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CONTRACT AF 33(616)—8438
PROJECT 7381; TASK 738103



# ZINC SELENIDE

Data Sheets

M. Neuberger

DS-132
September 1963

EPIC

ELECTRONIC
PROPERTIES
INFORMATION
CENTER

HUGHES

HUGHES AIRCRAFT COMPANY
CULVER CITY, CALIFORNIA

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# FOREWORD

This report was prepared by Hughes Aircraft Company under Contract No. AF 33(616)-8438. The contract was initiated under Project No. 7381, Task No. 738103. The work was administered under the direction of the Directorate of Materials and Processes, Aeronautical Systems Division, with Mr. R.F. Klinger acting as Project Engineer.

Many persons have contributed to the program which this report represents. The author wishes especially to acknowledge the contributions of the following: J.J. Anders, J.W. Atwood, C.L. Blocher, D.L. Grigsby, J.J. Grossman, F.S. Harter, D.H. Johnson, H.T. Johnson, J.T. Milek, and E. Schafer.

## ABSTRACT

The Electronic Properties Information Center has been established to collect, index and abstract the literature on the electrical and electronic properties of materials and to evaluate and compile the experimental data from that literature. A modified coordinate index to the literature is machine stored and printed for manual use. The Center publishes data sheets, summary reports, thesauri, glossaries, and similar publications as sufficient information is evaluated and compiled. This report consists of the compiled data sheets on Zinc Selenide.

This report has been reviewed and is approved for publication.

H. Thayne Johnson

H. Thayne Johnson, Supervisor
Electronic Properties Information Center

John W. Atwood

John W. Atwood
Project Manager

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# INTRODUCTION

In June 1961, a program was initiated under the direction of the Air Force to collect, index and abstract the literature on the electrical and electronic properties of materials and to evaluate and compile the experimental data from that literature. Placed at Hughes Aircraft Company in Culver City, California, the program, now called the Electronic Properties Information Center, was originally intended to cover ten major categories of materials: Semiconductors, Insulators, Ceramics, Ferroelectrics, Metals, Ferrites, Electroluminescent Materials, Ferromagnetics, Thermionic Emitters, and Superconductors.

During the first year, studies were completed on the Semiconductor and Insulator categories; and Ceramics was discontinued as a separate category and subsumed under the other nine. Vocabulary studies have now been completed on all categories, and retrospective documentation is virtually complete for Semiconductors and Insulators. A full index to the literature is maintained; and publications such as data sheets, summary reviews, glossaries, and thesauri are periodically issued. The use of the Center and these publications are available to anyone wishing information within the scope of the Center's objectives. A full list of publications to date appears at the end of this report.

This report contains data sheets on Zinc Selenide. The data sheets have been compiled direct from the literature. Articles are allowed to accumulate in the system until it is judged that a sufficient number are available on one material for adequate evaluation. The manual modified coordinate index is then used to retrieve all literature on the material to be compiled. Bibliographies are checked to make sure that valuable and relevant literature is not overlooked. Then the assembled literature is given to the specialist doing the evaluation and compilation.

Evaluation is confined to primary source data except when only secondary citations are available. If equally valid data are available from several sources, all are given. Data are rejected when judged questionable because of faulty or dubious measurements, unknown sample composition, or if more reliable data are available from another source. Selection of data is based upon that which is judged most representative, precise, reliable, and covers the widest range of variables. The addition of new data to a previously evaluated property requires a reappraisal of the reported values. Older data may be deleted if the new data are judged more accurate or representative.

After a thorough analysis and evaluation, the data are compiled into data sheets which present it in its most optimum form. This will be, primarily, but not limited to, curves or tabular form. Where possible, graphs are adapted directly from the original sources. If this is not possible, they are drawn from data compiled from the articles. Where thought important, notes are entered with each graph to help the user. The references, from which the data are drawn, are shown by reference number below each graph with the full bibliographic information at the end of the data sheets. The bibliography is referred to and listed in the order of entry into the Center (accession number). This provides a quick cross reference into the index used with the literature.

DATA SHEET

ELECTRICAL AND ELECTRONIC PROPERTIES

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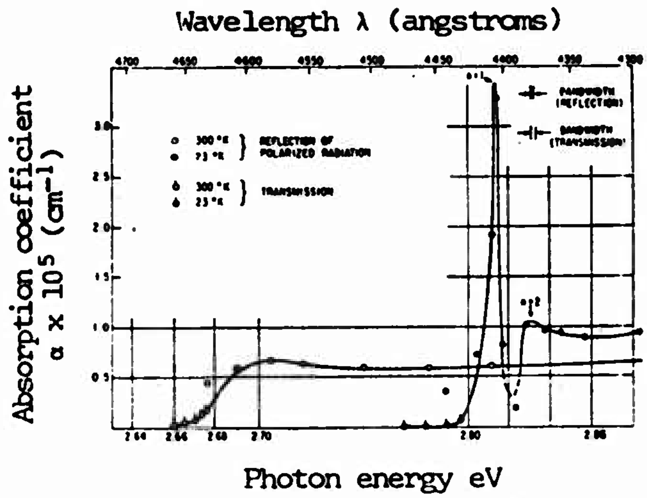
# SEMICONDUCTOR MATERIALS

September 1963

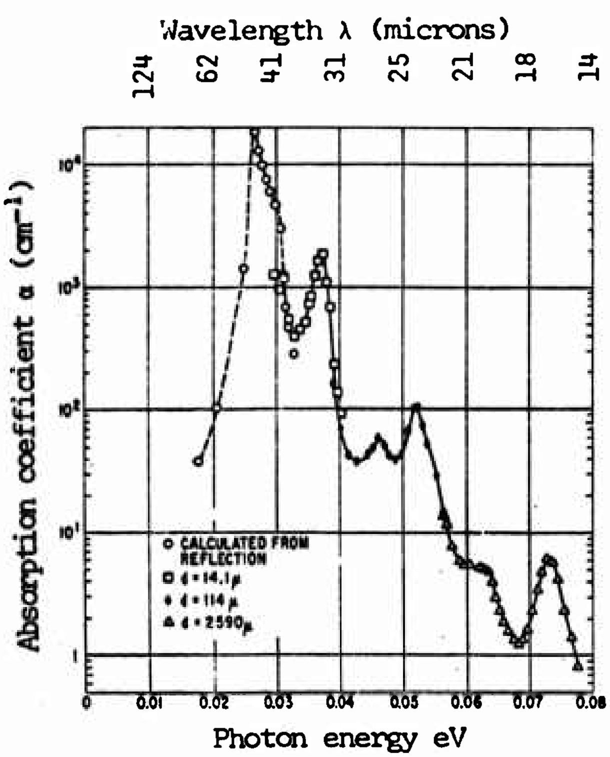
ZINC SELENIDE

## Absorption

Absorption coefficient for single crystal zinc selenide in the absorption edge region as a function of photon energy at 300°K and 23°K.




[Ref. 2618]



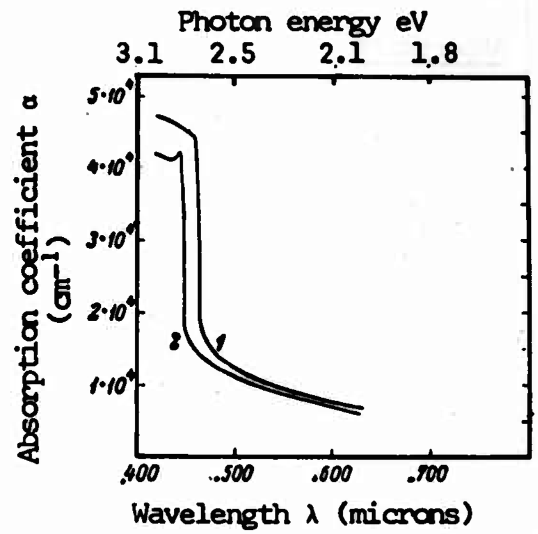

Absorption coefficient for single crystal zinc selenide in the infrared region as a function of photon energy at 300°K.

[Ref. 2618]

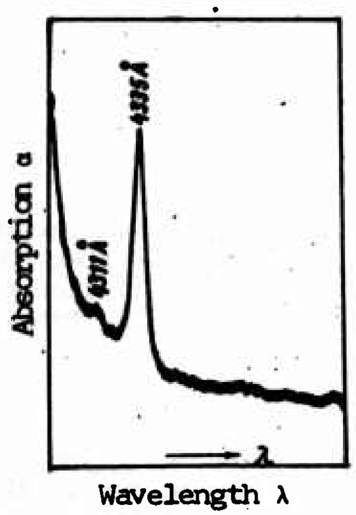
ZINC SELENIDE

__Absorption__

Spectral distribution curves for the absorption coefficient of intrinsic, polycrystalline zinc selenide films, 0.2-2μ thick. 1) at 393°K; 2) at 77°K.




[Ref. 690]




A microphotometer trace of the spectrum for absorption as a function of wavelength of single crystal, hexagonal zinc oxide. The sample is rotated in the extraordinary ray.
Absorption edge for a 10μ thick sample
α = .4356μ for polarized light normal to c-axis
α = .4292μ for polarized light parallel to c-axis

[Ref. 5942]

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# SEMICONDUCTOR MATERIALS

September 1963

## ZINC SELENIDE

### Absorption

Positions and polarizations of the A, B, and C exciton lines found in the spectra of single crystal, hexagonal zinc selenide at 4.2°K.

| | Position | Polarization |
|---|---|---|
| A | 4335 Å | $E_{\perp}c$ |
| B | 4311 Å | $E_{\perp}c$ |
| C | 4237 Å | $E_{\parallel}c$ |

Magnitudes of the valence band splitting energies $E_{AB}$ and $E_{AC}$.

| $E_{AB}$ | $E_{AC}$ |
|---|---|
| 0.016eV | 0.066eV |

[Ref. 5942]

Wavelengths of spectral lines in edge emission spectrum of single crystal, cubic zinc selenide at 4.2°K and 77°K, type I crystals.*

| Wavelengths at 4.2°K (A) | Wavelengths at 77°K (A) |
|---|---|
| $L_1$—4410 | $N_1$—4421 |
| $L_2$—4420 | $N_2$—4436 |
| $L_2'$—4424 | |
| $L_3$—4448 | |
| $L_3'$—4454 | |
| $L_{3a}$—4499 | |
| $L_{3b}$—4551 | |
| $L_{3c}$—4602 | |
| $L_{3d}$—4654 | |
| $L_{3e}$—4712 | |

| Wavelengths at 4.2°K (A) | Wavelengths at 77°K (A) |
|---|---|
| $L_1$—4420 | $N_1$—4388 |
| $L_2$—4427 | $N_8$—4590 |
| $L_3$—4437 | $N_{10}$—4638 |
| $L_4$—4453 | |
| $L_5$—4488 | |
| $L_6$—4506 | |
| $L_7$—4512 | |
| $L_8$—4548 | |
| $L_9$—4558 | |
| $L_{10}$—4598 | |
| $L_{10a}$—4655 | |
| $L_{10b}$—4712 | |
| $L_{10c}$—4770 | |
| $L_{10d}$—4832 | |

Wavelengths of spectral lines in edge emission spectrum of single crystal, cubic zinc selenide at 4.2°K and 77°K, type II crystals.*

*The two types of crystals may be due to different host lattice defects.

[Ref. 2500]

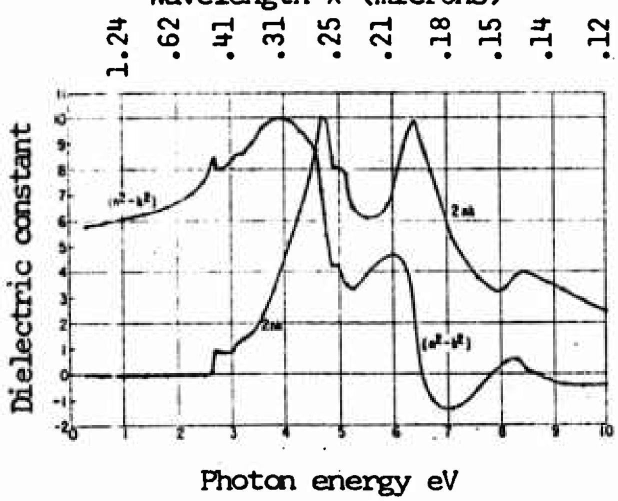
ZINC SELENIDE

**Debye Temperature**

| Symbol | Value | Type | Temperature | Ref. |
|---|---|---|---|---|
| $\theta_D$ | 400°K | polycrystalline | 80°K | 3030 |

**Dielectric Constant**

| Symbol | Value | Type | Temperature | Ref. |
|---|---|---|---|---|
| $\varepsilon_o$ | 9.1 | single crystal, cubic | 298°K | 10288 |
| $\varepsilon_o$ | 8.1±0.3 | single crystal | 300°K | 2618 |
| $\varepsilon_\infty$ | 5.75±0.1 | single crystal | 300°K | 2618 |




Real and imaginary parts of the dielectric constant, $(n^2-k^2)$ and 2nk, respectively, for single crystal zinc selenide as a function of photon energy at 300°K. n = refractive index; k = extinction coefficient; n and k are calculated from optical data.

[Ref. 2618]

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## SEMICONDUCTOR MATERIALS

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ZINC SELENIDE

### Effective Mass

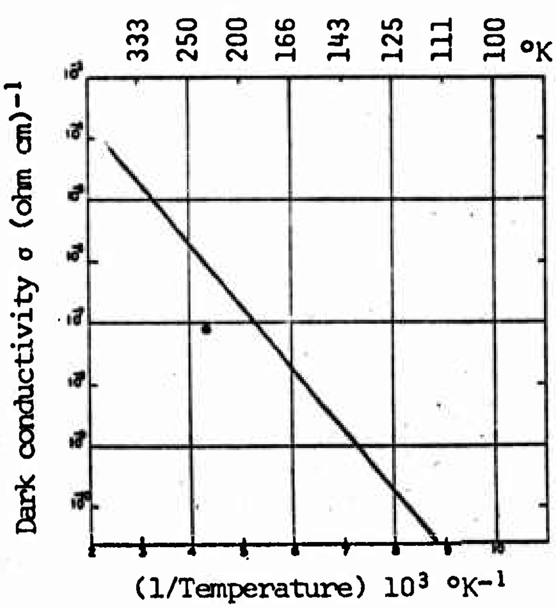
| Symbol | Value | Type | Test Conditions |
|---|---|---|---|
| $m^*_n$ | $\sim 0.1\ m_o$ | single crystal, n- and p-type | optical measurement, 300°K |
| $m^*_p$ | $\sim 0.6\ m_o$ | single crystal, n- and p-type | optical measurement, 300°K |

[Ref. 2618]

### Electrical Conductivity

| Symbol | Value $(\text{ohm cm})^{-1}$ | Dopant | Temperature | Test Conditions |
|---|---|---|---|---|
| $\sigma$ | $4 \times 10^{-2}$ | bromine, arsenic | 300°K | single crystal, dark conductivity |
| $\sigma$ | $7 \times 10^{-6}$ | bromine, antimony | 300°K | single crystal, dark conductivity |

[Ref. 780]




Dark conductivity as a function of temperature for single crystal zinc selenide doped with bromine and antimony.

[Ref. 780]

## SEMICONDUCTOR MATERIALS

September 1963

ZINC SELENIDE

### Electrical Resistivity

| Symbol | Value | Type | Temperature | Ref. |
|---|---|---|---|---|
| $\rho$ | $10^8$ to $10^9$ ohm cm | 0.2 to 2μ thick films polycrystalline, pure | 300°K | 690 |

### Electroacoustic Properties

| Symbol | Value | Type | Temperature | | Ref. |
|---|---|---|---|---|---|
| LO | 0.031 eV | single crystal | 300°K | optical data | 2618 |
| TO | 0.026 eV | | | | |
| LO | 0.03 eV | | 4.2°K | optical data | 2500 |
| TO | 0.027 eV | | | | |

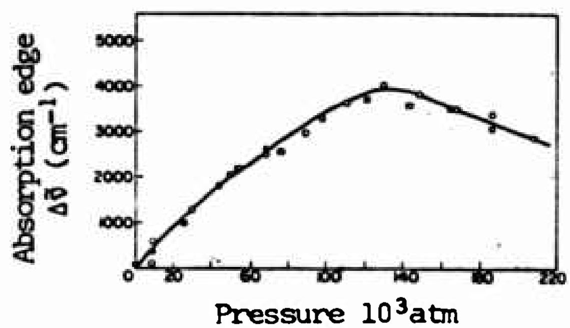
### Energy Bands

| Symbol | Value | Temperature | Test Conditions |
|---|---|---|---|
| dEg/dP | $6.0 \times 10^{-6}$ eV/atm | 300°K | single crystal, pure, experimental wave-length, λ= .481μ [Ref. 273] |
| | $0.49 \times 10^{-6}$ eV/atm (maximum shift) | 300°K | |
| | $-2.0 \times 10^{-6}$ eV/atm | 300°K | |
| dEg/dT | $7.2 \times 10^{-4}$ eV/°K | 90 - 400°K | single crystal, pure [Ref. 826] |

ZINC SELENIDE

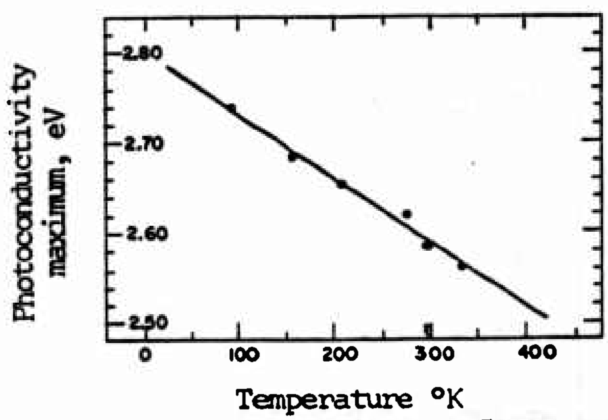
Energy Bands

Shift of zinc selenide absorption edge with pressure ($\nu_0$ = 20,800 cm$^{-1}$, $\alpha$ = 65 cm$^{-1}$).
Samples are single crystal, pure.




[Ref. 273]

The location of the photoconductivity maximum (or maxima) as a function of temperature for single crystal zinc selenide.




[Ref. 826]

ZINC SELENIDE

### Energy Gap

| Symbol | Value | Type | Temperature | Ref. |
|---|---|---|---|---|
| $E_g$ | 2.9 (calc.)<br>2.59<br>2.47<br>2.38 | polycrystalline film, zincblende symmetry, 1μ film, optical-absorption measurement | 0°K<br>295°K<br>398°K<br>496°K | 10250 |
| $E_g$ | 2.67 | single crystal | 297°K | 5201 |
| $E_g$ | 2.6 | polycrystalline film | 300°K | 7174 |
| $E_g$ | 2.786 | polycrystalline film | 77.3°K | 634 |
| $E_g$ | 2.81±0.01 | single crystal electro-optical | 4°K | 2618 |
| $E_g$ | 2.83 | cubic | 4.2°K | 2500 |

### Energy Levels

| Symbol | Value (eV) | Dopant | Type | Ref. |
|---|---|---|---|---|
| $E_D$ | 0.21 | Bromine | single crystal | 780 |
| $E_A$ | 0.6 | Copper | single crystal | 780 |
| $E_A$ | 0.6 | Silver | single crystal | 780 |
| $E_A$ | 0.7 | Antimony | single crystal | 780 |

Energy gaps calculated from reflectance data. Double entries correspond to peaks split by spin-orbit interaction. Sample is single crystal. Temperature = 300°K.

| Energy transitions | $L_{3'} \to L_1$ | $L_{3'} \to L_3$ | $X_4 \to X_1$<br>$X_5 \to X_1$ | $X_5 \to X_3$(?) |
|---|---|---|---|---|
| | 4.9<br>5.3 | 9.1<br>9.6 | 6.7 | 8.5 |

[Ref. 5949]

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### Energy Levels

Transitions at the L-absorption edge showing spin orbit splitting of the $L_3$ valence band in thin film zinc selenide, cubic sample.

| Value (eV) | Temperature (°K) |
|---|---|
| 4.94 | 20 |
| 4.92 | 78 |
| 4.89 | 200 |
| 4.80 | 297 |

[Ref. 2850]

Exciton absorption peaks associated with valence and conduction bands at $\Gamma$ for single crystal zinc selenide at 4°K. Principal peak at 2.81 ± 0.01 eV.

| | 1st. peak at $\Gamma$ | 2nd. peak at L |
|---|---|---|
| Exciton transition | 2.7 eV | 4.75 eV |
| Interband transition | 3.15 eV | 5.1 eV |
| Spin orbit valence-band split | 0.45 eV | 0.35 eV |

[Ref. 2618]

### Mobility

| Symbol | Value | Type | | Ref. |
|---|---|---|---|---|
| $\mu_n$ | 530 $cm^2(Vsec)^{-1}$ | single crystal, n-type, $\rho$=1 ohm cm | 300°K | 5954 |
| $\mu_n$ | ∿ 100 $cm^2(Vsec)^{-1}$ | | 300°K | 2911 |

| Material | Temp. range (°C) | Mobility ($cm^2$/v-sec) Electrons | Holes | Carrier concentration ($cm^{-3}$) 27°C | 200°C |
|---|---|---|---|---|---|
| ZnSe:Cu | 200–400 | | 11 | ... | $10^{10}$ |
| ZnSe:Cu, Se-fired | 130–260 | | 16 | ... | $10^{11}$ |
| ZnSe, Se-fired | 200–400 | | 15 | ... | $10^{10}$ |
| ZnSe:Ga | 27–400 | 80 | | $10^{6}$ | ... |
| ZnSe:Ga, Zn-fired | 27 | 150 | | $10^{15}$ | ... |
| ZnSe, Zn-fired | 27–250 | 260 | | $10^{16}$ | ... |

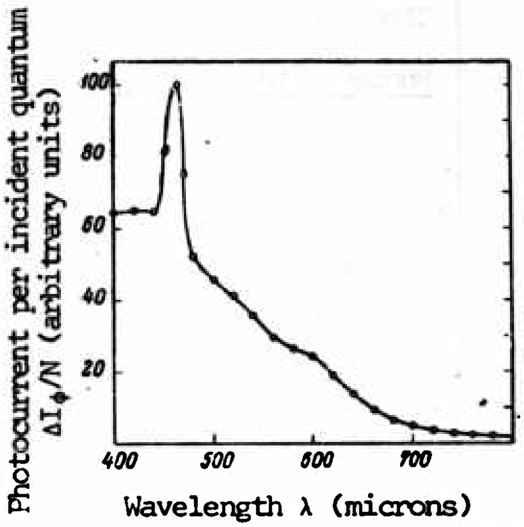
Mobility and carrier concentration for single crystal zinc selenide, variously doped at temperatures from 300°K to 673°K.

[Ref. 2618]

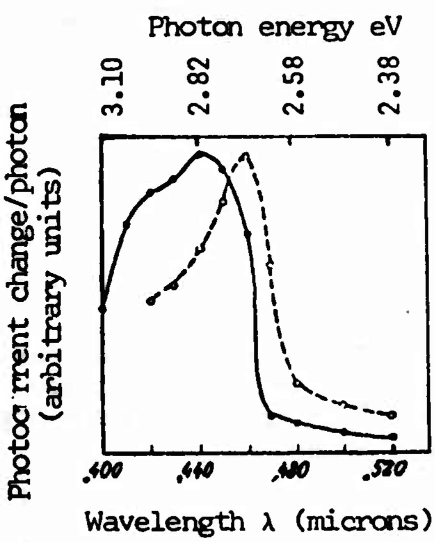
ZINC SELENIDE

### Photoelectronic Properties

Spectral distribution curves for the photoconductivity of intrinsic, polycrystalline zinc selenide films, 0.2 - 2μ thick at 300°K.

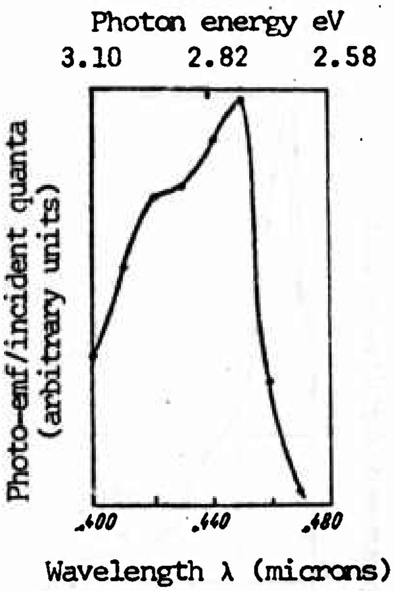



[Ref. 690]




Decrease in electrical conductivity on illumination in a polycrystalline zinc selenide film. The broken curve indicates photoconductivity.

[Ref. 622]



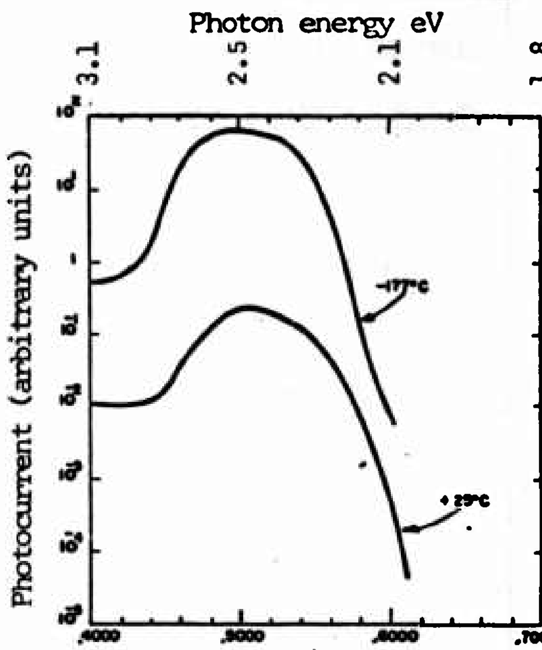

The photo-emf response spectrum of a polycrystalline zinc selenide sample.

[Ref. 622]

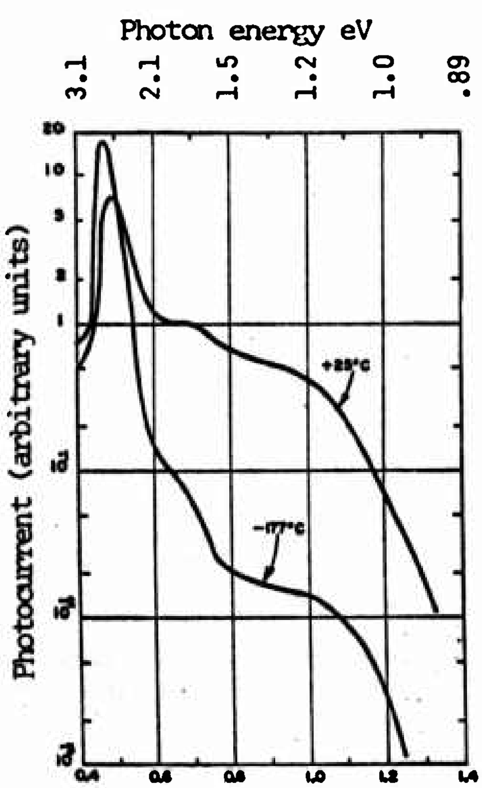
ZINC SELENIDE

Photoelectronic Properties

Spectral response curves for photoconductivity in single crystal, bromine-silver-doped zinc selenide.




[Ref. 780]




Spectral response curves for photoconductivity in single crystal, bromine-antimony-doped zinc selenide.

[Ref. 780]

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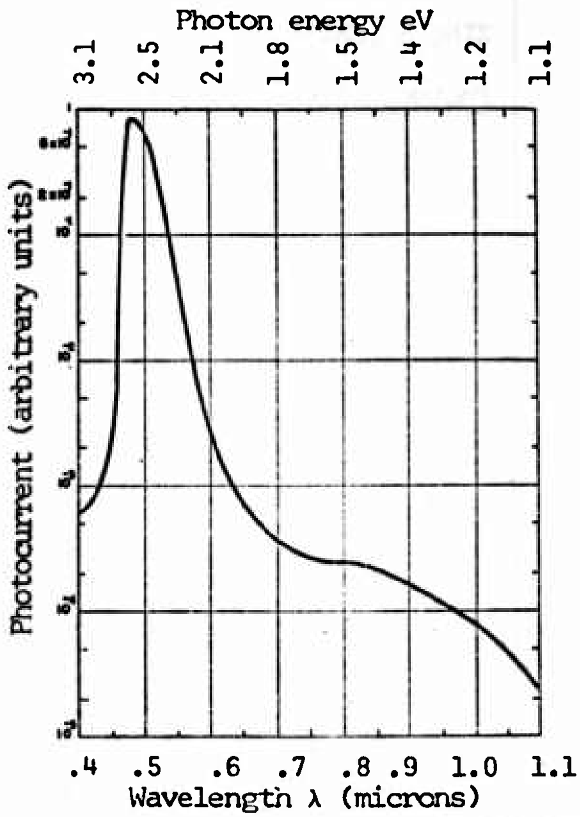
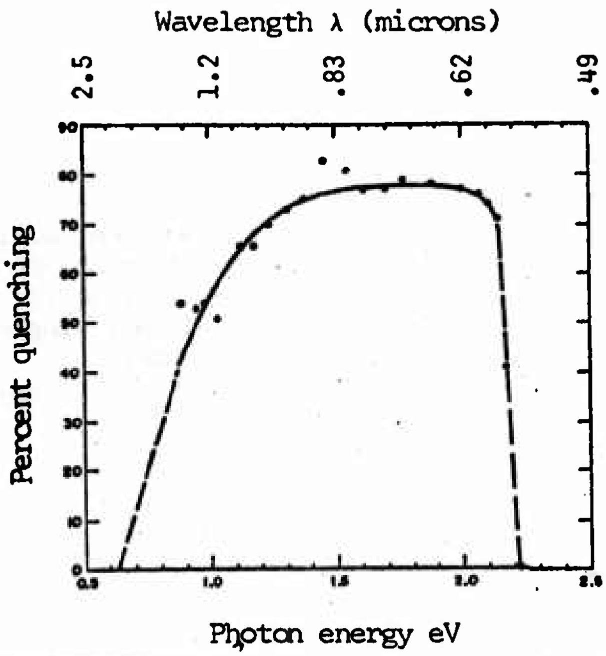
Photoelectronic Properties




Spectral response curve for photoconductivity in single crystal, bromine-arsenic-doped zinc selenide.

[Ref. 780]

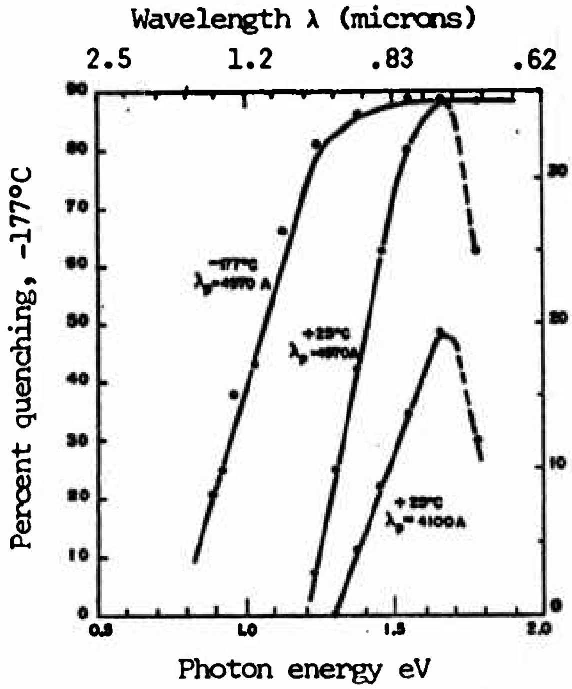



Infrared quenching spectrum for single crystal, bromine-copper-doped zinc selenide at 50°K.

[Ref. 780]

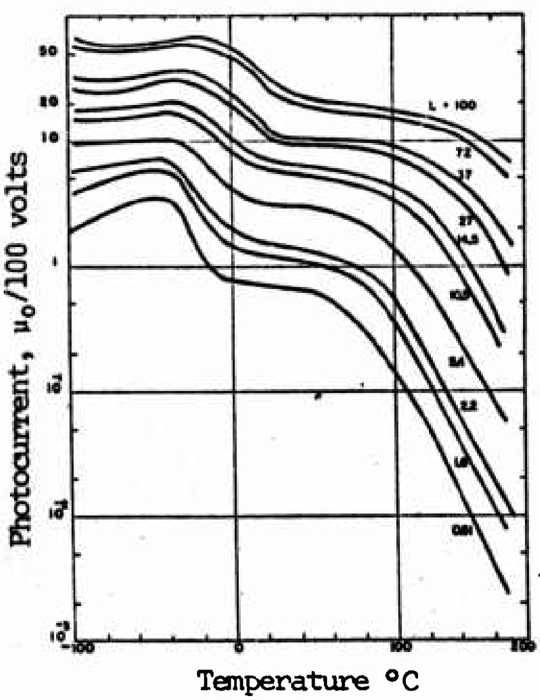
ZINC SELENIDE

Photoelectronic Properties




Infrared quenching spectra for single crystal, bromine-antimony-doped zinc selenide.

[Ref. 780]




Variation of photocurrent with temperature for different photo-intensities of excitation for bromine-antimony-doped, single crystal zinc selenide.

[Ref. 780]

# SEMICONDUCTOR MATERIALS

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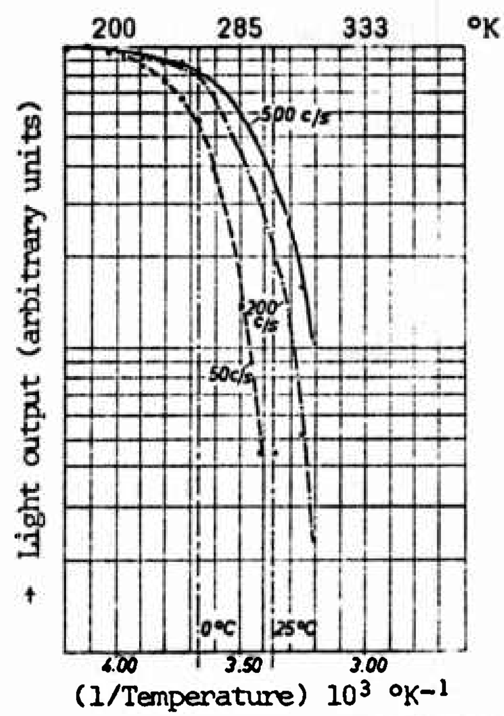
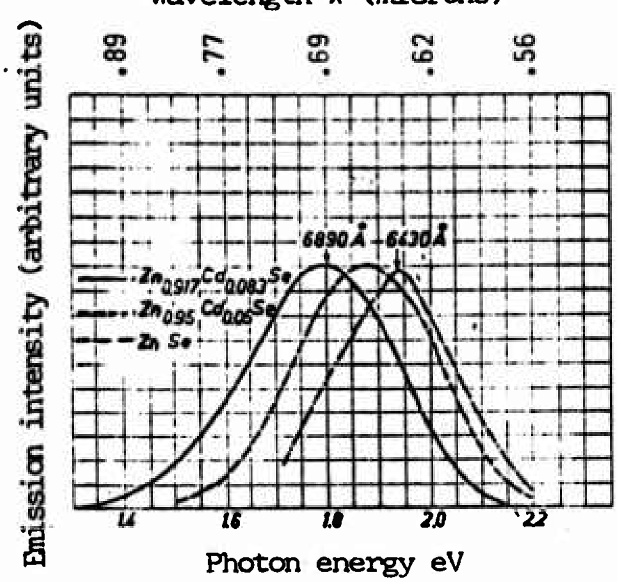
ZINC SELENIDE

## Photon Electroluminescence

Photon Electroluminescence: light output as a function of temperature for a copper-aluminum-doped zinc selenide red phosphor.




[Ref. 6458]




Emission intensity as a function of wavelength for a copper-aluminum-doped zinc selenide red phosphor and a mixed zinc cadmium selenide phosphor.

[Ref. 6458]

## SEMICONDUCTOR MATERIALS

September 1963

ZINC SELENIDE

### Piezoelectric Properties

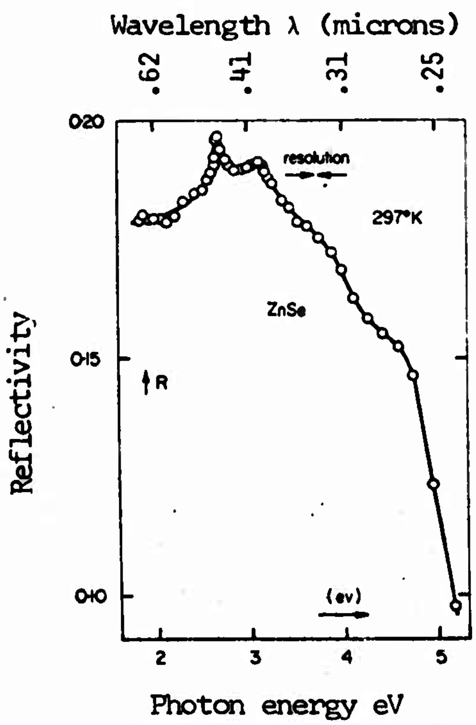
| Symbol | Value | Type | Temperature | Ref. |
|---|---|---|---|---|
| $d_{31}$ | $0.31 \times 10^{-12}$ | single crystal, cubic | 298°K | 10288 |
| $d_{14}$ | $1.10 \times 10^{-12}$ | single crystal, cubic | 298°K | 10288 |

### Reflectivity

| | Type | Temperature |
|---|---|---|
| Maximum reflectivity at .4242μ | single crystal, hexagonal | 4.2°K |
| Minimum reflectivity at .4232μ | single crystal, hexagonal | 4.2°K |

(polarized light parallel to c-axis)

[Ref. 5942]




Reflectivity spectrum of single crystal, cubic zinc selenide as a function of wavelength at 297°K.

[Ref. 3935]

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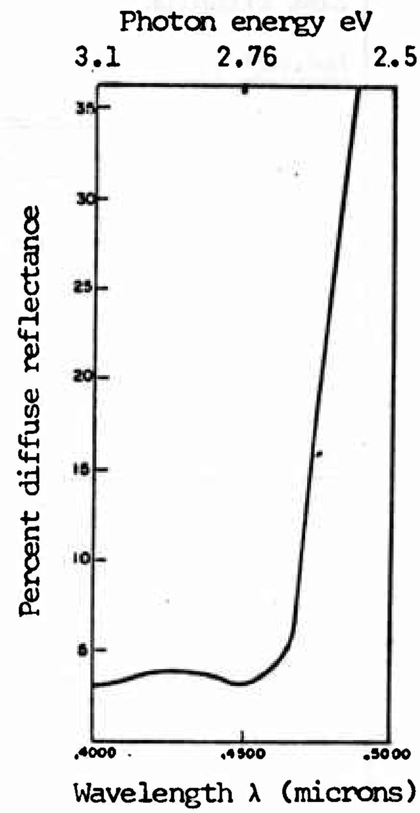
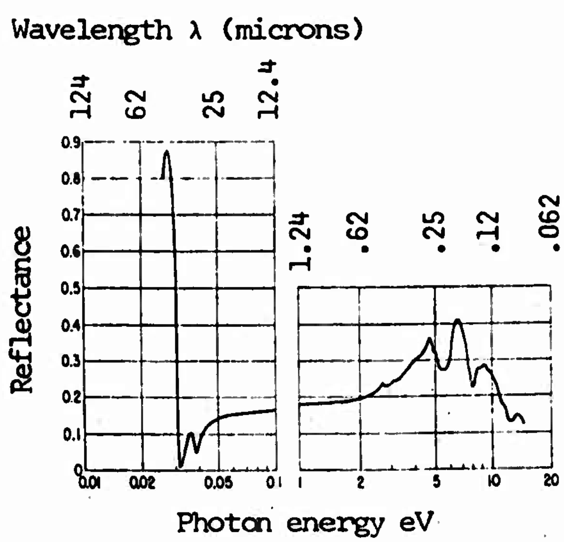
Reflectivity




Diffuse reflectance spectra of polycrystalline zinc selenide at 300°K.

[Ref. 914]




Reflectance of single crystal zinc selenide for near-normal incidence as a function of photon energy at 300°K.

[Ref. 2618]

## SEMICONDUCTOR MATERIALS

September 1963

ZINC SELENIDE

Refractive Index

| Symbol | Value | | Ref. |
|---|---|---|---|
| n | 2.89 | $\lambda = .589\mu$ | 7359 |

Thermal Conductivity

| Symbol | Value | | Temperature | Ref. |
|---|---|---|---|---|
| k | $33 \times 10^3$ | cal/cm sec deg | 300°K | 636 |
| k | $30\text{-}33 \times 10^3$ | cal/cm sec deg | | 3477 |

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