

Contributed Paper

X-RAY-INDUCED PHOTOCONDUCTIVITY IN DIELECTRIC MATERIALS*

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ABSTRACT

X-ray-induced photoconductivity has been measured in low-density polyethylene, Tefzel[†] (Dupont fluorocarbon), Durasan (Dupont fluorocarbon), polychlorotrifluoroethylene (Kel-F), polystyrene, polypropylene, polyvinylidene chloride, polyvinylidene fluoride, polyvinyl chloride and mica. Dose rates varied in the range $10^9 - 5 \times 10^{10}$ rad/s. The observed photoconductivity showed no apparent dependence on the molecular structure of the materials. The photoconductivity of polyethylene and Kel-F was observed to depend on the degree of crystallinity in these materials.

INTRODUCTION

In an earlier paper¹ we reported measurements of x-ray-induced photoconductivity in six common dielectric materials. We have completed measurements on a number of additional dielectrics, and we wish to add these data to our earlier published data. The experimental procedure we used is described in detail in the earlier paper and will not be repeated here. Dose rates varied in the range $10^9 - 5 \times 10^{10}$ rad/s and were produced by a pulsed x-ray-generator from a design by Blumlein.²

The purpose of the investigation was twofold. First, we wished to study as many common dielectric materials as was conveniently possible in order to provide information useful for designing systems which must operate in a radiation environment. Whenever possible we used commercially available dielectric films. In some cases commercially produced films were not available and samples were made at Bendix Corporation, Kansas City, Mo., using commercially available resins. It is expected that the samples prepared at Bendix would correspond closely to commercial films from the same resins. Any variations should be limited to impurities either introduced by handling or carried over by solvents, rather than fundamental differences in polymerization reactions. We have listed the composition, source, and method of preparation of the films in Table I.

Our second objective was to investigate the effect of the chemical composition, molecular structure, and degree of crystallinity on the photoconductivity. We were particularly interested in investigating polymers with the same molecular structure, but

differing chemical composition, e.g., polyethylene (C_2H_4)_n, Teflon (C_2F_4)_n, polyvinyl chloride (C_2H_3Cl)_n, Kel-F (C_2F_3Cl)_n, polyvinylidene fluoride ($C_2H_2F_2$)_n, and polyvinylidene chloride ($C_2H_2Cl_2$)_n.

It is also possible, for some polymers, to vary the degree of crystallinity. This was done for Kel-F, where amorphous and partially crystalline samples were prepared from the same starting resin by controlling the rate of cooling after the material had been heated above the glassy transition temperature. Amorphous (low-density) and crystalline (high-density) polyethylene were also studied, but the low-density and high-density samples were commercial films obtained from different sources.

RESULTS AND DISCUSSION

The photoconductivity data are summarized in Table II. All of the samples exhibited a linear variation of peak photocurrent with electric field. Delayed conductivity was negligible in all but four of the materials studied. Since the dose rates in the various materials varied by over an order of magnitude, a comparison of the materials is best made by normalizing the peak conductivities to the same dose rate. Figure 1 shows the peak conductivities of all of the materials we have studied,

normalized to a dose rate of 5×10^9 rads. The data for Teflon, polyethylene, Mylar, Kapton, epoxy and borosilicate glass are from an earlier study.¹

The photoconductivity appears to depend on the degree of crystallinity of the material. The high density polyethylene (Marlex) is more crystalline than the low density polyethylene and exhibited a higher photoconductivity. The crystalline Kel-F samples showed a larger photoconductivity than the amorphous Kel-F samples. The materials which showed the highest photoconductivities were Teflon and high-density polyethylene, and these are both highly ordered materials.

We can discern no apparent dependence of photoconductivity on the molecular structure of the materials we studied. One might expect, for example, that polyvinylidene fluoride ($C_2H_2F_2$)_n would have electrical properties intermediate between Teflon (C_2F_4)_n and polyethylene (C_2H_4)_n. Polyvinylidene fluoride has a photoconductivity nearly two orders of magnitude less than either polyethylene or Teflon.

The lack of correlation between photoconductivity and molecular structure may be due to electrically active impurities in the materials studied. The presence of trapping centers in photoconductors can change the mobility of charge carrier by many orders of magnitude. If impurity centers are present in sufficient number, the material properties can be completely masked by the impurities. A high impurity level is to be expected in the materials studied because of side reactions during polymerization, end groups in the polymer chains, and as a result of impurities deliberately added to control the properties of the polymer.

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[†]Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U. S. Atomic Energy Commission to the exclusion of others that may be suitable.

Table I. Composition, source, and method of preparation of the dielectric samples. The dielectric samples were fabricated at Bendix Corporation, Kansas City, Missouri.

Material	Thickness	Composition	Source	Method of preparation
Low-density polyethylene (Visqueen)	0.050 mm	$(C_2H_4)_n$	Phillips Petroleum	Commercial film
Tefzel	0.050	$(C_4H_4F_4)_n$	Dupont Corporation	Commercial film
Durasan	0.050	$(C_4H_4F_3Cl)_n$	Dupont Corporation	Commercial film
Kel-F (Amorphous)	0.125	$(C_2F_3Cl)_n$	Shamban, Inc. (sheet made from Allied Chemical Type 22 granules)	A 0.127 mm thick strip was placed in a heated platen press for 2 min @ 250°C and 1.4×10^4 N/cm ² pressure. It was then removed from the press and cooled by immersion in water.
Kel-F (Crystalline)	0.125	$(C_2F_3Cl)_n$	Shamban, Inc. (sheet made from Allied Chemical Type 22 granules)	The procedure was the same as for amorphous Kel-F, except that the samples were cooled slowly in air after removal from the press.
Polystyrene (Type IV, Class II)	0.070-0.080	$(C_8H_8)_n$	Monsanto Corporation	Material was dissolved in toluene, then solvent cast in a polyethylene container.
Polypropylene (Profax 6523)	0.050	$(C_3H_6)_n$	Hercules Inc. (pellets)	Bars were molded from the pellets. The bars were then backed with Al foil and pressed between ferrotype plates for 10 min @ 200°C, 0.7×10^4 N/cm ² pressure.
Polyvinylidene chloride (Saran)	0.050	$(C_2H_2Cl_2)_n$	Dow Chemical Corporation	Sheet Saran was dissolved in a solution of 25% cyclohexane, 75% tetrahydrofuran. Films were solvent cast from the decanted top of the solution.
Polyvinyl chloride (Type 7042)	0.125	$(C_2H_3Cl)_n$	Ethyl Corporation, Polymer Division	Pellets were dissolved in tetrahydrofuran and allowed to stand. Films were solvent cast from the decanted top of the solution.
Polyvinylidene fluoride (Kynar, grade 300)	0.050	$(C_2H_2F_2)_n$	Penwalt Inc.	A layer of pellets was backed with Al foil on sides and pressed between ferrotype plates for 2 min @ 250°C, 3.5×10^4 N/cm ² pressure.
Mica (Muscovite)	0.037-0.063	$K_2Al_6Al_2Si_6O_{20}(OH)_4$ + impurities	Spruce Pine Mica	Commercial sheet, Victor Type I (ASTM Standard).

Table II. A summary of the photoconductivity data.

Material	Peak ^a dose rate (rad/s)	Peak conductivity (Ohm-cm) ⁻¹	Delayed conductivity ^b (Ohm-cm) ⁻¹	Decay time ^c (ns)
Low-density polyethylene	3.9×10^9	1.25×10^{-9}	2.1×10^{-10} @ 4×10^5 V/cm	~50
Tefzel	1.0×10^{10}	2.98×10^{-10}	negligible	---
Durasan	2.9×10^{10}	6.37×10^{-10}	negligible	---
Kel-F (amorphous)	3.5×10^{10}	8.82×10^{-10}	1.48×10^{-10} @ 1.8×10^5 V/cm	~50
Kel-F (crystalline)	3.5×10^{10}	1.46×10^{-9}	1.65×10^{-10} @ 2.2×10^5 V/cm	~50
Polystyrene	3.6×10^9	2.37×10^{-10}	3.45×10^{-11} @ 2.6×10^5 V/cm	~50
Polypropylene	3.3×10^9	1.02×10^{-9}	negligible	---
Polyvinylidene chloride (Saran)	6.14×10^{10}	1.29×10^{-9}	negligible	---
Polyvinyl chloride	5.1×10^{10}	6.4×10^{-10}	negligible	---
Polyvinylidene fluoride (Kynar)	9.80×10^9	1.78×10^{-10}	negligible	---
Mica	4.1×10^{10}	6.39×10^{-9}	negligible	---

^aThe dose rate normalization was from a monitor pulse that was recorded at the same time as the sample signal. The monitor pulse was calibrated to dose rate in a separate experiment, as detailed in Ref. 1.

^bDelayed conductivity was measured at the end of the radiation pulse. The electric field at which it was measured is also given, since delayed conductivity is often field-dependent.

^cDecay time is defined to be the time for the conductivity persisting at the end of the radiation pulse to decay to half its value.

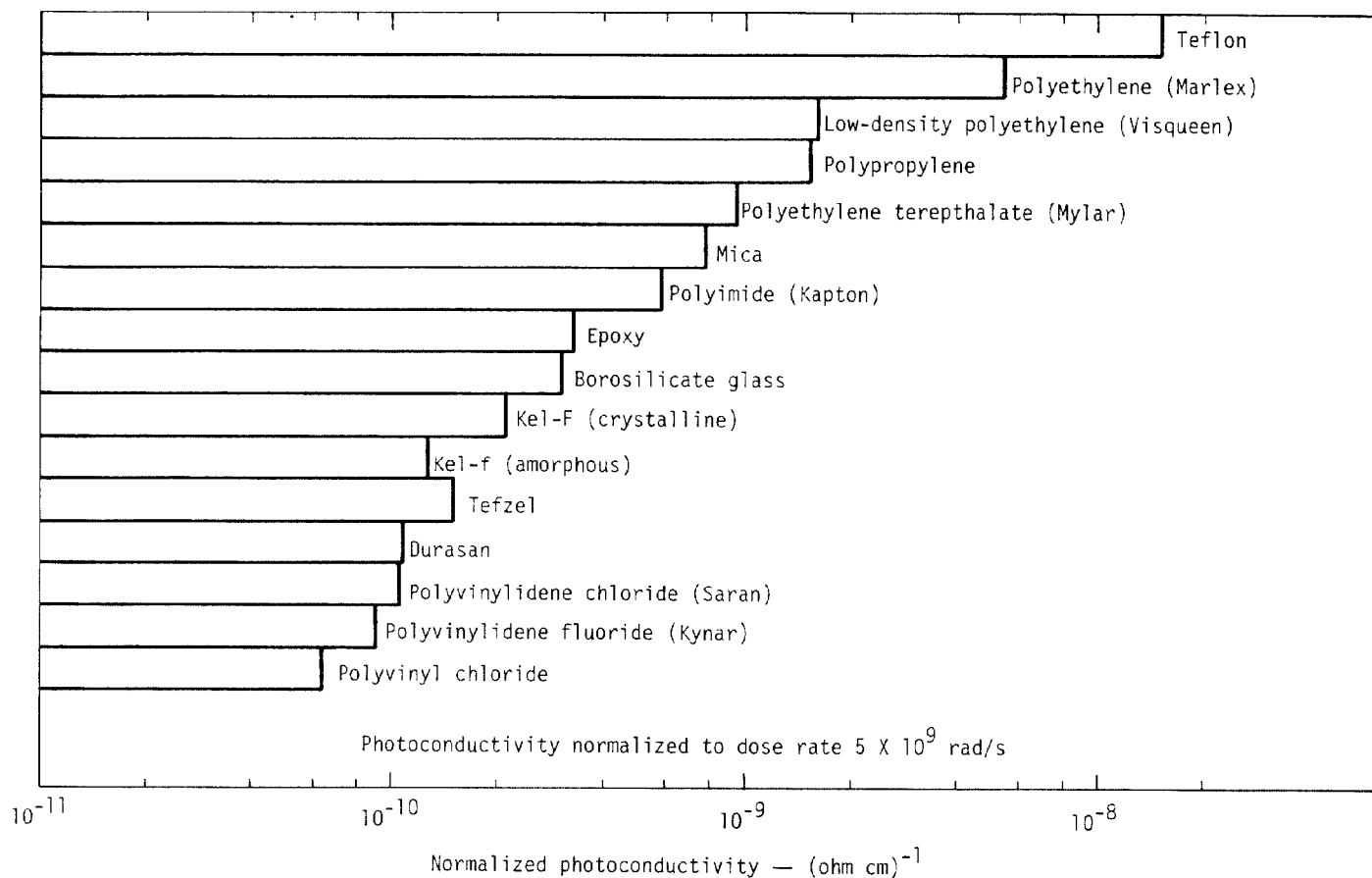


Fig. 1. Summary of peak photoconductivity data normalized to a dose rate of 5×10^9 rad/s. Data for Teflon, polyethylene, Mylar, Kapton, epoxy and borosilicate glass are from an earlier study.

References

1. R. C. Weingart, R. H. Barlett, W. W. Hofer, and R. S. Lee, IEEE Trans., Nucl. Scie. **NS-19**, 15 (1972).
2. A. Blumlein, British Patent 589127.

NOTES

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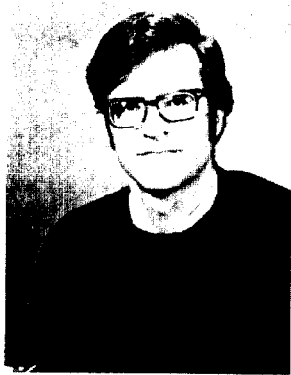
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