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GLASSES FOR FIBER-OPTIC SENSORS(U) NATIONAL BUREAU OF  
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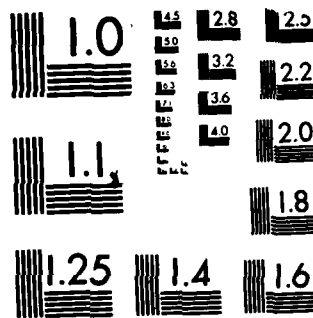
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Technical Report

GLASSES FOR FIBER-OPTIC SENSORS

D. H. Blackburn, A. Feldman, and R. M. Waxler

October 1982

Prepared for the Naval Research Laboratory

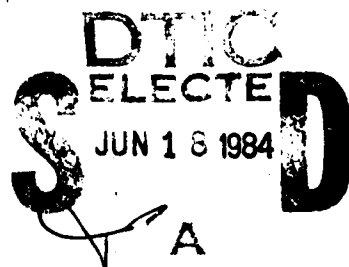
Monitor: N. Lagakos

Principal Investigator: A. Feldman

Period Covered: October 1, 1981-September 30, 1982

N00173-82-F-D044

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## GLASSES FOR FIBER-OPTIC SENSORS

### 1. Objective

To measure the relevant optical and mechanical properties of commercial glasses and glasses prepared at the National Bureau of Standards for the purpose of determining their suitability as fiber-optic sensor materials.

### 2. Introduction

The Department of the Navy is interested in the development of fiber-optic sensors for the detection of underwater acoustic waves. An advantage of such sensors over conventional piezoelectric sensors is their insensitivity to electromagnetic interference. However, a source of noise in such sensor systems is expected to arise from optic path variations due to temperature and pressure fluctuations in the fiber-optic leads connected to the sensors. In order to minimize this noise, a program has been instituted at the Naval Research Laboratory to develop fibers that are insensitive to pressure and temperature fluctuations. In order to assist with this program, the Glass Group of the National Bureau of Standards has been preparing experimental glasses and measuring their relevant mechanical and optical properties.

The work this year has centered on the development of cladding glasses for pressure insensitive fibers. The accomplishments have been: (a) the synthesis of eight glasses of varying composition for the minimization of linear thermal expansion coefficient; (b) the measurement of elastic moduli and thermal expansion coefficients of the aforementioned glasses; (c) the development of glasses with linear thermal expansion coefficients comparable to Pyrex; (d) the fabrication of a cladding preform from one of the NBS produced glasses which was selected for optimum values of bulk modulus and linear thermal expansion coefficient so as to produce a pressure insensitive fiber; (e) the provision of bulk specimens and thin rods to EOTEK Corporation

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per instructions from the contract monitor; and (f) the filing of an invention disclosure with the NBS patent attorney to ascertain whether the glass compositions formulated at NBS merit a patent. *to p. 1*

### 3. Results

It has been pointed out that substrate materials for pressure insensitive fiber-optic leads should have a large bulk modulus and a small thermal expansion coefficient. To this end, NBS has been preparing a series of experimental glasses. In the previous year, in a series of eleven glasses, we had shown that the gradual addition of  $Ta_2O_5$  and removal of  $CaO$  from a calcium aluminate based glass formulation led to glasses with both a large bulk modulus and a decreasing linear thermal expansion coefficient. For the present year, eight additional experimental glasses were synthesized with the hope of further decreasing the thermal expansion coefficient without adversely affecting the bulk modulus.

The method of specimen preparation and the measurement of elastic moduli and thermal expansion were presented in our previous report and so will not be discussed here. Table 1 summarizes the results of this year's study and the study of the previous year. The eight glasses studied this year are denoted by K-1780 and higher. It was found that as the concentration of  $Ta_2O_5$  was increased, the linear thermal expansion coefficient reached a minimum value and then began to increase. Two glasses, K-1824 and K-1825, had  $Nb_2O_5$  substituted for  $Ta_2O_5$ ; no significant change was found in the bulk modulus, but the linear thermal expansion appeared to increase slightly. Some  $B_2O_3$  was added to glasses K-1847 and K-1848 as small amounts of this substance are known to decrease expansion coefficients. Indeed, K-1848 had the smallest expansion coefficient in the series. However, the bulk modulus showed a significant decrease.

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Based on the results for the nineteen glasses, it was decided that glass K-1780 had the best combination of properties for the production of a cladding preform. This glass has a respectfully large bulk modulus and a linear thermal expansion coefficient comparable to Pyrex. A cladding preform of this glass was fabricated at NBS and shipped to EOTEK Corporation which is under contract with NRL for prototype drawing of fibers. EOTEK also required bulk material and some thin rods so as to study the fiber drawing properties of the NBS glass prior to the use of the preform; these specimens were prepared and have been sent to EOTEK.

The glasses we have formulated have some unique properties which make them useful for a variety of applications. We have, therefore, prepared an invention disclosure for the NBS patent attorney to evaluate. A copy of this disclosure is attached; it outlines some of the more important applications for these glasses.

#### References

1. N. Lagakos and J. A. Bucaro, "Pressure Desensitization of Optical Fibers," Appl. Opt., 20, 2716 (1981).

Table 1.

## Properties of NBS Prepared Glasses

| Glass No. | CaO | Al <sub>2</sub> O <sub>3</sub> | MgO | TiO <sub>2</sub> | ZrO <sub>2</sub> weight % | SiO <sub>2</sub> | Ta <sub>2</sub> O <sub>5</sub> | Nb <sub>2</sub> O <sub>5</sub> | B <sub>2</sub> O <sub>3</sub> | Young's Modulus (10 <sup>11</sup> dyn/cm <sup>2</sup> ) | Shear Modulus (10 <sup>11</sup> dyn/cm <sup>2</sup> ) | Bulk Modulus | Poisson's Ratio | $\alpha(10^{-6}/K)$ at 20 °C |
|-----------|-----|--------------------------------|-----|------------------|---------------------------|------------------|--------------------------------|--------------------------------|-------------------------------|---------------------------------------------------------|-------------------------------------------------------|--------------|-----------------|------------------------------|
| K-1671    | 25  | 25                             | 10  | 10               | 10                        | 20               |                                |                                |                               | 11.62                                                   | 4.52                                                  | 9.01         | 0.285           | 6.49                         |
| K-1679    | 25  | 20                             | 10  | 10               | 10                        | 25               |                                |                                |                               | 11.45                                                   | 4.45                                                  | 8.92         | 0.286           | 6.21                         |
| K-1689    | 30  | 15                             | 10  | 10               | 10                        | 25               |                                |                                |                               | 11.31                                                   | 4.40                                                  | 8.81         | 0.286           | 7.21                         |
| K-1701    | 25  | 20                             | 10  | 10               |                           | 25               | 10                             |                                |                               | 11.20                                                   | 4.37                                                  | 8.52         | 0.281           | 6.75                         |
| K-1703    | 20  | 20                             | 10  | 10               |                           | 25               | 15                             |                                |                               | 11.46                                                   | 4.46                                                  | 8.88         | 0.285           | 5.95                         |
| K-1717    | 20  | 20                             | 15  | 10               |                           | 25               | 10                             |                                |                               | 11.55                                                   | 4.50                                                  | 8.87         | 0.283           | 6.48                         |
| K-1719    | 20  | 20                             | 10  | 15               |                           | 25               | 10                             |                                |                               | 11.48                                                   | 4.49                                                  | 8.66         | 0.279           | 6.07                         |
| K-1729    | 15  | 20                             | 10  | 10               |                           | 25               | 20                             |                                |                               | 11.65                                                   | 4.54                                                  | 8.99         | 0.284           | 5.62                         |
| K-1733    | 10  | 20                             | 10  | 10               |                           | 25               | 25                             |                                |                               | 11.62                                                   | 4.56                                                  | 8.65         | 0.276           | 4.85                         |
| K-1734    | 5   | 20                             | 10  | 10               |                           | 25               | 30                             |                                |                               | 11.90                                                   | 4.65                                                  | 9.06         | 0.281           | 4.35                         |
| K-1772    | 0   | 20                             | 10  | 10               |                           | 30               | 30                             |                                |                               | 11.56                                                   | 4.63                                                  | 7.71         | 0.250           | 3.21                         |
| K-1780    |     | 20                             | 20  | 5                |                           | 35               | 30                             |                                |                               | 11.31                                                   | 4.42                                                  | 8.52         | 0.279           | 2.94                         |
| K-1787    |     | 20                             | 10  |                  |                           | 35               | 35                             |                                |                               | 11.04                                                   | 4.39                                                  | 7.54         | 0.256           | 2.88                         |
| K-1788    |     | 20                             | 10  |                  |                           | 30               | 40                             |                                |                               | 11.52                                                   | 4.57                                                  | 8.07         | 0.262           | 2.94                         |
| K-1789    |     | 20                             | 10  |                  |                           | 25               | 45                             |                                |                               | 12.14                                                   | 4.78                                                  | 8.82         | 0.271           | 3.13                         |
| K-1824    |     | 20                             | 10  |                  |                           | 30               | 20                             | 20                             |                               | 11.36                                                   | 4.48                                                  | 8.12         | 0.268           | 3.02                         |
| K-1825    |     | 20                             | 10  |                  |                           | 30               |                                | 40                             |                               | 11.30                                                   | 4.45                                                  | 8.14         | 0.268           | 3.22                         |
| K-1847    |     | 20                             | 10  |                  |                           | 26.25            | 35                             |                                | 8.75                          | 10.52                                                   | 4.22                                                  | 6.88         | 0.245           | 2.84                         |
| K-1848    |     | 20                             | 10  |                  |                           | 30               | 35                             |                                | 5.0                           | 10.78                                                   | 4.26                                                  | 7.63         | 0.263           | 2.69                         |

## PATENT DISCLOSURE

### Low Compressibility, Low Expansivity Glasses

Douglas Blackburn, Albert Feldman  
Glass and Optical Materials Group  
National Bureau of Standards

and

Nicolas Lagakos  
Physical Acoustics Branch  
Naval Research Laboratory

*Low P. 22*

A series of beryllium-free glasses have been formulated that exhibit a high Young's modulus (E), a high bulk modulus (K), and a wide range of expansivities. Several of the glasses exhibit unusually small linear thermal expansion coefficients ( $\alpha$ ) at room temperature. The glasses were formulated with the view of not including BeO as a constituent because of its potential toxicity.

#### Formulations:

The compositions fall in the following weight percent ranges:

|                                |          |
|--------------------------------|----------|
| CaO <sub>2</sub>               | 0 - 30%  |
| Al <sub>2</sub> O <sub>3</sub> | 15 - 25% |
| MgO                            | 5 - 15%  |
| TiO <sub>2</sub>               | 0 - 15%  |
| ZrO <sub>2</sub>               | 0 - 10%  |
| SiO <sub>2</sub>               | 20 - 30% |
| B <sub>2</sub> O <sub>3</sub>  | 0 - 10%  |
| Ta <sub>2</sub> O <sub>5</sub> | 0 - 45%  |
| Nb <sub>2</sub> O <sub>5</sub> | 0 - 40%  |

Particular compositions show desirable combinations of properties. The highest Young's modulus was exhibited by the glass with the following composition:



|           |     |                                                                 |
|-----------|-----|-----------------------------------------------------------------|
| $Al_2O_3$ | 20% | $E = 12.1 \times 10^{11} \text{ dyn/cm}^2$                      |
| $MgO$     | 10% | $K = 8.8 \times 10^{11} \text{ dyn/cm}^2$                       |
| $SiO_2$   | 25% | $\alpha = 3.1 \times 10^{-6} / ^\circ C \text{ at } 20^\circ C$ |
| $Ta_2O_5$ | 45% |                                                                 |

The highest bulk modulus was exhibited by the glass with the following composition:

|           |     |                                                                 |
|-----------|-----|-----------------------------------------------------------------|
| $CaO$     | 5%  |                                                                 |
| $Al_2O_3$ | 20% | $E = 11.9 \times 10^{11} \text{ dyn/cm}^2$                      |
| $MgO$     | 10% | $K = 9.1 \times 10^{11} \text{ dyn/cm}^2$                       |
| $Ti_2O_3$ | 10% | $\alpha = 4.4 \times 10^{-6} / ^\circ C \text{ at } 20^\circ C$ |
| $SiO_2$   | 25% |                                                                 |
| $Ta_2O_5$ | 30% |                                                                 |

The smallest linear thermal expansion coefficient was exhibited by the glass with the following composition:

|           |     |                                                                 |
|-----------|-----|-----------------------------------------------------------------|
| $Al_2O_3$ | 20% |                                                                 |
| $MgO$     | 10% | $E = 10.8 \times 10^{11} \text{ dyn/cm}^2$                      |
| $SiO_2$   | 30% | $K = 7.6 \times 10^{11} \text{ dyn/cm}^2$                       |
| $Ta_2O_5$ | 35% | $\alpha = 2.7 \times 10^{-6} / ^\circ C \text{ at } 20^\circ C$ |
| $B_2O_3$  | 5%  |                                                                 |

The following glass composition was optimized to possess a large bulk modulus and a small linear thermal expansion coefficient:

|           |     |                                                                 |
|-----------|-----|-----------------------------------------------------------------|
| $Al_2O_3$ | 20% |                                                                 |
| $MgO$     | 10% | $E = 11.3 \times 10^{11} \text{ dyn/cm}^2$                      |
| $TiO_2$   | 5%  | $K = 8.5 \times 10^{11} \text{ dyn/cm}^2$                       |
| $SiO_2$   | 35% | $\alpha = 2.9 \times 10^{-6} / ^\circ C \text{ at } 20^\circ C$ |
| $Ta_2O_5$ | 30% |                                                                 |

Uses:

(1) Glasses for graded seals. Thermal expansion coefficients at 20 °C in the range  $2.7 \times 10^{-6}$  to  $7.2 \times 10^{-6}$  are obtainable.

(2) Temperature stable optical glass. Because the melts of the glasses described herein are of low viscosity, it is possible to produce homogeneous glasses possessing low expansivities. The expansivity of the glass with the smallest expansion coefficient approximates the expansivity of Pyrex. However, because of its high melt viscosity, Pyrex is not usable as a high quality optical glass.

(3) Pressure insensitive fibers. Cladding glasses with high bulk modulus are required to produce fibers that are insensitive to pressure fluctuations. Typically, fiber cores are made from high silica glasses, which have very small expansivities; thus, in order to produce mechanically stable fibers, with these core glasses, it is necessary to use cladding glass with small expansivities. The glasses described herein can be produced both with high bulk modulus and low expansivity thus increasing the probability for successful drawing of pressure insensitive fibers.

Importance of Pressure Insensitive Fibers

A major research effort is underway, especially at the Department of Defense, for development of fiber-optic sensors as an alternate technology to current sensor technology. Such sensors would be used for sensitive detection of pressure, temperature, electric fields and magnetic fields. These sensors require special fiber-optic cables for transmission and reception of sensor signals over distances of several kilometers. Over such large distances, fluctuations in the ambient pressure will lead to superimposition of noise on the sensor signal. Thus fiber-optic cables insensitive to these pressure fluctuation are required for maximizing the signal to noise ratio in the received signals. Immediate potential applications for these fibers would be underwater acoustic detection, acoustic detection related to oil exploration, acoustic detection related to underground nuclear explosions, and earthquake detection.

|                                                                                                                                                            |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                                |                        |                                                          |                                     |                                                                     |                        |
|------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------|------------------------|----------------------------------------------------------|-------------------------------------|---------------------------------------------------------------------|------------------------|
| FORM CG-240<br>(REV. 6-63)<br>PREP. BY<br>CAO 7-6-64                                                                                                       | U.S. DEPARTMENT OF COMMERCE<br><b>FOR PATENT ADVISER'S USE</b><br>Case No. _____                                                                                                                                                                                                                                                                                                                                                                                                  |                                                                |                        |                                                          |                                     |                                                                     |                        |
| <b>INVENTION DISCLOSURE AND RIGHTS QUESTIONNAIRE</b>                                                                                                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                                |                        |                                                          |                                     |                                                                     |                        |
| <b>INSTRUCTIONS:</b> Complete and send to Patent Adviser, Office of the Legal Adviser, National Bureau of Standards, Washington, D.C. 20234.               |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                                |                        |                                                          |                                     |                                                                     |                        |
| Title of Invention (Attach full description)<br><div style="text-align: center; padding: 5px;"> <b>Low Compressibility, Low Expansivity Glasses</b> </div> |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                                |                        |                                                          |                                     |                                                                     |                        |
| Inventor<br><b>Douglas Blackburn</b>                                                                                                                       | Title and Grade<br><b>Chemist, GS-13</b>                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                                                |                        |                                                          |                                     |                                                                     |                        |
| Division Name<br><b>Materials Chemistry Division</b>                                                                                                       | Building<br><b>Matls/223</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                                |                        |                                                          |                                     |                                                                     |                        |
|                                                                                                                                                            | Room No.<br><b>B316</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                                                |                        |                                                          |                                     |                                                                     |                        |
|                                                                                                                                                            | Telephone<br><b>x.2817</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                                |                        |                                                          |                                     |                                                                     |                        |
| Inventor<br><b>Albert Feldman</b>                                                                                                                          | Title and Grade<br><b>Physicist, GS-15</b>                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                                |                        |                                                          |                                     |                                                                     |                        |
| Division Name<br><b>Materials Chemistry Division</b>                                                                                                       | Building Room No.<br><b>Matls/223</b>                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                                |                        |                                                          |                                     |                                                                     |                        |
|                                                                                                                                                            | Room No.<br><b>A249</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                                                |                        |                                                          |                                     |                                                                     |                        |
|                                                                                                                                                            | Telephone<br><b>x.2817</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                                |                        |                                                          |                                     |                                                                     |                        |
| Inventor<br><b>Nicolas Lagakos</b>                                                                                                                         | Title and Grade<br><b>Physicist, GS-13</b>                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                                |                        |                                                          |                                     |                                                                     |                        |
| Division Name<br><b>Naval Research Laboratory</b>                                                                                                          | Building<br><b>71</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                                |                        |                                                          |                                     |                                                                     |                        |
|                                                                                                                                                            | Room No.<br><b>Code 5134</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                                |                        |                                                          |                                     |                                                                     |                        |
|                                                                                                                                                            | Telephone<br><b>767-3179</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                                |                        |                                                          |                                     |                                                                     |                        |
| <b>STATEMENT OF INVENTOR(S)</b>                                                                                                                            |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                                |                        |                                                          |                                     |                                                                     |                        |
| 1. Has the invention been published? (Attach copy of paper, preprint, report, etc.)                                                                        | Informal report attached<br><table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 50%; text-align: center;">Yes</td> <td style="width: 50%; text-align: center;">No</td> </tr> <tr> <td style="text-align: center;"><input type="checkbox"/></td> <td style="text-align: center;"><input checked="" type="checkbox"/></td> </tr> </table>                                                                                                     | Yes                                                            | No                     | <input type="checkbox"/>                                 | <input checked="" type="checkbox"/> |                                                                     |                        |
| Yes                                                                                                                                                        | No                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                                |                        |                                                          |                                     |                                                                     |                        |
| <input type="checkbox"/>                                                                                                                                   | <input checked="" type="checkbox"/>                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                |                        |                                                          |                                     |                                                                     |                        |
| 2. Has the invention been used only experimentally?                                                                                                        | <input checked="" type="checkbox"/>                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                |                        |                                                          |                                     |                                                                     |                        |
| 3. Do you know of relevant prior art? (Attach copy) <b>NBS Report No. 5188 (1957)</b>                                                                      | <input checked="" type="checkbox"/>                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                |                        |                                                          |                                     |                                                                     |                        |
| 4. Was the invention sponsored by another agency? (Identify agency and Order No.) <b>Naval Research Lab. N00173-82-F-0044</b>                              | <input checked="" type="checkbox"/>                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                |                        |                                                          |                                     |                                                                     |                        |
| 5. Does the invention bear a direct relation to or was it made in consequence of your official duties? (If no, attach copy of position description)        | <input checked="" type="checkbox"/>                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                |                        |                                                          |                                     |                                                                     |                        |
| 6. Was the invention made                                                                                                                                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                                |                        |                                                          |                                     |                                                                     |                        |
| A. During working hours                                                                                                                                    | <input checked="" type="checkbox"/>                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                |                        |                                                          |                                     |                                                                     |                        |
| B. With a contribution by the government of                                                                                                                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                                |                        |                                                          |                                     |                                                                     |                        |
| a. Facilities                                                                                                                                              | <input checked="" type="checkbox"/>                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                |                        |                                                          |                                     |                                                                     |                        |
| b. Equipment                                                                                                                                               | <input checked="" type="checkbox"/>                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                |                        |                                                          |                                     |                                                                     |                        |
| c. Materials                                                                                                                                               | <input checked="" type="checkbox"/>                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                |                        |                                                          |                                     |                                                                     |                        |
| d. Funds                                                                                                                                                   | <input checked="" type="checkbox"/>                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                |                        |                                                          |                                     |                                                                     |                        |
| e. Information available only by reason of your official duties                                                                                            | <input checked="" type="checkbox"/>                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                |                        |                                                          |                                     |                                                                     |                        |
| f. Time or services of other government employees on official duty                                                                                         | <input checked="" type="checkbox"/>                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                |                        |                                                          |                                     |                                                                     |                        |
| 7. Estimate the market for the invention.<br>Selling price \$ _____ x Number of sales _____ = Market \$ <b>10M-100M at least</b>                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                                |                        |                                                          |                                     |                                                                     |                        |
| <b>8. CERTIFICATION OF INVENTOR(S)</b>                                                                                                                     | <table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 80%;">Signature<br/><b>Douglas Blackburn</b> <i>Douglas Blackburn</i></td> <td style="width: 20%;">Date<br/><b>9-20-82</b></td> </tr> <tr> <td>Signature<br/><b>Albert Feldman</b> <i>Albert Feldman</i></td> <td>Date<br/><b>9-17-82</b></td> </tr> <tr> <td>Signature<br/><b>Nicolas Lagakos</b> <i>Nicolas Lagakos per a.g.</i></td> <td>Date<br/><b>9-20-82</b></td> </tr> </table> | Signature<br><b>Douglas Blackburn</b> <i>Douglas Blackburn</i> | Date<br><b>9-20-82</b> | Signature<br><b>Albert Feldman</b> <i>Albert Feldman</i> | Date<br><b>9-17-82</b>              | Signature<br><b>Nicolas Lagakos</b> <i>Nicolas Lagakos per a.g.</i> | Date<br><b>9-20-82</b> |
| Signature<br><b>Douglas Blackburn</b> <i>Douglas Blackburn</i>                                                                                             | Date<br><b>9-20-82</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                                                |                        |                                                          |                                     |                                                                     |                        |
| Signature<br><b>Albert Feldman</b> <i>Albert Feldman</i>                                                                                                   | Date<br><b>9-17-82</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                                                |                        |                                                          |                                     |                                                                     |                        |
| Signature<br><b>Nicolas Lagakos</b> <i>Nicolas Lagakos per a.g.</i>                                                                                        | Date<br><b>9-20-82</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                                                |                        |                                                          |                                     |                                                                     |                        |
| <b>SUPERVISORY CONCURRENCE</b>                                                                                                                             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                                |                        |                                                          |                                     |                                                                     |                        |
| 9. Do you agree with the replies to questions 1 - 7?                                                                                                       | <table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 50%; text-align: center;">Yes</td> <td style="width: 50%; text-align: center;">No</td> </tr> <tr> <td style="text-align: center;"><input type="checkbox"/></td> <td style="text-align: center;"><input type="checkbox"/></td> </tr> </table>                                                                                                                                            | Yes                                                            | No                     | <input type="checkbox"/>                                 | <input type="checkbox"/>            |                                                                     |                        |
| Yes                                                                                                                                                        | No                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                                |                        |                                                          |                                     |                                                                     |                        |
| <input type="checkbox"/>                                                                                                                                   | <input type="checkbox"/>                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                                                |                        |                                                          |                                     |                                                                     |                        |
| 10. Are you aware of any question as to inventorship?                                                                                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                                |                        |                                                          |                                     |                                                                     |                        |
| Signature of Supervisor<br>_____                                                                                                                           | Date<br>_____                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                |                        |                                                          |                                     |                                                                     |                        |
| Signature of Division Chief<br><b>TD Coyle</b>                                                                                                             | Date<br><b>9/21/82</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                                                |                        |                                                          |                                     |                                                                     |                        |

**DATE**  
**FILME**