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EFFECT OF 1 MeV ELECTRONS ON CERIA-DOPED SOLAR CELL COVER GLASS

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16. Abstract

This report covers an experiment to determine the effect of 1 MeV electrons on the transmission properties of 1.5-percent ceria-doped solar cell cover glass (Micro-Sheet). Samples of doped and undoped cover glass and synthetic fused silica were irradiated with a total integrated flux of 10^{15} e/cm^2. Wideband transmission and spectral transmission measurements were made before and after irradiation.

The results of the experiment indicate that 1.5-percent ceria-doped cover glass is much less sensitive to radiation-induced discoloration than undoped cover glass. Consequently, the glass is comparable to synthetic fused silica when used as a radiation-resistant solar cell cover for many space missions.

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EFFECT OF 1 MeV ELECTRONS ON CERIA-DOPED SOLAR CELL COVER GLASS

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SUMMARY

This report covers an experiment to determine the effect of 1 MeV electrons on the transmission properties of 1.5-percent ceria-doped solar cell cover glass (Micro-Sheet). Samples of doped and undoped cover glass and synthetic fused silica were irradiated with a total integrated flux of 10^{15} e/cm^2. Wideband transmission and spectral transmission measurements were made before and after irradiation.

The results of the experiment indicate that 1.5-percent ceria-doped cover glass is much less sensitive to radiation-induced discoloration than undoped cover glass. Consequently, the glass is comparable to synthetic fused silica when used as a radiation-resistant solar cell cover for many space missions.

INTRODUCTION

Silicon solar cells used in space power systems are generally provided with a thin cover of synthetic fused silica or glass (Micro-Sheet) to provide radiation shielding and thermal control. The glass is used when it is determined that the expected radiation environment should induce little or no discoloration; otherwise, synthetic fused silica is used.

Recent tests (ref. 1) have shown that radiation-induced discoloration in Micro-Sheet can be substantially reduced by doping the glass with ceria (cerium oxide). The purpose of the present investigation was to determine the effects of 1 MeV electrons on the transmission properties of 1.5-percent ceria-doped Micro-Sheet and to compare these effects with those for synthetic fused silica and undoped glass. Synthetic fused silica is known to be very resistant to radiation-induced discoloration.

One MeV electrons were used in this experiment because this radiation is similar to that found in the Van Allen belts, and many radiation experiments, involving solar cells and cover glasses, have included electrons at or near this energy; hence, many data are available for comparison. (See refs. 1 to 8.)

EXPERIMENTAL PROCEDURE

The ceria-glass (Micro-Sheet) used in the tests was manufactured by current commercial procedures for melting, drawing, and fire polishing this type of glass. The ceria doping to a level of 1.5 percent was made an additional part of the melting procedure. The glass was cut into 25.4 by 12.7 mm (1 by 0.5 inch) samples for the experiment, and some samples were coated with antireflection and ultraviolet (uv) reflection coatings whereas others were not coated. Other types of samples included synthetic fused silica and undoped glass (Micro-Sheet). These samples were coated with one or both of these coatings.

A description of the samples tested is given in table I, in which the thickness and type coatings are cited. Included in the table is a 5.0-percent ceria-doped glass produced in England.

The preirradiation and postirradiation parametric tests on the samples consisted of spectral and wideband transmission tests. The spectral transmission was measured with a recording spectrophotometer. The wideband transmission was measured with a silicon solar cell and a xenon arc solar simulator. The simulator spectrum is shown in figure 1 along with the spectra for the solar and tungsten light sources. The solar cell spectral response determined the bandwidth of the wideband transmission. The spectral response of a typical solar cell is shown in figure 2. The accuracy of all measurements was within 1 percent.

The samples were irradiated with a cascade rectifier type electron accelerator located at the Langley Research Center space radiation effects laboratory (operated under contract by the College of William and Mary). All samples were irradiated simultaneously with a swept electron beam in a vacuum of approximately 10^{-5} torr. The total integrated fluence of 10^{15} e/cm^2 was given in three stages: 10^{13} e/cm^2, 10^{14} e/cm^2, and 10^{15} e/cm^2. Parametric measurements were made after each stage of irradiation. The 10^{15} e/cm^2 total integrated fluence is equivalent to several years of radiation exposure (depending on satellite orbit) to the Van Allen belts.

RESULTS AND DISCUSSION

The electron radiation used in this experiment was expected to cause little damage in most of the samples tested. However, direct comparisons of the effects of the radiation on the transmission properties of ceria glass, undoped glass, and synthetic fused silica were possible. First, comparisons with the preirradiation transmission characteristics were made. The wideband transmission characteristics for all samples tested, except the English sample, are given in table II. Note that the preirradiation transmissions of all samples shown were comparable. Consequently, the use of 1.5-percent ceria-doped cover glass instead of undoped glass or synthetic fused silica (the two most commonly used solar cell covers) would cause no loss in the "beginning-of-life" performance of a solar array in orbit.

The effect of electron radiation on the spectral transmission of single-coated (antireflection coating only) and double-coated (antireflection and uv reflection coatings) synthetic fused silica is shown in figure 3. There was no radiation-induced degradation. The small amount of variation that appears in the postirradiation curve for the double-coated sample is within the measuring accuracy of the spectrometer. Also it is shown in table II that little or no damage results because of irradiation, the small damage apparent in items 2 and 3 being within measuring accuracy.

The effect of electron radiation on the spectral transmission of undoped cover glass is shown in figures 4 and 5. These figures show that undoped glass is susceptible to radiation-induced discoloration, and the discoloration begins at relatively low fluences. The effect can be seen visually as a brownish discoloration. Wideband transmission results, given in table II, show losses of 3.85 and 3.60 percent, respectively, for single- (antireflection only) and double- (antireflection and uv reflection) coated undoped glass. These losses would have to be compensated for by overdesign of the solar array if this type of glass were to be used in a radiation environment of the aforementioned severity. The losses cited are higher by a factor of two than those cited in reference 2 for undoped glass of the same type and thickness. The difference results from differences in the experimental setup. One important difference was the use of a solar simulator, in the experiment being discussed, instead of a tungsten light. The tungsten spectrum is very different from that of the solar spectrum as can be seen in figure 1.

The effects of the electron radiation on the wideband transmission of 1.5-percent uncoated ceria glass are given in table II. The thicker samples showed slightly more degradation than the thinner samples. This difference could be minimized by increasing the ceria dopant level. (See ref. 1.)

The effects of the radiation on the spectral transmission of single-coated and double-coated samples of 1.5-percent ceria cover glass are shown in figures 6 and 7. The wideband transmission results are given in table II. The curves for the ceria cover glass shown in figure 6 can be compared with the curves for the cover glass shown in figure 4. The advantages gained through doping with ceria can be seen from such a comparison. The difference in losses in wideband transmission can be seen in table II by comparing item 15 with item 7. The losses in wideband transmission of 1.5-percent ceria cover glass are very small compared with the losses in undoped cover glass.

Figure 8 shows the effect of electron radiation on the spectral transmission properties of a 5.0-percent ceria glass produced in England. Comparison of the curves of figures 6 and 8 indicates that an increase in ceria dopant level yields insignificant differences for 0.152-mm-thick (0.006 inch) material.

The curve of figure 6 representing unirradiated ceria cover glass indicates that uv radiation cutoff is approximately 0.32 μm. For this reason it is believed that the uv reflection coating (used to protect organic cements) is not needed. The uv light between 0.32 μm and 0.40 μm is not expected to discolor the cement used to attach the cover glass to the solar cell. The use of the uv reflection coating on cover glass increases the cost, and it slightly decreases the solar cell output by restricting the solar cell spectral response in the wavelength region below 0.40 μm. This condition can be seen in figure 2 by comparing the two curves shown. Consequently, the elimination of the uv reflection coating would result in a decrease in cost and a small increase in output, since the solar spectrum is relatively high in intensity in the 0.30 μm to 0.40 μm wavelength region. (See fig. 1.) Further study would be required for verification.

Comparison of the wideband transmission of items 12 and 15 of table II suggests that a decrease in output would result from the use of single-coated ceria glass in lieu of double-coated ceria glass. The slightly lower transmission of the single-coated glass can be explained by the fact that only one surface of the glass is optimized for minimum reflection, whereas the double-coated glass is coated on the second surface which also reduces surface reflection losses. If a single-coated glass were used in solar array fabrication, the reflection at the second surface would be minimized by the close index match of the glass-to-cement (instead of glass-to-air) interface.

A phenomenon discussed in reference 1, the development of electron discharge fissures, also deserves mentioning here. No such phenomenon occurred during the testing covered in this investigation. Fissures were not expected to develop in the samples, since they were too thin to absorb an appreciable number of electrons.

CONCLUDING REMARKS

The effects of 1 MeV electrons on the transmission properties of 1.5-percent ceria-doped solar cell cover glass (Micro-Sheet) have been determined. The effects were compared with corresponding effects in undoped cover glass (Micro-Sheet) and synthetic fused silica. Results showed that the ceria-doped glass was much less sensitive to radiation-induced discoloration than undoped glass. The improvement makes the ceria-doped glass comparable to synthetic fused silica for this application.

The ceria glass may be used without the ultraviolet (uv) reflection coating, since the ceria additive blocks the uv light that might be expected to discolor the cover glass. Further study would be required for verification.

The experiment discussed verifies the findings of previous work in showing that ceria-doped glass would be a satisfactory substitute for the more expensive synthetic fused silica as a solar cell cover.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., May 3, 1973.

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TABLE I.- DESCRIPTION OF SAMPLES IRRADIATED

WITH 1 MeV ELECTRONS

Item	Material	Thickness, mm	Antireflection coating	Antireflection and uv reflection coating
1	Synthetic fused silica	0.152	x	
2	Synthetic fused silica	.304	x	
3	Synthetic fused silica	.508	x	
4	Synthetic fused silica	.152		x
5	Synthetic fused silica	.304		x
6	Synthetic fused silica	.508		x
7	Undoped glass	.152	x	
8	Undoped glass	.152		x
9	Ceria glass[1]	.152		
10	Ceria glass[1]	.304		
11	Ceria glass[1]	.456		
12	Ceria glass[1]	.152	x	
13	Ceria glass[1]	.304	x	
14	Ceria glass[1]	.456	x	
15	Ceria glass[1]	.152		x
16	Ceria glass[1]	.304		x
17	Ceria glass[1]	.456		x
18	Ceria glass[2] (English)	.152	x	

[1] $1\frac{1}{2}$-percent ceria dopant.

[2] 5-percent ceria dopant.

TABLE II.- EFFECT OF 1 MeV ELECTRONS (FLUENCE 10^{15} e/cm^2) ON THE WIDEBAND TRANSMISSION OF SEVERAL SOLAR CELL COVER MATERIALS

Item	Material	Preirradiated wideband transmission, percent	Postirradiation loss, percent
1	Synthetic fused silica	94.3	---
2	Synthetic fused silica	94.4	0.3
3	Synthetic fused silica	94.3	.2
4	Synthetic fused silica	94.4	---
5	Synthetic fused silica	94.0	.3
6	Synthetic fused silica	94.5	.6
7	Undoped glass	94.0	3.8
8	Undoped glass	95.4	3.6
9	Ceria glass	91.6	.6
10	Ceria glass	91.8	1.2
11	Ceria glass	91.4	1.4
12	Ceria glass	93.6	.6
13	Ceria glass	93.6	1.2
14	Ceria glass	93.2	2.0
15	Ceria glass	95.1	.6
16	Ceria glass	95.0	.8
17	Ceria glass	95.2	1.9

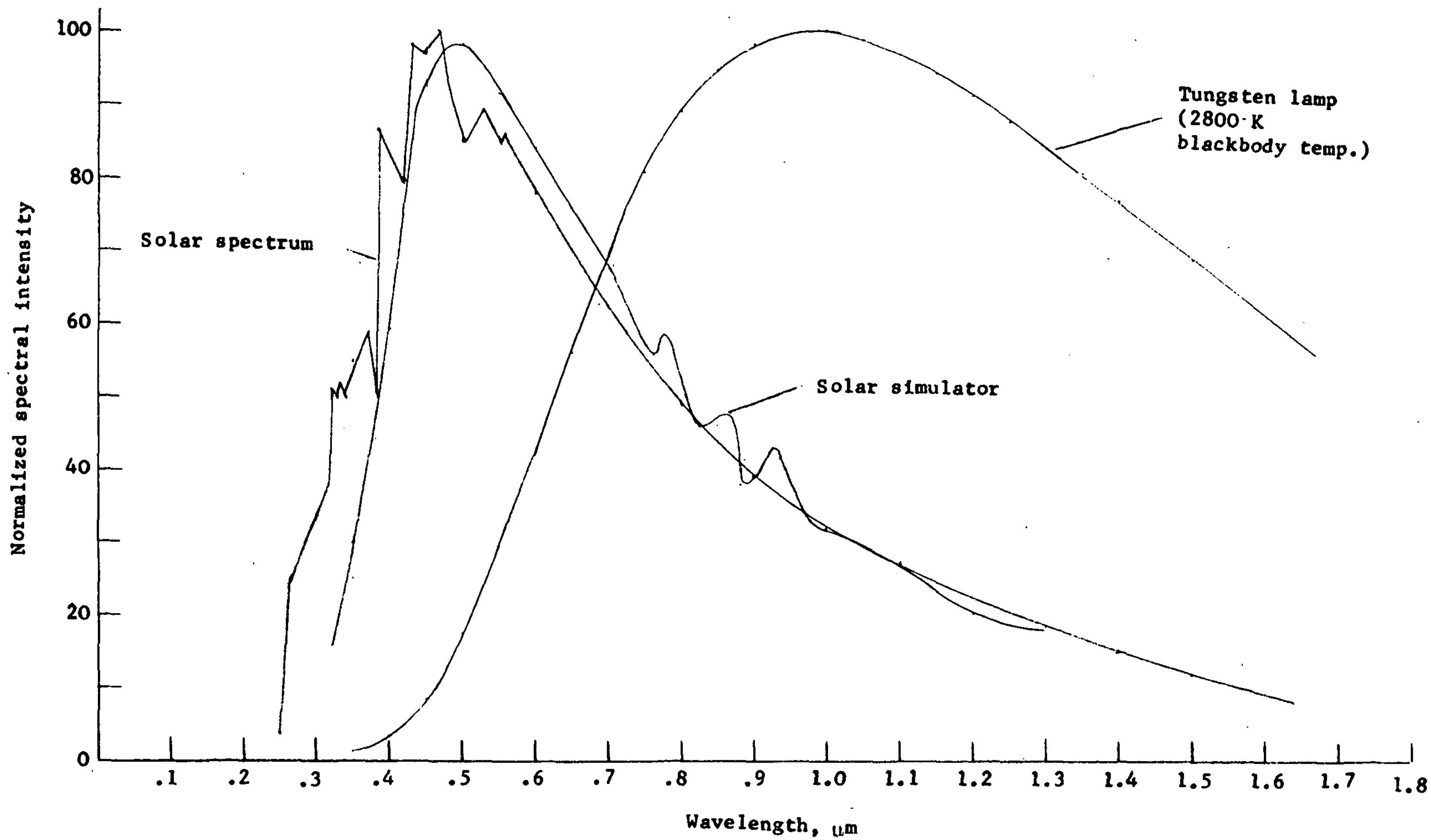

Figure 1.- Relative spectra of several light sources.

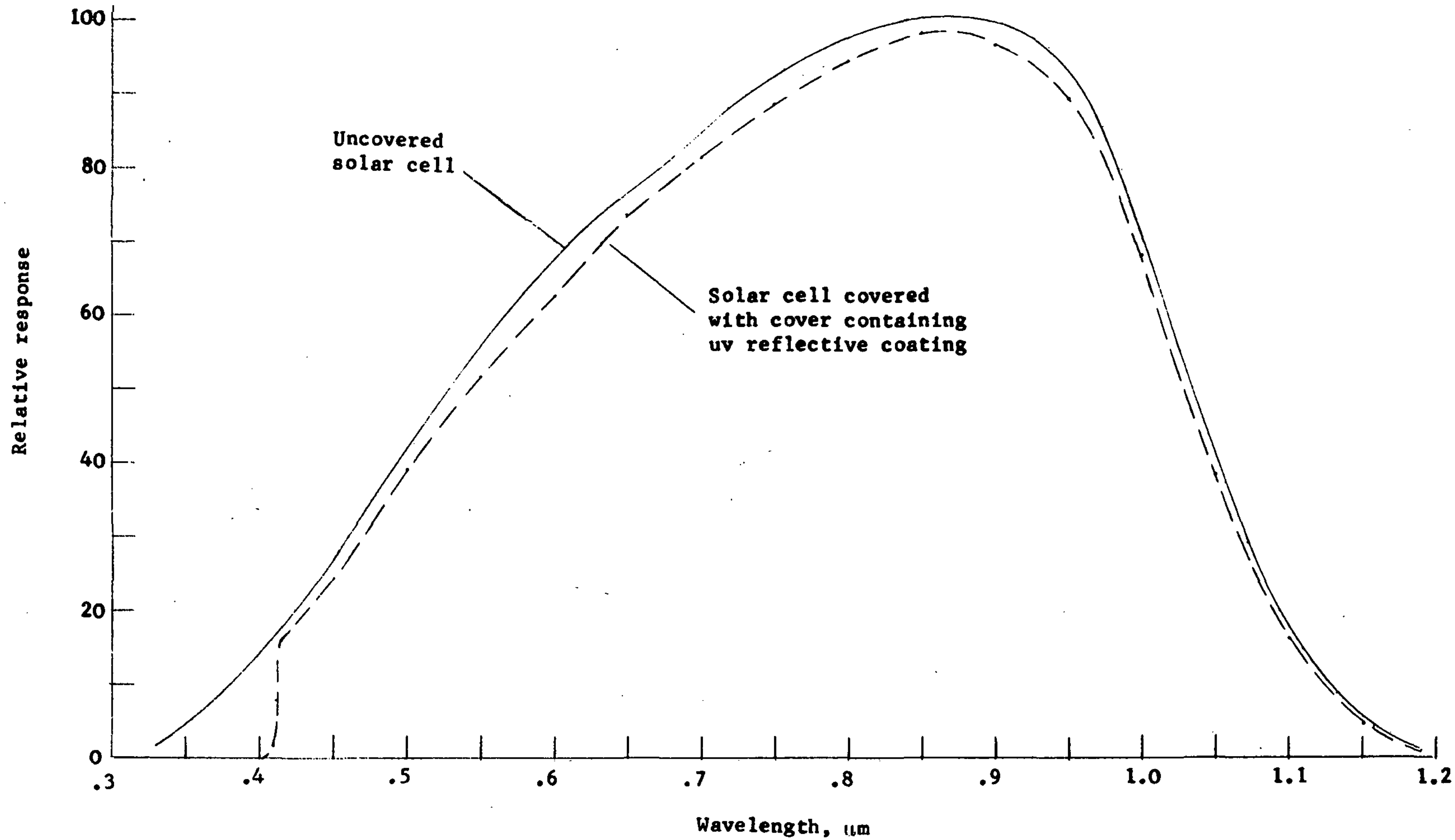

Figure 2.- Spectral response of a typical solar cell.

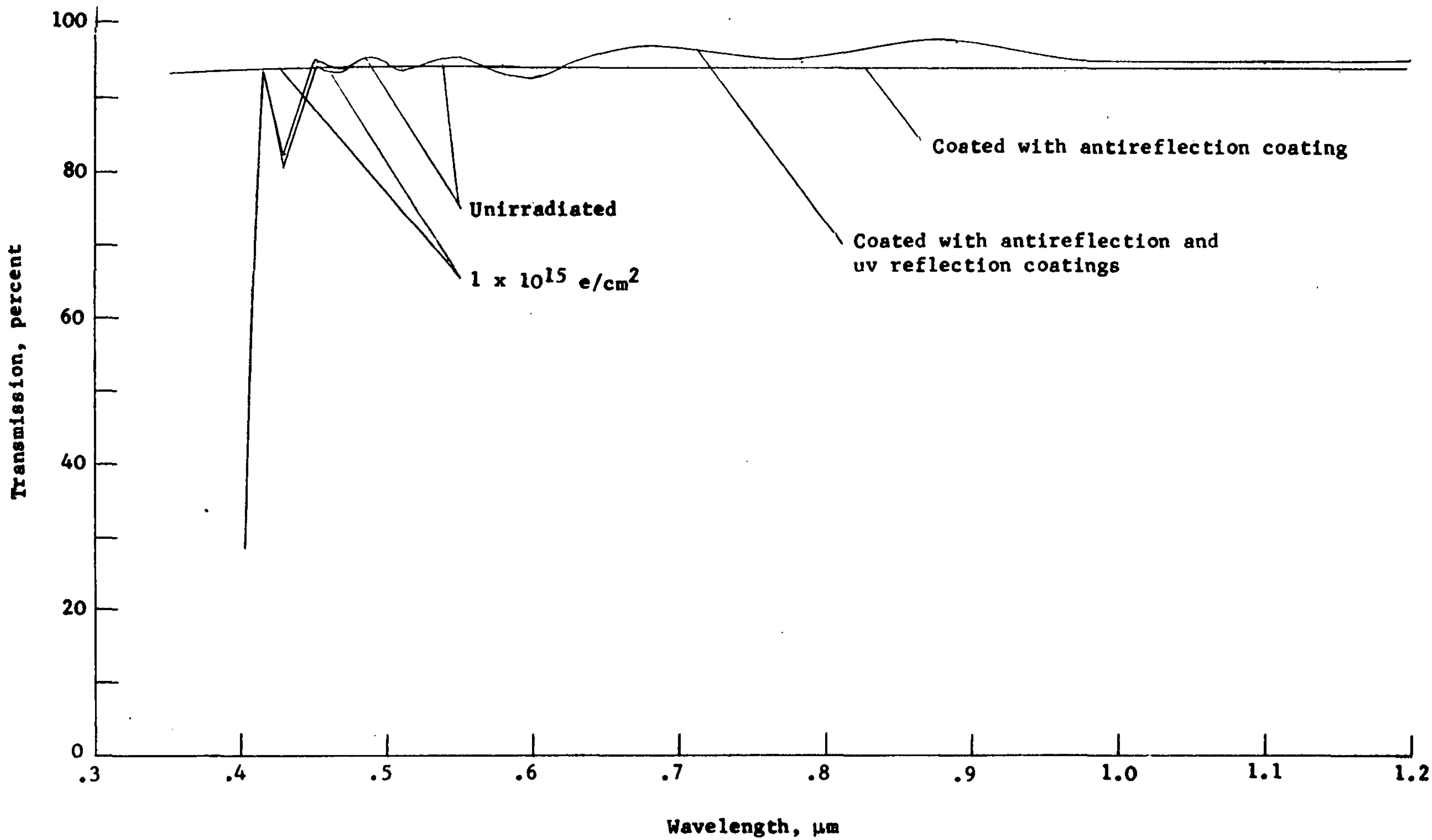

Figure 3.- Effect of 1 MeV electron radiation on the spectral transmission of synthetic fused silica samples.

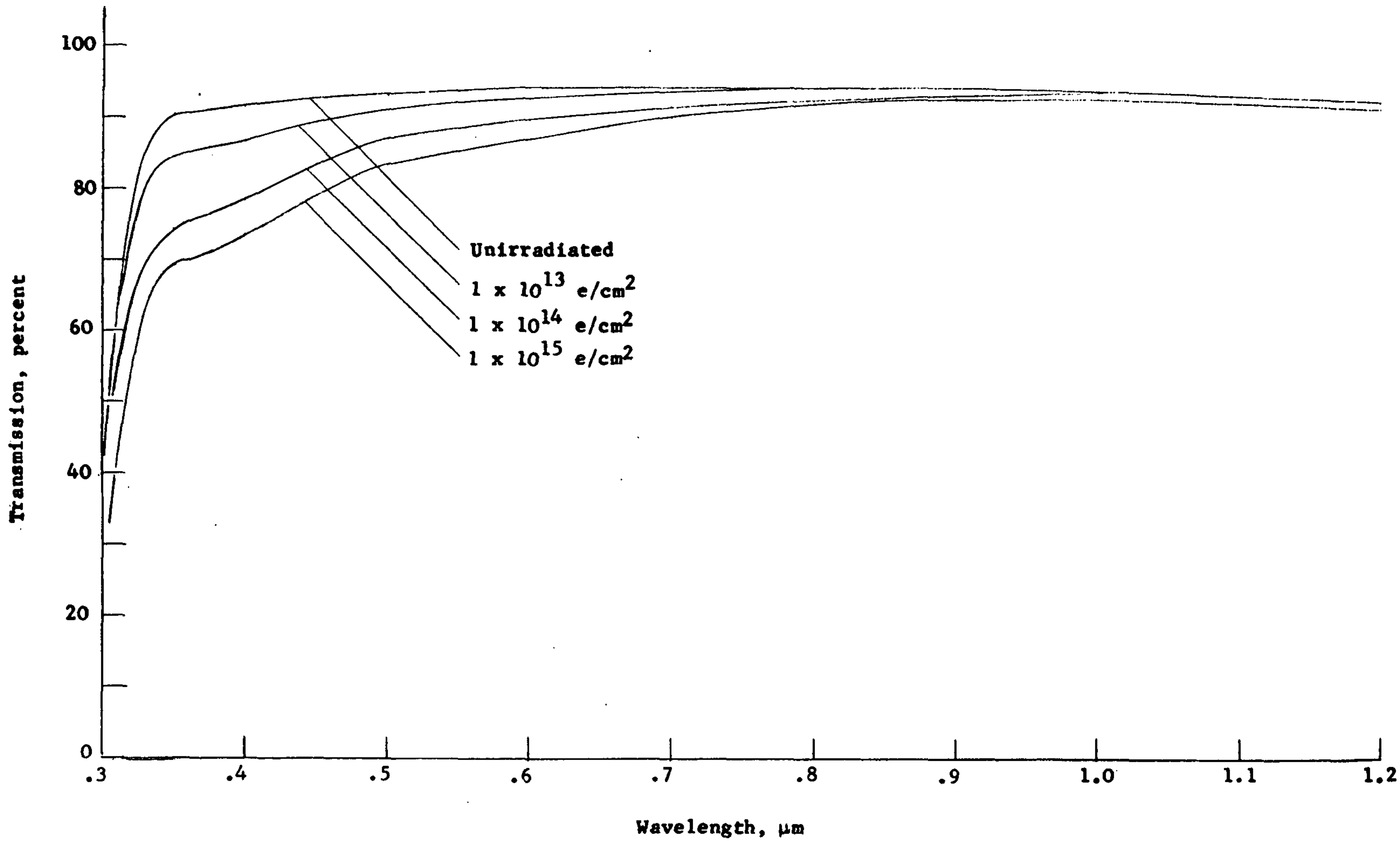

Figure 4.- Effect of 1 MeV electron radiation on the spectral transmission of undoped solar cell cover glass (Micro-Sheet). Sample coated with antireflection coating.

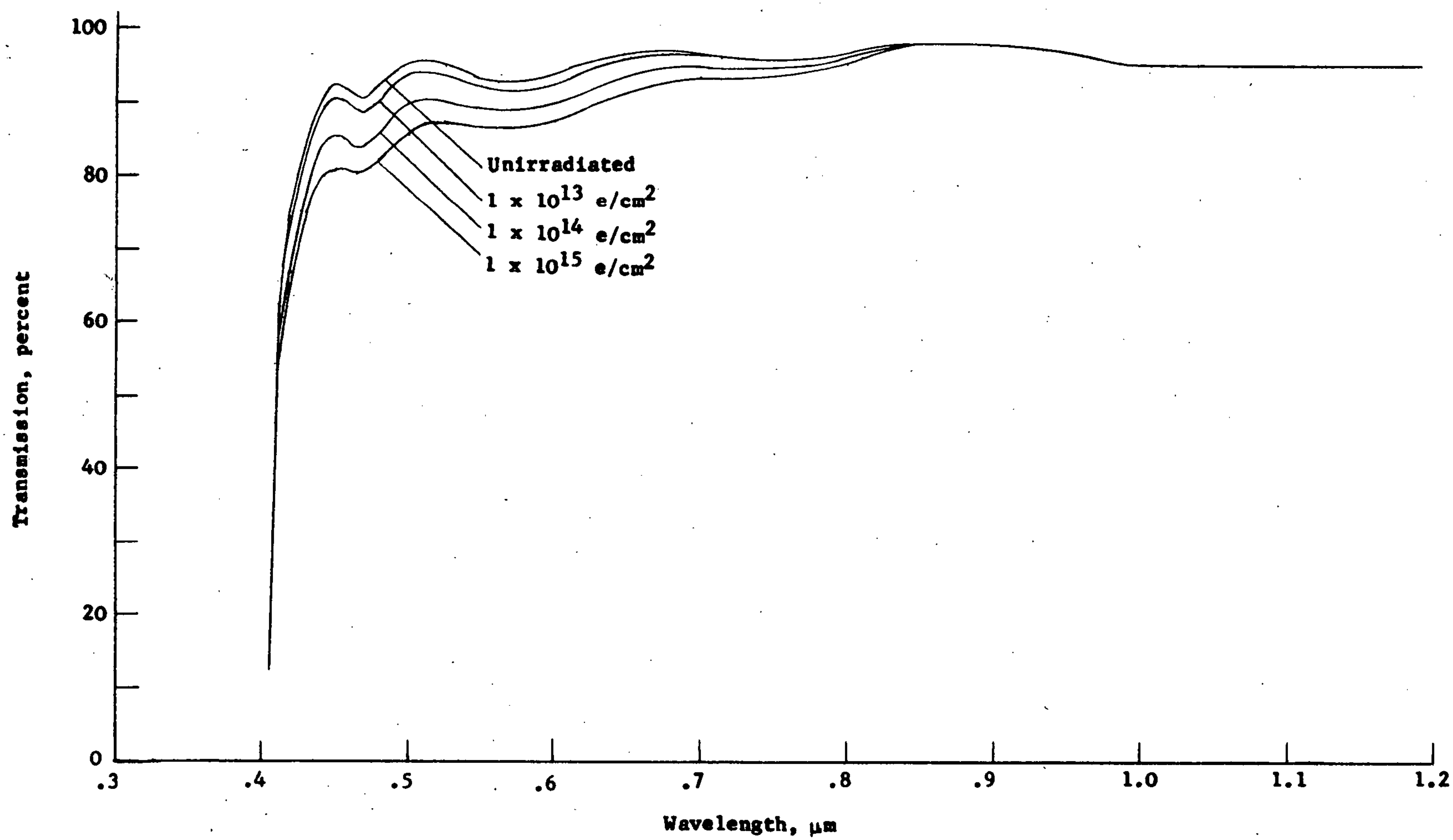

Figure 5.- Effect of 1 MeV electron radiation on the spectral transmission of undoped solar cell cover glass (Micro-Sheet). Sample coated with antireflection and ultraviolet reflection coatings.

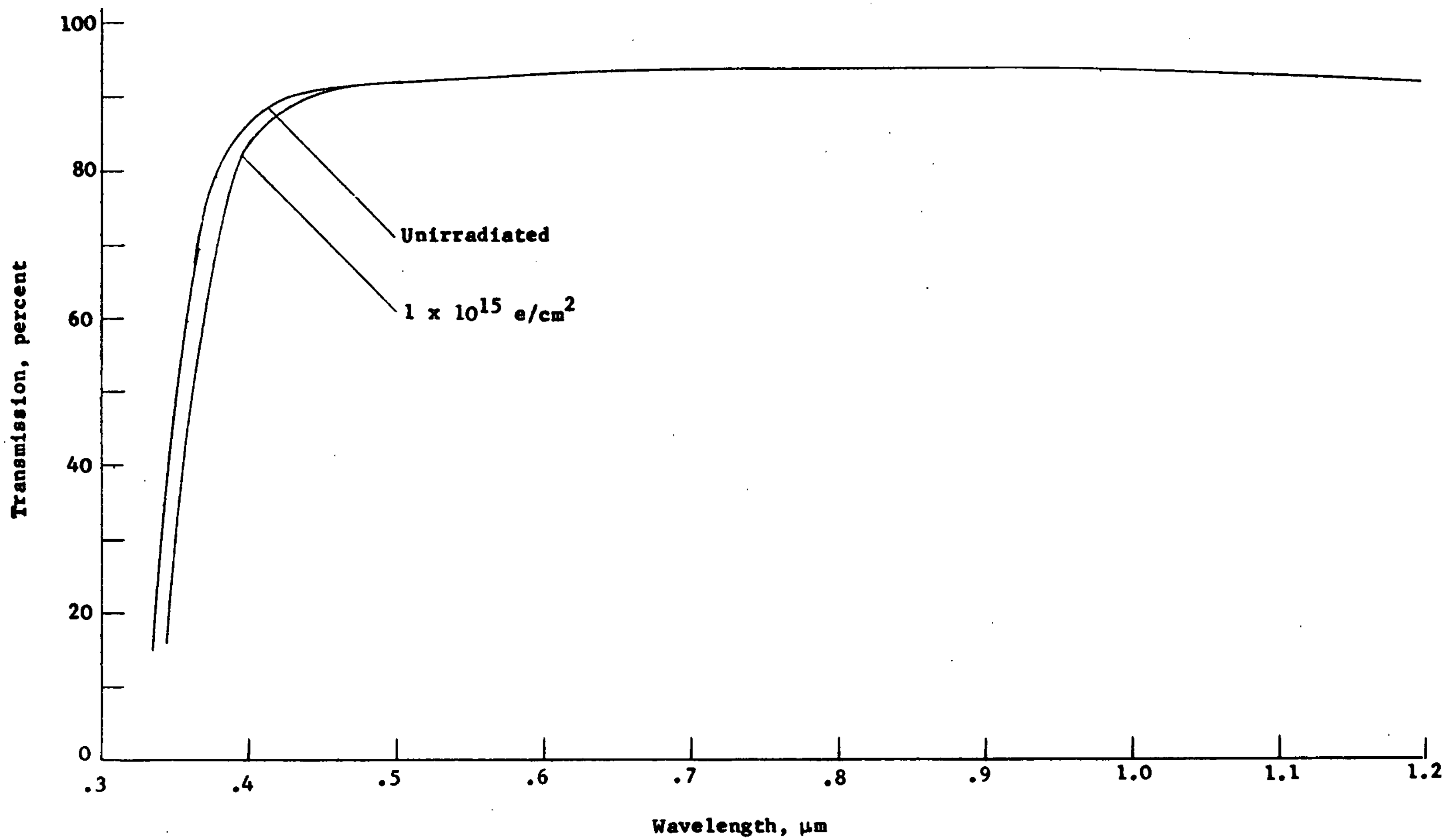

Figure 6.- Effect of 1 MeV electron radiation on the spectral transmission of 1.5-percent ceria-doped cover glass. Samples were coated with an antireflection coating.

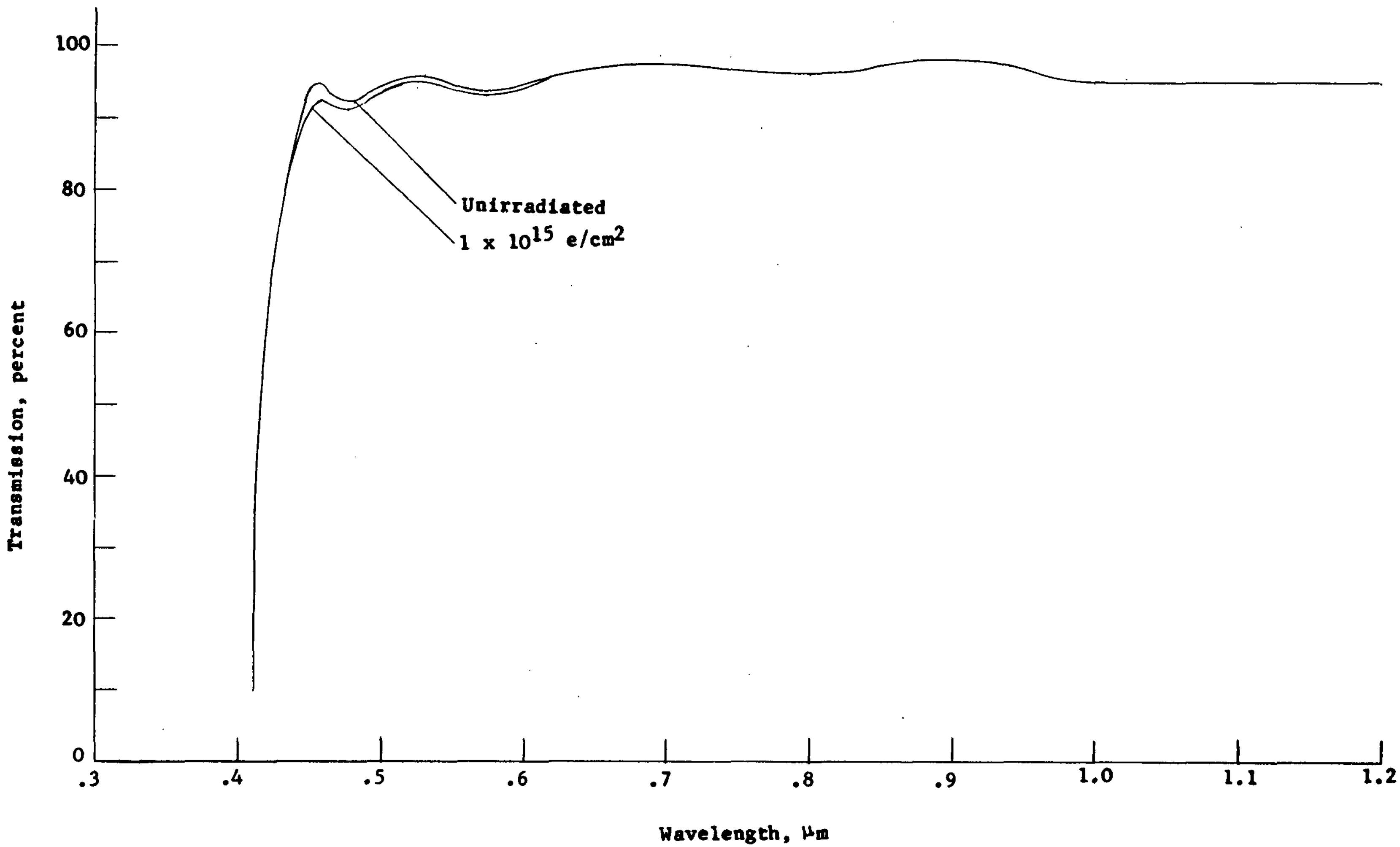

Figure 7.- Effect of 1 MeV electron radiation on the spectral transmission of 1.5-percent ceria-doped cover glass. Samples were coated with an antireflection and an ultraviolet reflection coating.

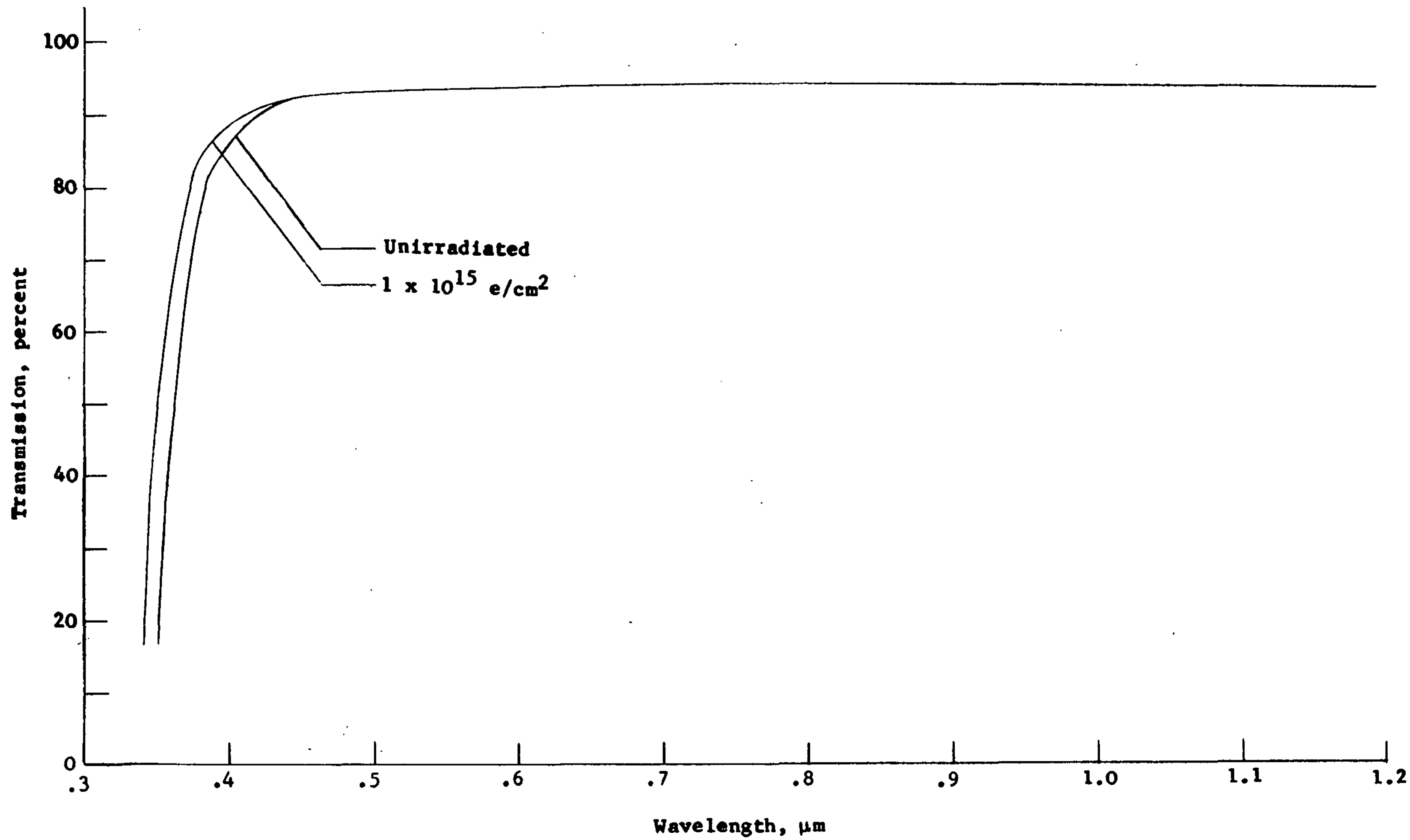

Figure 8.- Effect of 1 MeV electrons on the spectral transmission of 5-percent ceria-doped glass. Samples were 0.152 mm thick (0.006 inch) and coated with an antireflection coating.

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