350-320. SR

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# United States Patent

[11] 3,580,664

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[73] Assignee **U.S. Philips Corporation**
**New York, N.Y.**
[32] Priority **Jan. 11, 1968**
[33] **Netherlands**
[31] **6800387**

## [54] TRANSMISSION ELEMENT FOR MAGNETO-OPTICAL APPLICATIONS, PARTICULARLY FOR THE MODULATION OF INFRARED RADIATION IN THE WAVELENGTH RANGE BETWEEN 1 AND 20 MICRONS

**4 Claims, 5 Drawing Figs.**

[52] **U.S. Cl.** .......... **350/320,**
252/62.51, 340/174.1, 350/151
[51] **Int. Cl.** .......... **G02f 1/22**
[50] **Field of Search** .......... 350/151,
160; 252/62.51, 301.6; 340/194.1

[56] **References Cited**

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3,491,026 1/1970 Lehmann et al. .......... 252/62.51

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Baltzer et al., " Insulating Ferromagnetic Spinels" Phys. Rev. Letters Vol. 15, No. 11 (13 Sept. 1965) pp. 493— 495 350/151

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**ABSTRACT:** A novel magneto-optical transmission element consisting of a substrate transparent to radiation in the wavelength range between 1 and 20 microns having thereon a monocrystalline or polycrystalline layer of a material having a spinel structure, a magnetic permeability, in vacuo, $\mu_0 = B/H$ exceeding 1.2 at temperatures lower than the Curie point, i.e. the material is either ferromagnetic or ferrimagnetic, a resistivity at the Curie point exceeding 100 ohm-cm and a chemical composition having the formula A $Cr_2Z_4$, Z being selenium, sulfur, or telluorium and A being in general a divalent metal or complex, preferrably cadmium. The transmission element may also serve as a memory element in which information therein can be read out by determining the sign of the remanent magnetization thereof by means of polarized infrared radiation.

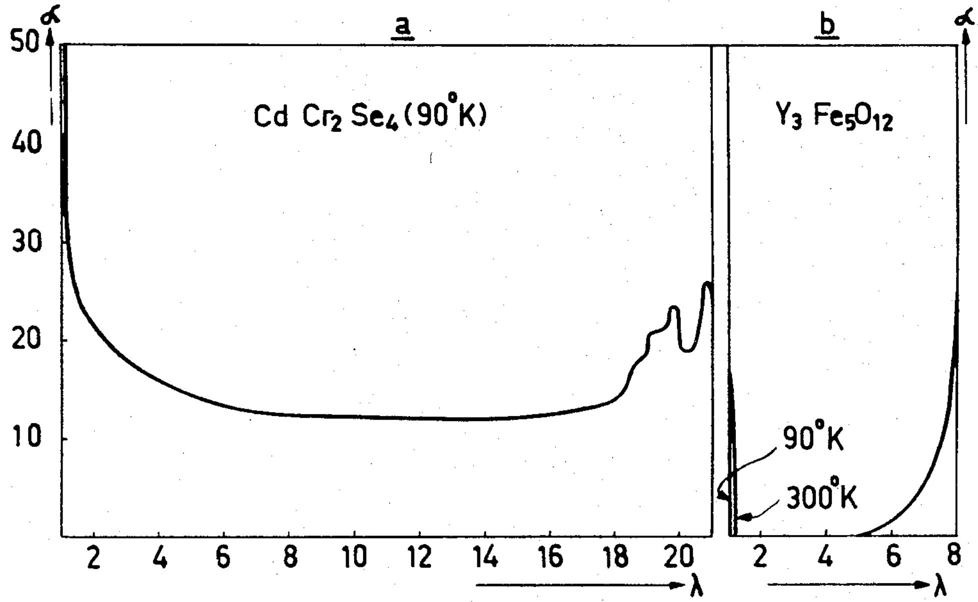


FIG.1

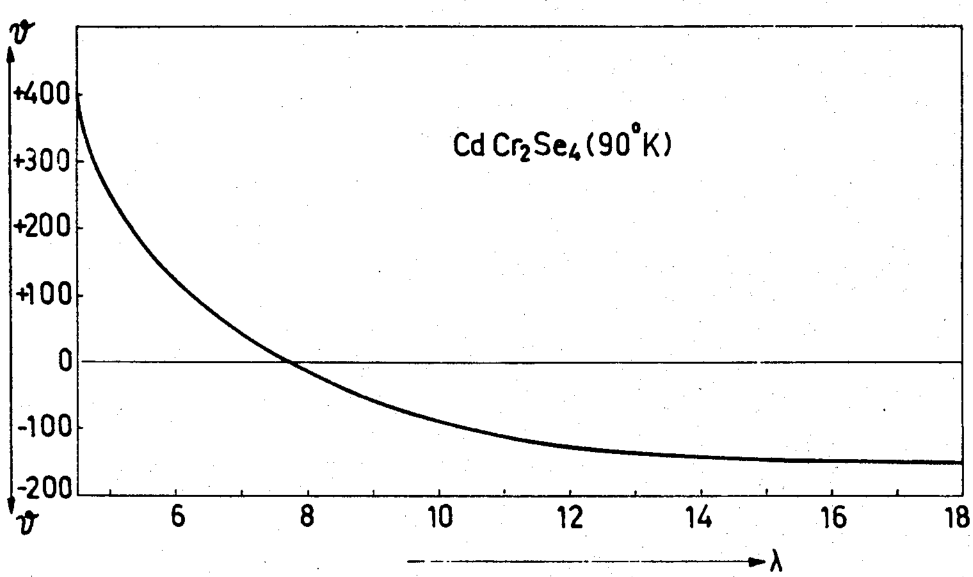


FIG.3

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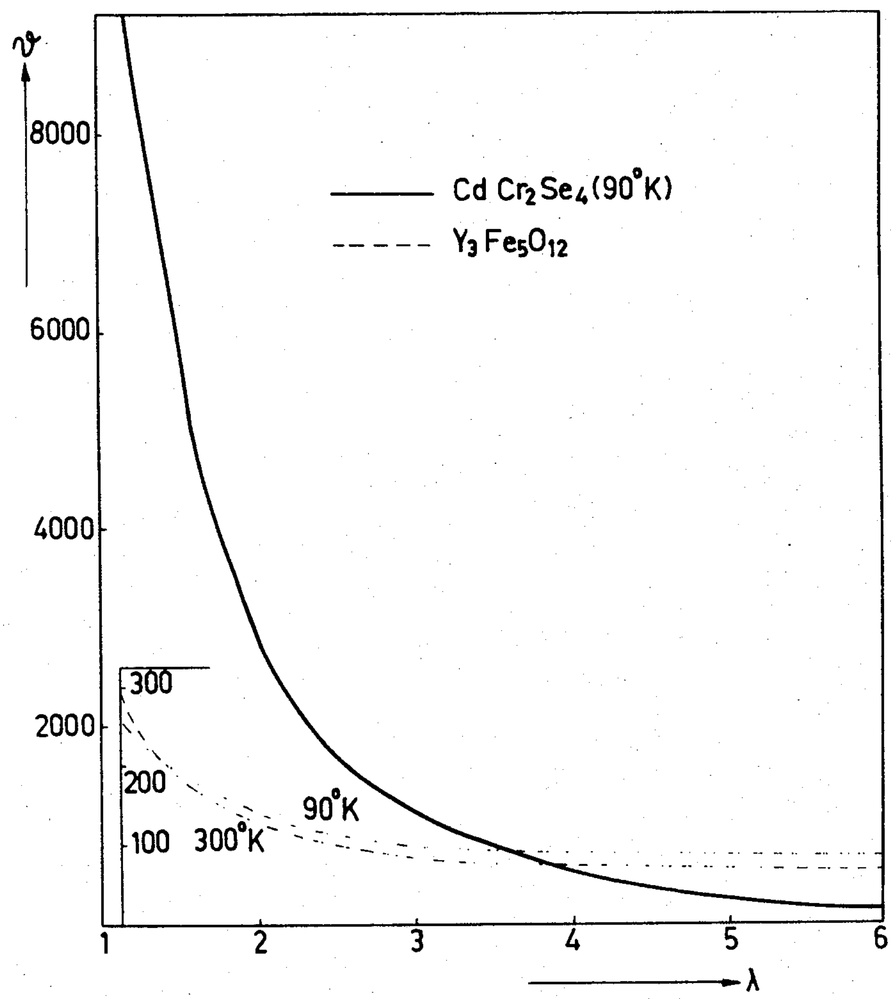


FIG.2

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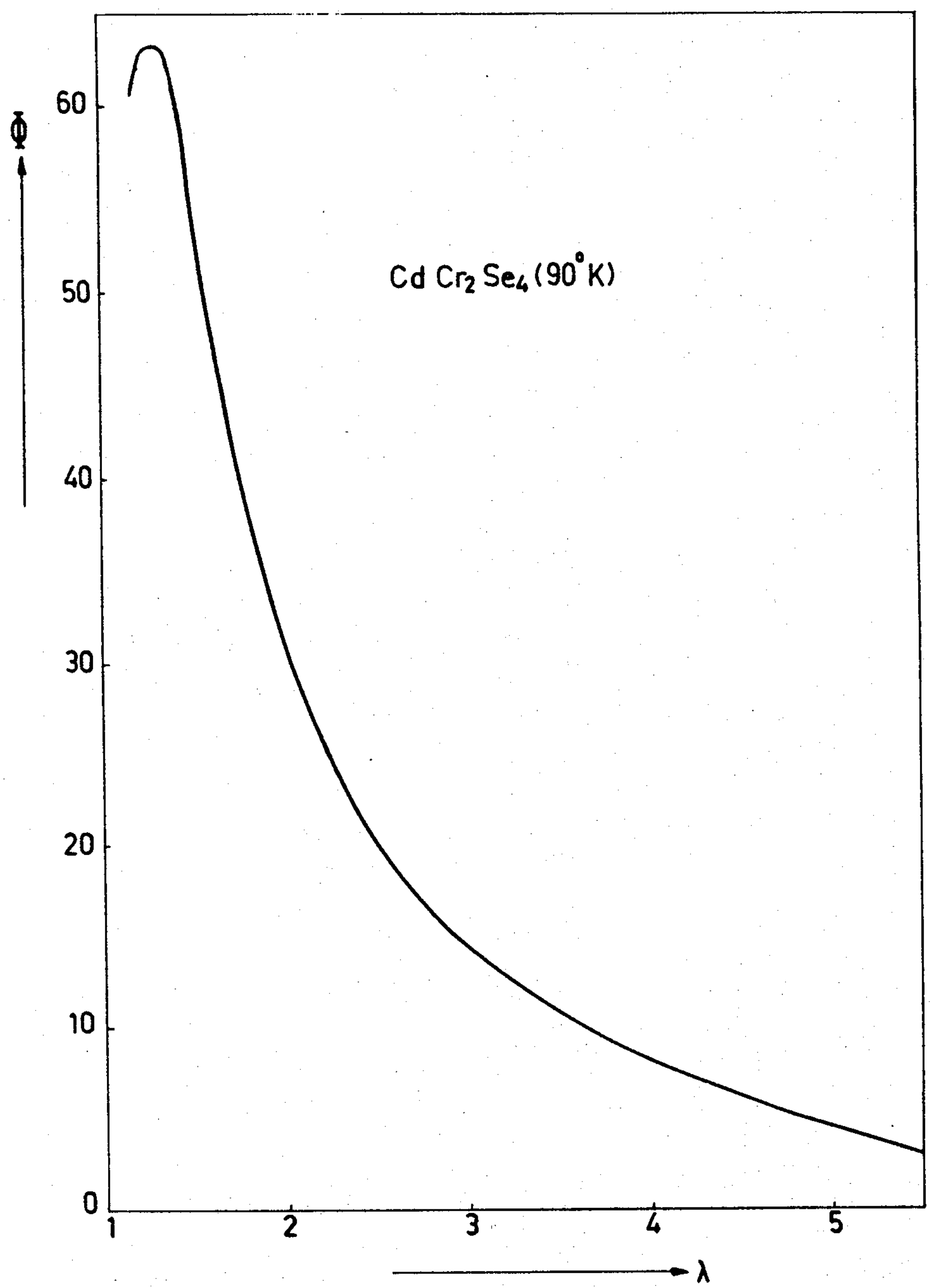


FIG.4

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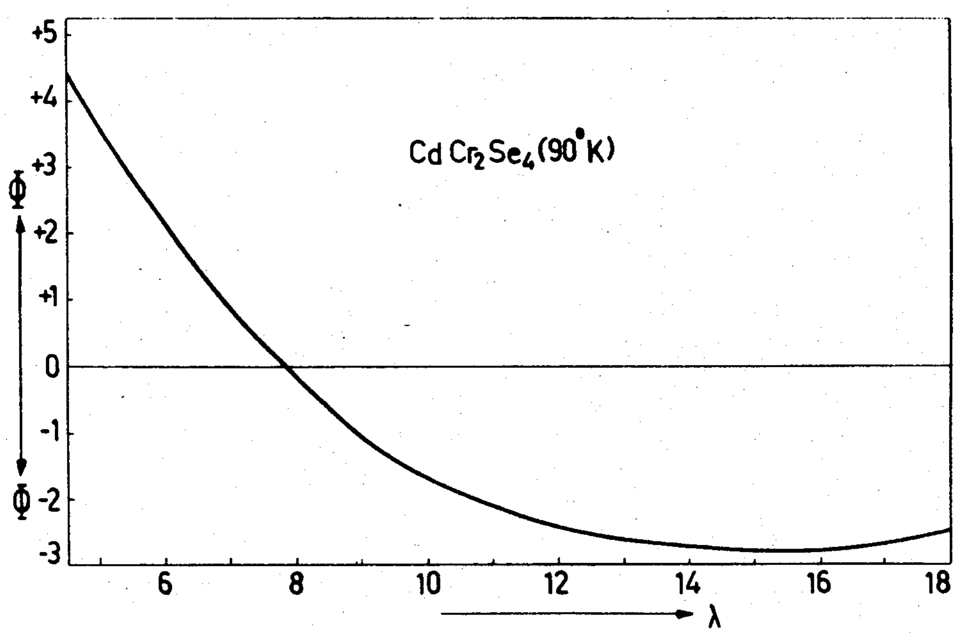


FIG.5

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# TRANSMISSION ELEMENT FOR MAGNETO-OPTICAL APPLICATIONS, PARTICULARLY FOR THE MODULATION OF INFRARED RADIATION IN THE WAVELENGTH RANGE BETWEEN 1 AND 20 MICRONS

The invention relates to a transmission element for magneto-optical applications, particularly for the modulation of infrared radiation in the wavelength range between 1 and 20 microns. Transmission elements as meant here consist of one or more single crystals or of a monocrystalline or polycrystalline layer on a substrate transmitting infrared radiation. The above-mentioned application is based on the ability of the substance of which the transmission element in question consists to rotate the plane of polarization of an incident linearly polarized electromagnetic radiation under the influence of a magnetic field which has a component in the direction of propagation of the radiation. The rotation is known as "-Faraday-rotation." The value of the Faraday-rotation (Φ) is expressed here in the number of degrees of rotation of the plane of polarization per cm. of path length of the radiation covered in the transmission element, when the latter is magnetized to saturation in a magnetic field parallel to the direction of radiation.

In order to obtain a large Faraday-rotation, which can be noticeably influenced already by small magnetic fields or by small variations in the orientation of the magnetic field, usually magnetic materials are used which readily transmit the radiation to be modulated. Said magnetic materials are to be understood to means herein materials which, at temperatures lower than a critical temperature (Curie point), characteristic of the material in question, are ferromagnetic or ferrimagnetic. As a measure of the usability of a magnetic material as a modulator material for radiation of a given wavelength band is used, in addition to the quantity as above, also the so-called "figure of merit" Φ·Φ is to be understood to mean the number of degrees of rotation of the plane of polarization of the radiation per db attenuation of the radiation intensity for the material magnetized to saturation. In this case the relation holds

$$\Phi=\frac{\vartheta d-}{10(^{10}\log e)\alpha d}=0.23\frac{\vartheta}{\alpha}$$

wherein d=the path length in cm traversed by the radiation in the transmission element,

e=the base of the system of natural logarithms,

α=the absorption coefficient expressed in cm$^{11}$; this quantity is defined by the relation

α=1/d$^e$log$^I$o/$I$ (wherein $^I$o/$I$)=the quotient of the intensities of the radiation, $I_o$, and the transmitted radiation, I), while the quantity was already defined above.

The so far best known materials for transmission elements to be used for the modulation of infrared radiation having a wavelength between 1 and 6 microns, are yttrium-iron garnet, $Y_3Fe_5O$, and the compounds which can be derived therefrom, inter alia by the partial replacement of iron by gallium. These substances are ferrimagnetic at room temperature. They are preferably used in the form of single crystals. Although the Faraday rotation of these garnets increases when the wavelength decreases below a value of 1 micron, this advantage is undone by a radiation absorption which also increases strongly, so that the figure of merit assumes low values. For wavelengths exceeding 6 microns, both the rotation is small and the absorption coefficient is large so that garnets are useless at those wavelengths for the applications in view.

The invention relates to a transmission element for the modulation of infrared radiation in the wavelength range between 1 and 20 microns. This transmission element must satisfy each of the following conditions:

1. it must consist of one or more crystals having a spinel structure;

2. it must be ferromagnetic or ferrimagnetic at temperatures lower than a temperature which is characterized of the substance of which the transmission element in question consists and it must have a magnetic permeability, in vacuo, $\mu_o$=B/H, exceeding 1.2;



3. at this temperature (Curie point) it must have a resistivity exceeding 100 ohm-cm.;

4. the crystal or the crystal must have a chemical composition which satisfies the formula

$$A\ Cr_2Z_4,\ \text{wherein}\ A=Cd,\ Zn,\ Hg,\ Mn,\ F^{II},\ Co,\ Mg,\ Ni,\ Pb,\ \frac{Cu^I+Ga^{III}}{2},\ \frac{Cu^I+In^{III}}{2},\ \frac{Cu^I+Fe^{III}}{2},\ \frac{Ag^I+In^{III}}{2},\ \text{and}\ \frac{Ag^I+Fe^{III}}{2}$$

either separately or in combinations of two or more, while Z=S, Se and Te, either separately or in combinations of two or more.

The crystals in question can be obtained, for example, by synthesis. For example, crystals of the compounds cadmium chromium selenide, $CdCr_2Se_4$, may be prepared in such a manner that cadmium selenide, CdSe, and chromium selenide, $Cr_2Se_3$, are dissolved in anhydrous, molten cadmium chloride and the resulting solution is slowly cooled for example, at a rate of 1°—5° C. per hour. The cadmium chromium selenide is one of the most important representatives of the group of substances which have the above-defined chemical composition and the crystals of which are suitable for the formation of transmission elements according to the invention. It is ferromagnetic at temperatures lower than approximately 135° K.

FIG. 1*a* is a graph which shows the variation of the absorption coefficient, α (in cm.$^{11}$), of a crystal of $CdCr_2Se_4$ as a function of the wavelength λ (in microns) in the wavelength range of approximately 1—21 microns, at a temperature of 90° K. It was found that the absorption coefficient is low throughout the wavelength range of approximately 1 to 21 microns, with a highest value not exceeding approximately 13 cm.$^{11}$ in the wavelength range between 6 and 18 microns. From the substantially constant value of α in the last-mentioned wavelength range it may be concluded that the measured absorption is mainly to be ascribed to the presence of chemical and physical inhomogeneities in the crystal so that the absorption measured in a substantially homogenous crystal will be considerably lower than the one actually measured.

For comparison reference is made to FIG. 1*b* which shows corresponding graphs for a crystal of yttrium-iron garnet, $Y_3Fe_5O$, at 90° K and at 300° K. It may be seen that, although this crystal has a still considerably lower absorption at wavelengths between approximately 1.1 and 6 microns than the crystal of $CdCr_2Se_4$ to which FIG. 1*a* relates, the absorption of the yttrium-iron garnet crystal at wavelengths exceeding 6 microns increases so strongly as a function of the wavelength that the use of the said material is restricted to wavelengths of 1.1—6 microns.

It may be seen from FIG. 2 that the value of the Faraday-rotation, Φ, (in degrees cm$^{11}$) of the yttrium-iron garnet crystal in the wavelength range of 1.1—6 microns, strongly drops behind that of the $CdCr_2Se_4$ crystal. A large Faraday rotation is of particular importance for those applications in which the thickness of the transmission element must be small, for example, in optically reading a memory element.

The graph shown in FIG. 3 represents the Faraday-rotation of the $CdCr_2Se_4$ crystal considered, as a function of the wavelength, within the wavelength range of 4.5—18 microns, at a temperature of 90° K. It is seen from this FIG. that at a wavelength of approximately 7.8 microns, the Faraday-rotation of the $CdCr_2Se_4$ crystal in question (at 90° K.) changes its sign, so that the crystal at that temperature cannot be used for modulating radiation having a wavelength between approximately 7.5 and 8 microns.

FIGS. 4 and 5 shown graphs for the figure of merit of the present $CdCr_2Se_4$ crystal as a function of the wavelength, also at a temperature of 90° K.

Transmission elements according to the invention may also be used as memory elements which are read by determining the sign of the remanent magnetization thereof by means of polarized infrared radiation.

We claim:

**1.** A transmission element for magneto-optical applications, consisting of a substrate transparent to radiation having a wavelength between 1 and 20 microns having a layer thereon of at least one crystal having a layer thereon of at least one crystal having a spinel structure, having a magnetic permeability, in vacuo, $\mu_o$=B/H, exceeding 1.2 at temperatures lower than the Curie point, a resistivity at the Curie point exceeding 100 ohm-cm., and a chemical composition having the formula A $Cr_2Z_4$, wherein A is one of the members of the group consisting of Cd, Zn, Hg, Mn, Fe'', Co, Mg, Ni, Pb,

$$\frac{Cu^{I}+Ga^{III}}{2}, \frac{Cu^{I}+In^{III}}{2}, \frac{Cu^{I}+Fe^{III}}{2}, \frac{Ag^{I}+In^{III}}{2} \text{ and } \frac{Ag^{I}+Fe^{III}}{2}$$

and Z is a member of the group consisting of S, Se and Te.

**2.** A transmission element as claimed in claim **1**, wherein the crystal consists of cadmium chromium selenide $CdCr_2Se_4$.



**3.** A process of storing and retrieving information from a memory element consisting of a substrate transparent to radiation having a wavelength between 1 and 20 microns having a layer thereon of at least one crystal having a spinel structure, having a magnetic permeability, in vacuo, $\mu_o$=B/H exceeding 1.2 at temperatures lower than the Curie point, a resistivity at the Curie point exceeding 100 ohm-cm., and a chemical composition having the formula A $Cr_2Z_4$, wherein A is one of the members of the group consisting of Cd, Zn, Hg, Mn, Fe'', Co, Mg, Ni, Pb,

$$\frac{Cu^{I}+Ga^{III}}{2}, \frac{Cu^{I}+In^{III}}{2}, \frac{Cu^{I}+Fe^{III}}{2}, \frac{Ag^{I}+In^{III}}{2} \text{ and } \frac{Ag^{I}+Fe^{III}}{2}$$

and Z is a member of the group consisting of S, Se and Te comprising the steps of magnetizing said element to store information therein, and transmitting polarized infrared radiation through said element to determine the sign of the remanent magnetization thereof.

**4.** A process as claimed in claim **3** wherein the memory element crystal consists of cadmium chromium selenide.

PO-1050
(5/69)

# UNITED STATES PATENT OFFICE
# CERTIFICATE OF CORRECTION

Patent No. 3,580,664 Dated May 25, 1971

Inventor(s) PIET FRANS BONGERS ET AL

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 1, line 17, "The" should be --This--;
line 45, "$cm^{11}$" should be --$cm^{-1}$--;
line 53, "$Y_3Fe_50$" should be $Y_3Fe_5O_{12}$--;

Column 2, line 32, "in $cm^{11}$" should be --$cm^{-1}$--;
line 38, "$cm^{11}$" should be --$cm^{-1}$--;
line 48, "$Y_3Fe_50$" should be --$Y_3Fe_5O_{12}$--;
line 58, "$\phi$" should be --$\nu$--;
line 73, "shown" should be --show--.

Signed and sealed this 17th day of October 1972.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents