TEMPERATURE AND INTENSITY DEPENDENCE OF THE PERFORMANCE OF AN ELECTRON-IRRADIATED (AlGa)As/GaAs SOLAR CELL

Clifford K. Swartz and Russell E. Hart, Jr.
National Aeronautics and Space Administration
Lewis Research Center

SUMMARY

The performance of a Hughes, liquid-phase epitaxial 2-centimeter-by-2-centimeter, (AlGa)As/GaAs solar cell was measured before and after irradiations with 1-MeV electrons to fluences of 1×10^{16} electrons/cm^2. The temperature dependence of performance was measured over the temperature range 135 to 415 K at each fluence level. In addition, temperature dependences were measured at five intensity levels from 137 to 2.57 mW/cm^2 before irradiation and after a fluence of 1×10^{16} electrons/cm^2. For the intermediate fluences, performance was measured as a function of intensity at 298 K only.

At a fluence of 1×10^{16} electrons/cm^2, the maximum power had decreased to about 40 percent of original, with most of the loss in short-circuit current. This performance is typical of cells with 0.5-micrometer-deep junctions. Variation of short-circuit current density with temperature showed the presence of three distinct slopes. The upper slope, above about 310 K, had a temperature coefficient twice that of the intermediate slope. The temperature breakpoint between these two slopes varied with fluence level. A third slope existed at temperatures below 210 K. The temperature coefficient of the open-circuit voltage did not change with temperature or with irradiation. In contrast, the temperature coefficient of maximum power at the fluence of 1×10^{16} electrons/cm^2 was about one-half its unirradiated value. Over the intensity range studied, the open-circuit voltage varied as the logarithm of intensity, with slopes from 3 kT/q to 1 kT/q.

INTRODUCTION

The behavior of solar cells in a radiation environment is of great importance for space applications. Studies have shown that (AlGa)As/GaAs solar cells are generally less susceptible to radiation damage than silicon cells. However, these studies have only determined performance at room temperature after irradiation. Their data are not sufficient for system analyses of the (AlGa)As/GaAs cells. Additional data on performance as a function of temperature and intensity, as well as temperature coefficients of performance, are also needed. This paper reports the electrical characteristics of a (AlGa)As/GaAs solar cell for a wide range of temperatures and illumination intensities as a function of radiation damage. These conditions are typical of those encountered in space.

PROCEDURE AND APPARATUS

The cell used in this electron irradiation test was a typical Hughes Research Laboratory, 2-centimeter-by-2-centimeter (AlGa)As/GaAs solar cell that is in laboratory production. A cross section of the cell is shown in figure 1. These cells are formed by liquid-phase epitaxial (LPE) deposition of n-type GaAs on n^+ GaAs substrates. Subsequently, an (AlGa)As layer is also formed by LPE. The junction is obtained during the growth of the p-type (AlGa)As layers by allowing the p-dopant to diffuse into the n-type GaAs substrate. Both (AlGa)As window thickness and GaAs cell junction depth are approximately 0.5 micrometer. This cell was also covered with a 300-micrometer-thick cover glass.

The Lewis Research Center Cockraft-Walton accelerator was used for the 1-MeV-electron irradiation. The cells were mounted on a metal plate, and the defocused beam was swept across them in a horizontal plane. The irradiations were conducted in air at a dose rate low enough that the cell temperature never exceeded 40°C. The dose was measured with a Faraday cup. Immediately after each irradiation level was reached, the cells were stored in a nitrogen atmosphere for about 20 hours. The performance of the cells was then measured under a X-25L xenon-arc solar simulator. The intensity of the simulator was adjusted to a simulated 137-mW/cm^2 (AMO) condition by using an airplane-flown, calibrated (AlGa)As/GaAs reference solar cell. The temperature of the cell was maintained at 25°C during the performance measurements. The spectral response of the cell was measured with a filter wheel, consisting of nine narrow-bandpass monochromatic interference filters spanning the wavelength range from 0.4 to 1.0 micrometer.

After the measurements in the standard test facilities, the cell was mounted on a temperature-controlled block located inside a box purged with dry nitrogen. Vacuum was used to hold the cell in good thermal contact with the control block. The cell was again illuminated with the X-25L xenon-arc solar simulator. The intensity of the light was adjusted to give the previously measured short-circuit current of the (AlGa)As test cell. The cell was then cycled over the temperature range 415 to 135 K; performance was measured with an automatic data acquisition system at 5-kelvin intervals. These measurements were repeated after each incremental fluence level was reached. Before irradiation and at a fluence of 1×10^{16} electrons/cm^2, the temperature dependence of the cell performance was also measured at intensities of 137, 60.35, 11.75, 4.19, and 2.57 mW/cm^2. At the intermediate fluences, the performance as a function of intensity was measured only at 25°C.

RESULTS

The degradation in performance of the (AlGa)As/GaAs solar cell after 1-MeV-electron irradiation is shown in figure 2 normalized to the initial starting data. The data show a loss in maximum power of about 60 percent at a fluence of 1×10^{16} electrons/cm^2. The decrease in performance is primarily due to a loss in the short-circuit current. This is verified by the spectral response measurements shown in figure 3. This performance is typical of (AlGa)As/GaAs solar cells with a junction depth of about 0.5 micrometer (ref. 1).

A typical plot of the temperature dependence at one particular fluence is shown in figure 4. The data show that the open-circuit voltage V_{oc} varies linearly with temperature. However, the plot of short-circuit current density J_{sc} shows three distinct slopes over the temperature range 135 to 415 K. One slope was in the higher temperature range of 300 to 415 K and is called the upper slope. A second slope was in the intermediate temperature range of 200 to 300 K. The third slope was at temperatures below 200 K. This low-temperature range is outside the normal operating temperature of the cell, and temperature coefficients were therefore not calculated.

Temperature coefficients for each cell parameter were determined for each fluence level and are presented in figure 5. The temperature coefficient of the V_{oc} remained constant with fluence at a mean value of -2.03 mV/K. However, the temperature coefficient for J_{sc} depended on both the radiation fluence and the temperature range. The temperature coefficient of the upper slope (above 300 K) for J_{sc} was 0.03 mA/cm^2 K for the unirradiated condition. The temperature coefficient dropped very rapidly after irradiation with 1-MeV electrons to a fluence of 1×10^{13} electrons/cm^2. After this initial irradiation, the temperature coefficient remained constant at a mean value of 0.0213 mA/cm^2 K to a fluence of 1×10^{16} electrons/cm^2. In the intermediate temperature range, the temperature coefficients of J_{sc} remained constant at 0.0108 mA/cm^2 K, independent of fluence. Temperature coefficient of maximum power density P_{max} started at -0.045 mW/cm^2 K in the unirradiated condition but decreased to less than half that value (0.018 mW/cm^2 K) at a fluence of 1×10^{16} electrons/cm^2.

In obtaining temperature coefficients for J_{sc}, we found that the intercept between the upper slope and the intermediate slope varied. The temperature at which the two slopes intercepted is shown in figure 6 as a function of fluence. The intercept occurred at 325 K for the unirradiated condition. The temperature at which the intercept occurred gradually decreased with fluence to 3×10^{15} electrons/cm^2. After the last fluence level of 1×10^{16} electrons/cm^2 was reached, the temperature at which the intercept occurred rose sharply for some unexplained reason.

The short-circuit current was linear with light intensity to 137 mW/cm^2 (AMO), as shown in figure 7. Fluences to 1×10^{16} electrons/cm^2 had no effect on this linearity.

The variation of V_{oc} with intensity can supply insight into the physics of the cell, provided V_{oc} is plotted as the abscissa, as shown in figure 8. This is contrary to normal practice. Because I_{sc} is linear with intensity, the ordinate is proportional to current. Thus, this plot becomes the forward-diode characteristic of the device without the effects of series resistance (ref. 2).

In the unirradiated condition, this solar cell has an A value as determined from the slope of about 2.5 at intensities below 137 mW/cm^2. As the solar cell is irradiated, the slopes approach an A value of 1.15. The dotted-line extensions of the zero-fluence and 1×10^{16} electron/cm^2 curves were obtained from subsequent measurements made at light intensities greater than AMO. The slopes of these data are also about 1.15.

These data show that in the forward diode characteristic the recombination generation component of the reverse saturation current I_0 was dominant at light levels below AMO in the unirradiated condition. In the irradiated condition, the diffusion component became dominant at fluences above 1×10^{14} electrons/cm^2.

The intensity dependence of the temperature coefficient for this GaAs solar cell is shown in figure 9. The data show the V_{oc} temperature coefficient to decrease with increasing intensity to 137 mW/cm^2. The percent change in the J_{sc} temperature coefficient remained unchanged within 2 percent over the intensity range used in these studies.

SUMMARY OF RESULTS

A typical Hughes (AlGa)As/GaAs solar cell was subjected to 1-MeV-electron-irradiation to a fluence of 1×10^{16} electrons/cm^2. The performance of the solar cell was measured over the temperature range 135 to 415 K and at five intensity levels from 137 to 2.57 mW/cm^2 after each fluence level was reached.

The following results were obtained from these data:

1. Three distinct slopes were observed in the variation of short-circuit current density J_{sc} with temperature.

2. Above 300 K, the J_{sc} temperature coefficient was initially 0.03 mA/cm^2 K but it decreased after a fluence of 1×10^{13} electrons/cm^2 to 0.0213 mA/cm^2 K.

3. At 200 to 300 K, the J_{sc} temperature coefficient was 0.0108 mA/cm^2 K and showed no change in temperature.

4. The open-circuit-voltage temperature coefficient remained constant at -2.03 mV/K with fluence.

5. The maximum-power temperature coefficient at a fluence of 1×10^{16} electrons/cm^2 was about one-half its unirradiated value of -0.045 mW/cm^2 K.

6. The recombination generation component of the reverse saturation current was dominant at light levels below 137 mW/cm^2 (AMO) in the unirradiated condition. The diffusion coefficient dominated at fluences above 1×10^{14} electrons/cm^2.

REFERENCES

1. Kamath, S.; and Wolff, G.: High Efficiency GaAs Solar Cell Development. Final Rep. Aug. 1976-July 1978, Hughes Aircraft Co., Jan. 1979. (AFAPL-TR-78-96)

2. Wolf, Martin; and Rauschenbach, Hans: Series Resistance in Solar Cell Measurements. Advan. Energy Convers., vol. 3, no. 2, Apr.-June 1963, pp. 455-479

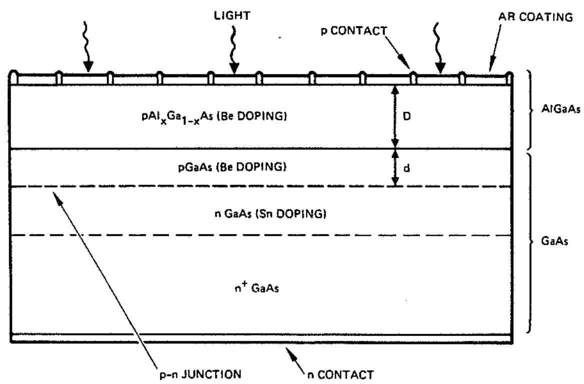

Figure 1. - GaAs solar cell structure.

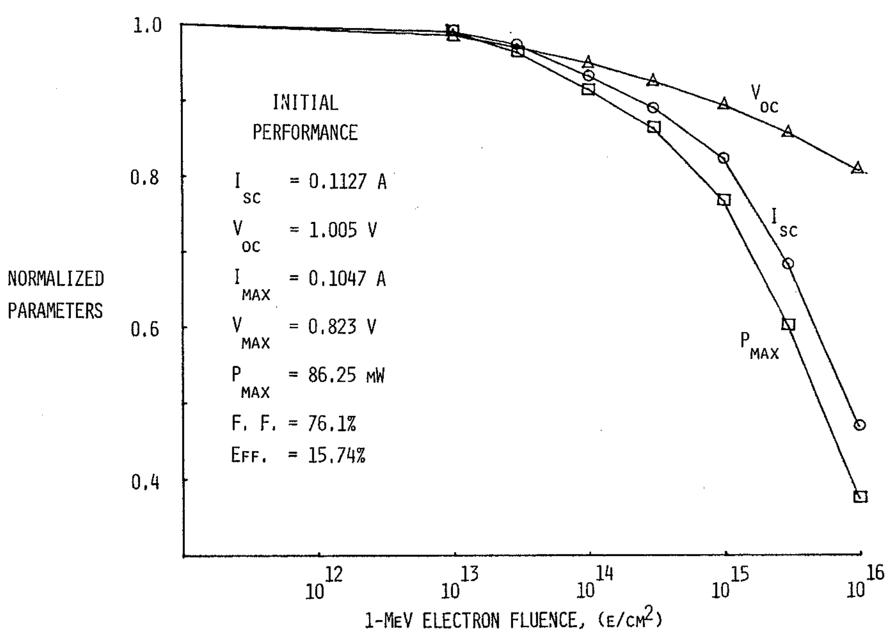

Figure 2. - Performance of (AlGa)As solar cell irradiated with 1-MeV electrons.

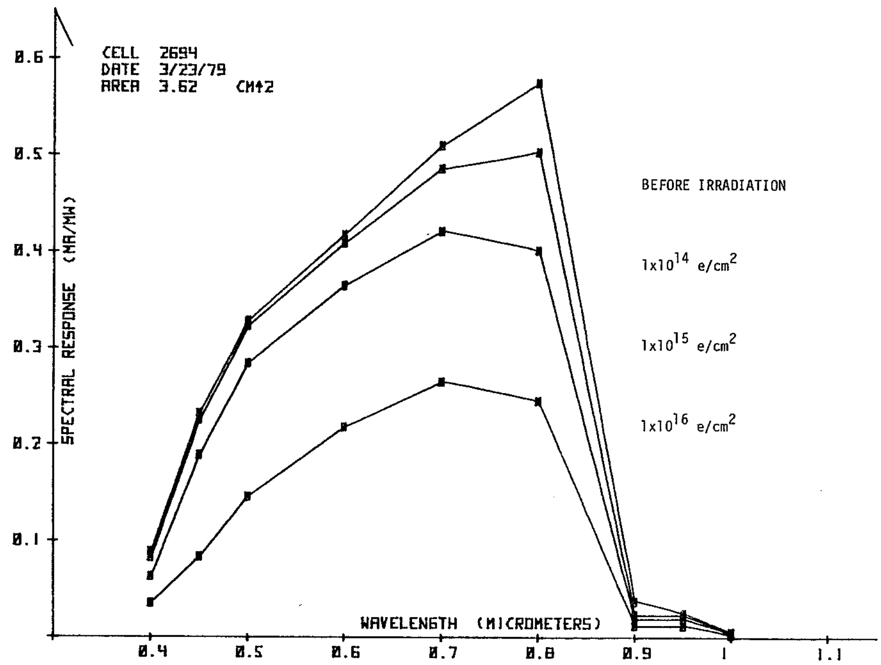

Figure 3.- Spectral response of 1-MeV-irradiated (AlGa)As solar cell.

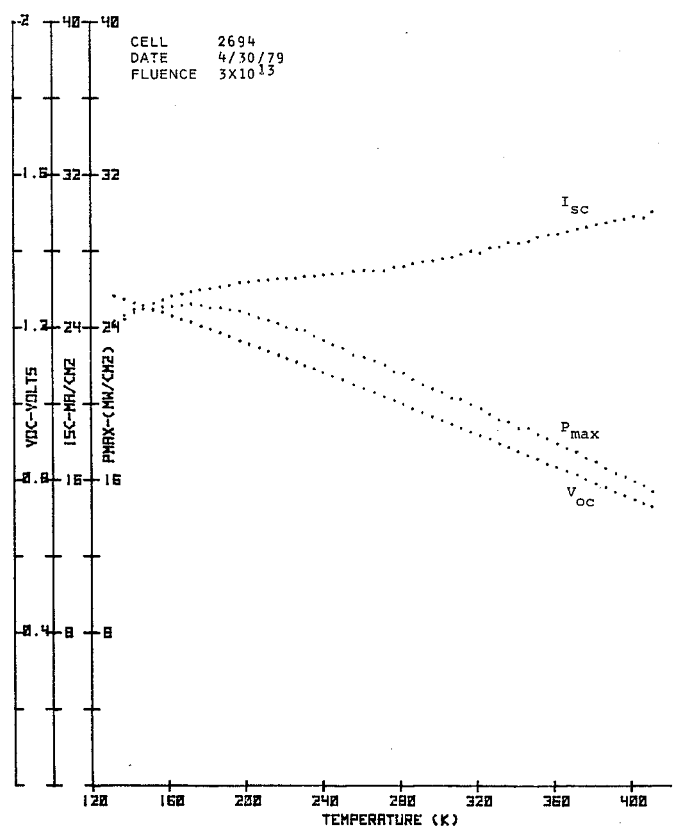

Figure 4.- Temperature dependence of (AlGa)As solar cell.

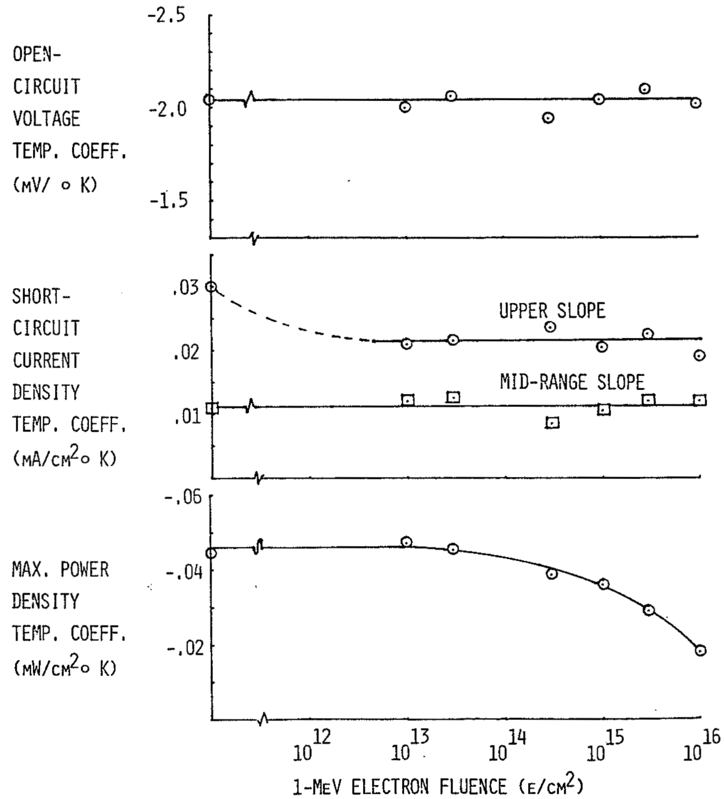

Figure 5.- Temperature coefficients of 1-MeV-irradiated (AlGa)As solar cell.

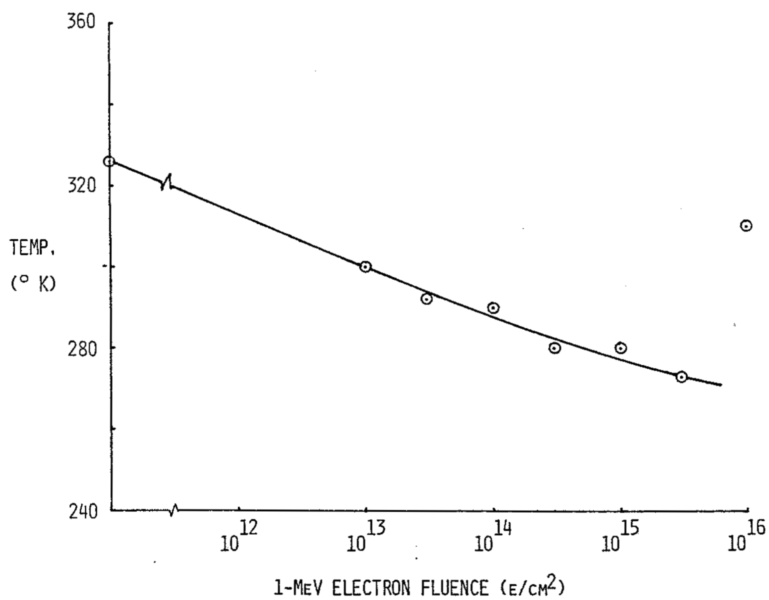

Figure 6.- Temperature for intercept point of upper and midrange current density slopes.

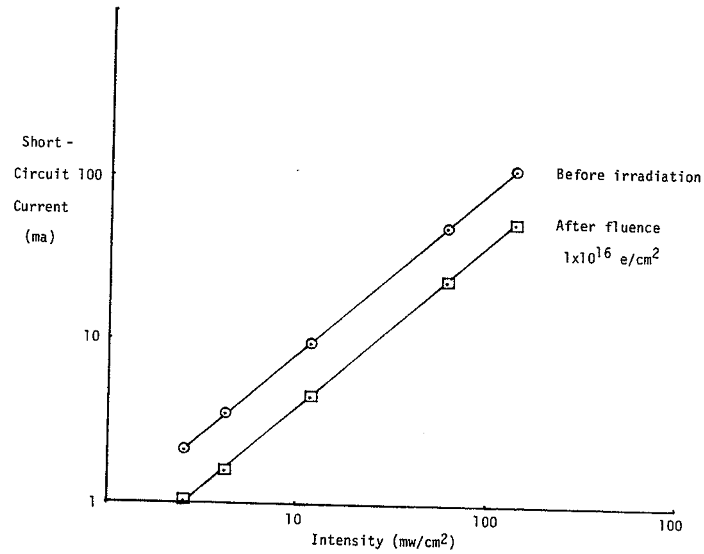

Figure 7. - Short-circuit dependence with intensity for irradiated (AlGa)As solar cell.

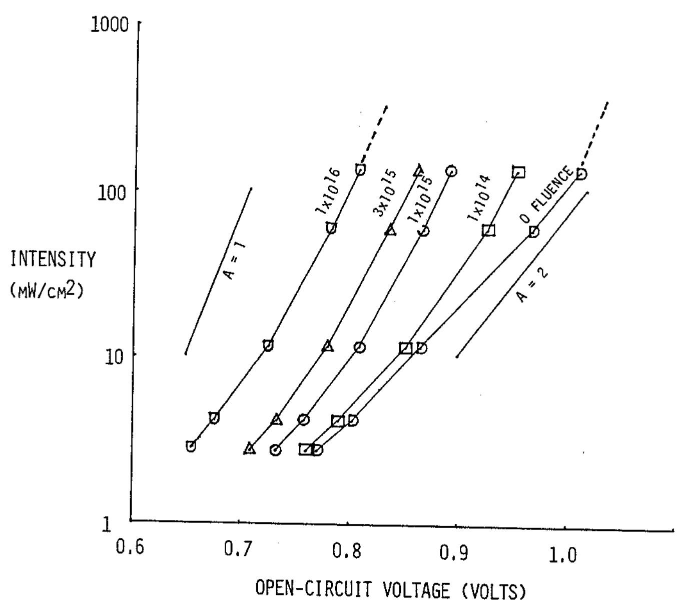

Figure 8. - Open-circuit voltage - intensity variation in irradiated (Al Ga)As solar cell.

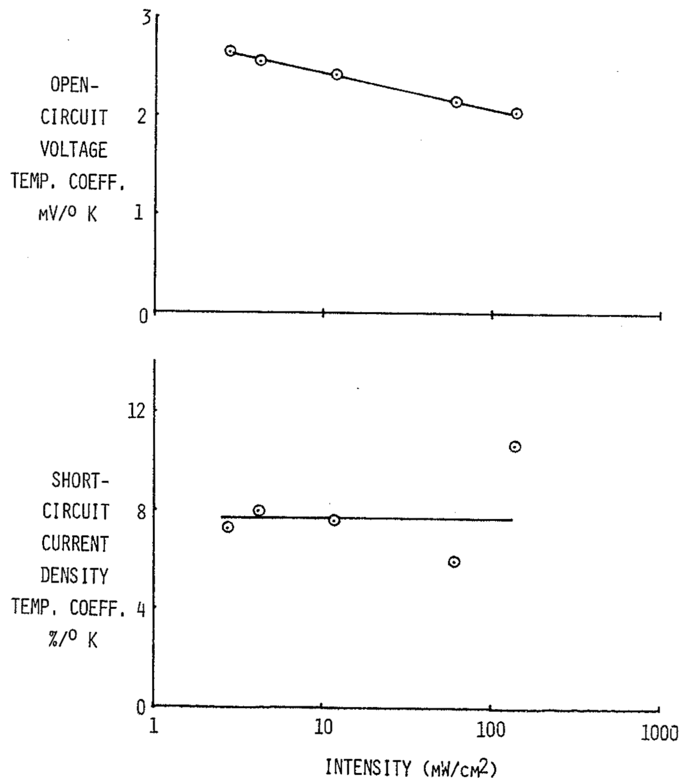

Figure 9.- Intensity dependence of (AlGa)As solar cell on temperature coefficient.