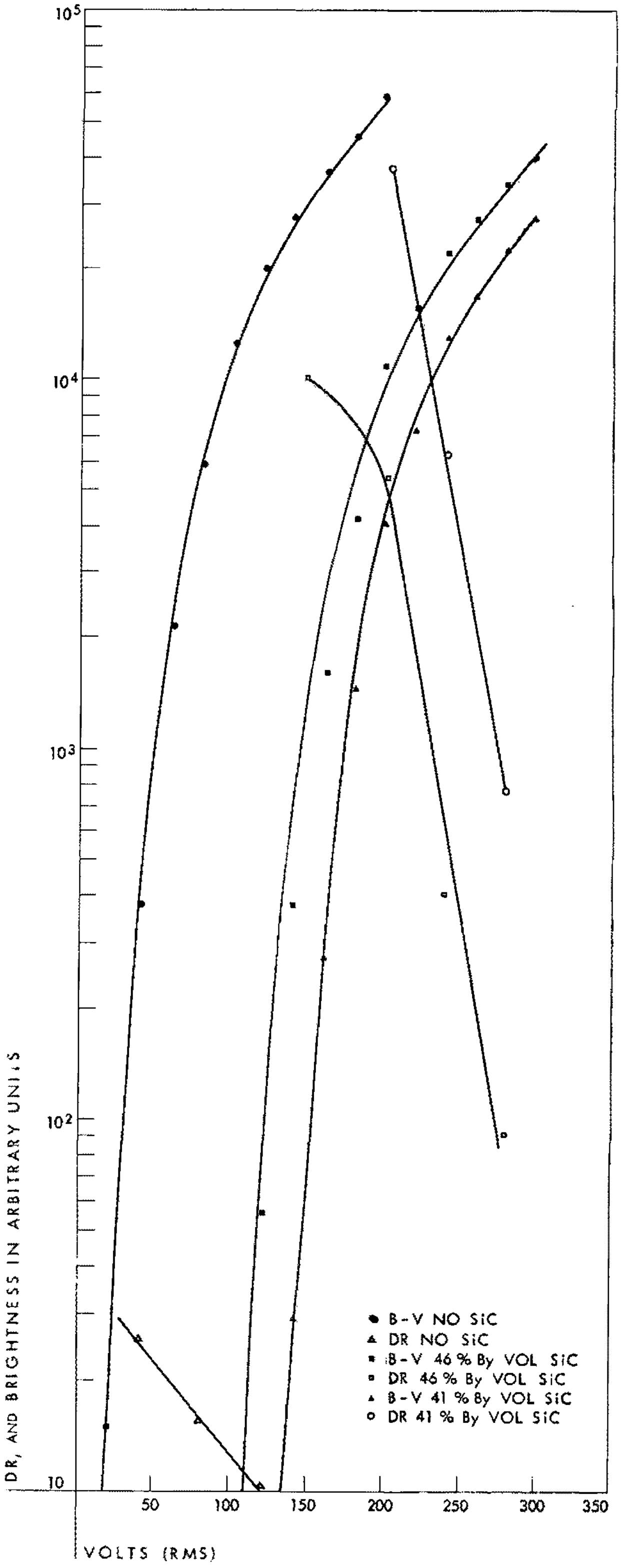


Figure 3 **Brightness/voltage and discrimination-ratio/voltage as a function of SiC concentration at 1 kc.**

thickness at fixed concentration. Data for representative samples at 1 kc are given in Table 1.

Table 1

Sample	*SiC Conc. (volume)*	*SiC Thickness (mils)*	V_d *(volts)*	*Max. DR*	*Brightness (Ft-L)*
1181	41%	5	60	1.5×10^4 (120 volts)	0.6
1282	41%	8	110	4×10^4 (200 volts)	1.3
1383	41%	11	150	7×10^4 (280 volts)	4.0

The above changes in EL emission characteristics directly reflect variations in the current-voltage characteristics of the SiC layer. The results are exactly what one would expect from an equivalent circuit consideration of the SiC device.[10]

- *Influence of electrode geometry*

In all samples, the size of the isolated electrode was held constant relative to the bottom electrode. Device characteristics could be altered by varying the width of the top electrodes.

Narrowing the top electrodes increased the effective impedance of the SiC elements, and increased V_d and maximum *DR*. The narrow widths required higher operating voltage and gave decreased emission.

Variations in spacing between bottom conductors exerted no influence on device characteristic, other things being equal, down to resolutions of 10 lines per

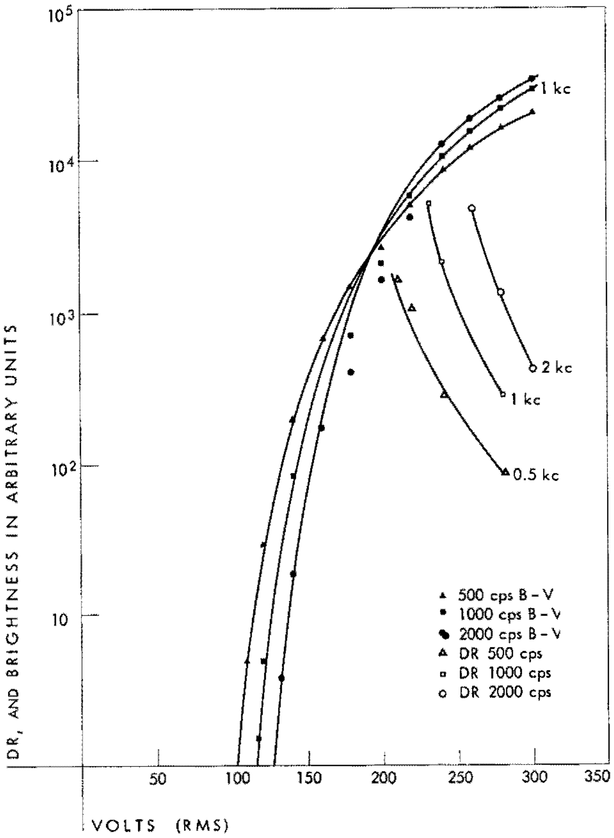
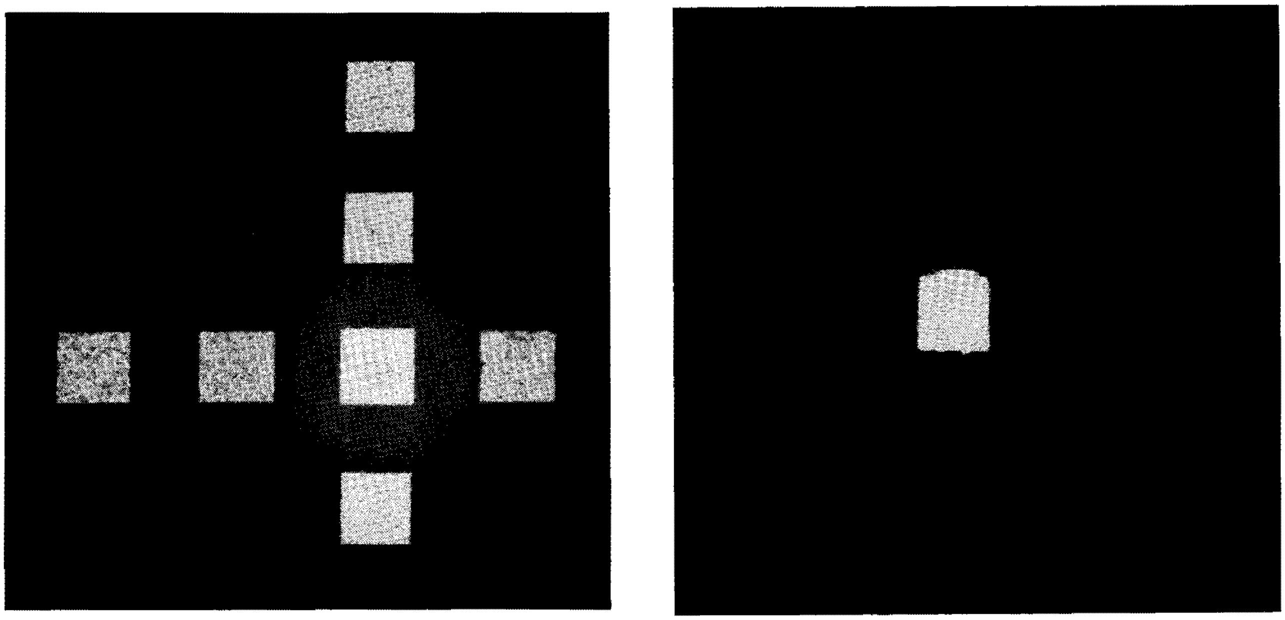


Figure 4 **Brightness/voltage and discrimination-ratio/voltage for three frequencies.**

Figure 5 **Comparison of x-y panels made without SiC layer (left) and with SiC layer (right).**



inch. As long as the width of the top electrode was maintained 1/8 to 1/10 the width of the bottom electrode, *DR*'s of the order of 10^4 at useful brightness levels were obtained from samples made with SiC layers of proper thickness and concentration.

In high-resolution panels, the resistance of evaporated or screened top electrodes increased markedly as their width was decreased. Fine copper wires were imbedded in the SiC layer to avoid increasing lead resistance.

- *Frequency behavior*

Figure 4 shows *B-V* curves and *DR*'s at 0.5, 1 and 2 kc. At higher operating frequencies, larger values of *DR* were obtained and higher cell brightnesses were observed. V_d increased with increased frequency because of a decrease in EL impedance with frequency. A crossover in the curves was observed at higher voltages because of increased integrated EL emission with voltage at higher frequencies and the shift of peak EL emission toward the blue at higher frequencies, coupled with the higher blue sensitivity of the photomultiplier tube used in the optical measurements.

- *Conclusion*

It has been shown that marked improvement in EL *B-V* nonlinearity and greatly enhanced *DR*'s can be obtained by the inclusion of SiC resistive layers in series with EL elements.

Variations in *B-V* characteristics reflect variations in the properties of the applied SiC layer. *x-y* test panels showed striking suppression of "crosstalk" and greatly improved contrast.

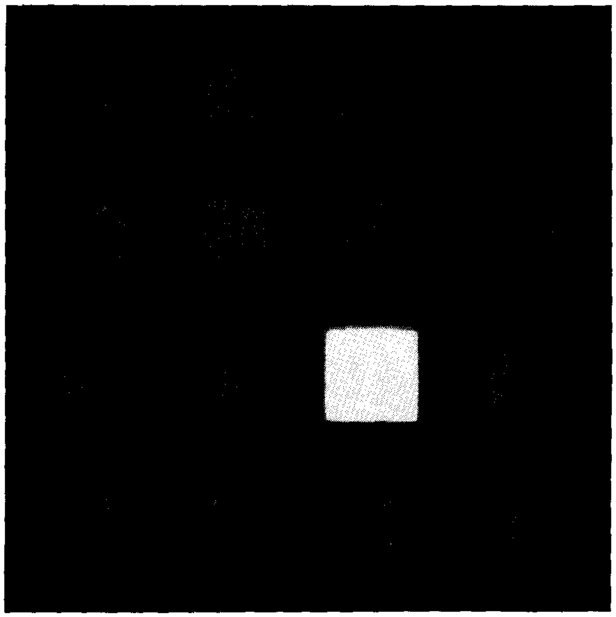


Figure 6 **x-y panel with suppressed cross-talk.** *Halation is eliminated through the use of a Fotoform glass substrate.*

Figure 5 shows a comparison between two *x-y* panels, one made without SiC, (left), the other with it (right). The marked suppression of "crosstalk" is apparent on the latter panel.

In all panels made with clear glass substrates, scatter and reflection halation caused spreading of the EL emission. Figure 6 shows the elimination of this halation though the use of a Fotoform substrate.

References and footnotes

1. The discrimination ratio (*DR*) or voltage half-select ratio is defined as the quotient of EL brightness at some voltage *V* to that at half-voltage, *V*/2, i.e., $B/B_{v/2}$, where *B* is the brightness.
2. Orthuber et al, German Patent 1,017,648; U. S. Patent 2,877,371.
3. J. Matarese and M. Wasserman, paper presented at 1959 Electron Devices Meeting, Washington, D. C.
4. E. A. Sack, *Proc. IRE* **46,** 1694 (1958).
5. R. E. Halstead, U. S. Patent 2,836,766.
6. H. Hollman, *Proc IRE* **40,** 538 (1952).
7. Matarese and Wasserman, Ref. 3, have used the same type of construction.
8. Discrimination ratios at low voltages of EL-SiC devices were essentially undefined because of immeasurably low emission at corresponding half-select voltages. The term "maximum discrimination ratio" used in this note refers to the maximum real ratio obtained from experimental data at voltages where nonvanishing values could be inserted in the denominator.
9. Below this range the SiC layers were insulating because of an absence of particle-to-particle contacts. Above this range, varistor characteristics were suppressed because of an overabundance of parallel particle-to-particle contacts.
10. J. N. Shive, *Semiconductor Devices,* D. van Nostrand, Princeton, 1959.

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