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14. ABSTRACT Acousto-optic (AO) modulators, deflectors, filters offer convenience, reliability, compact size and fast speed in regulation of optical beams. So far there are only a few AO materials available for use in the long infrared region of spectrum. The major disadvantage of such AO materials is the extremely low acousto-optic figure of merit, which automatically results in high requirements on driving electric power and poor diffraction efficiency. It is expected that the materials that satisfy the requirements on the high efficiency are the crystalline compounds based on mercury, tellurium, lead and other heavy metals. In the present Report, we list Universities, Institutes and Laboratories in Eastern European countries capable of growth and characterization of the new crystals. Short description of the found Institutes and Laboratories is presented in the Report. Mailing and electronic addresses of the Universities and Institutes as well as of specialists responsible for the crystal growth are also included in the presentation.						
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Growth of Acousto-Optic Crystals for Applications in Infrared Region of Spectrum

Final Report

by

Vitaly B.Voloshinov

(April 30, 2005)

United States Army

EUROPEAN RESEARCH OFFICE OF THE U.S. ARMY

London, England

Contract number **N 62558-05-P-0189** of February 23, 2005

Contractor: Prof. Vitaly B.Voloshinov

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Growth of Acousto-Optic Crystals for Applications in Infrared Region of Spectrum

Final Report

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The Contractor, Prof. Voloshinov hereby declares that, to the best of his knowledge and belief, the technical data delivered herein under Contract No. N 62558-05-P-0189 of February 23, 2005 is complete, accurate, and complies with all requirements of the contract.

Date: April 30, 2005

Name and Title of Authorized Official:

Vitaly Voloshinov

Professor of Physics



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Abstract

Acousto-optic (AO) modulators, deflectors, filters, and other instruments of optical beams regulation offer convenience, reliability, compact size and fast speed. So far there are only a few AO materials available for use in the long infrared region of spectrum at the wavelength 8-12 microns. The major disadvantage of such AO materials is the extremely low acousto-optic figure of merit, which automatically results in high requirements on driving electric power, poor diffraction efficiency and narrow linear and angular apertures of the acousto-optic devices. It is expected that the materials that satisfy the requirements on high AO efficiency are the crystalline compounds based on mercury, tellurium, lead and other heavy metals. In the Report, the Contractor lists Universities, Institutes and Laboratories in Eastern European countries capable of growth and characterization of the crystals with the goals of further application in the acousto-optic instruments. A short description of the found Institutes and Laboratories is presented in the Report. Mailing and electronic addresses of the Universities and Institutes as well as of specialists responsible for the crystal growth are also included in the presentation.

Key words: acousto-optics, mercury chloride, mercury bromide, mercury iodide, tellurium, tellurium dioxide, lead molybdate, tunable acousto-optic filter, acousto-optic imaging, acousto-optic figure of merit

Technical objective: It was planned to use the Internet facilities to find Eastern European Universities, Institutes and Laboratories capable of growing new efficient acousto-optic crystalline materials transparent in the long infrared region of spectrum.

This Report is in response to ARL-ARO-ERO BAA for Contracts, Grants, Cooperative Agreements, and Other Transactions, DAAD 19-00-R-0010, Research Area 5, Material Science and 11 40 Acousto-Optic Tunable Filters.

Introduction

Recent decade was characterized by increasing demands and interest of specialists in methods to control parameters of radiation in the middle and long infrared regions of spectrum. Acousto-optic modulation, scanning and filtering of coherent and non-coherent beams have many advantages in comparison with other electronic methods of optical radiation control because acousto-optic modulators, deflectors, filters and other instruments of optical beams regulation offer convenience, reliability, small size and fast speed. Dozens of modifications of acousto-optic devices have successfully been used in processing of radiation in the visible light as well as in the near infrared regions of spectrum. As for the long infrared region, only a few materials such as **Germanium**, **Gallium Arsenide**, **Calomel** and **Thallium Arsenide-Selenide (TAS)** have so far been used in acousto-optic cells.

The major disadvantage of all known acousto-optic materials used in the long infrared region of spectrum is the extremely low acousto-optic figure of merit. The low figure of merit automatically results in high requirements on driving electric power, poor diffraction efficiency and narrow angular and linear apertures of acousto-optic devices. It may be stated that many fundamental problems of modern Optics, Spectroscopy, Optical Information Processing and Laser Technology have not so far been solved because of

lack of efficient infrared materials similar to paratellurite widely used in the visible light. Therefore, growth and characterization of the infrared materials with perfect acousto-optic properties becomes an urgent problem in modern Optics, Acousto-Optics, Optical Engineering and Laser Technology.

As known, driving RF power required for reliable operation of the acousto-optic instruments is dependent on the wavelength of optical radiation as “lambda square”[1]. It means that acousto-optic efficiency, i.e. the so-called “figure of merit” of **fused silica (SiO₂)** $M_2 = 1.0$ arb. units in the visible light at $\lambda = 633$ nm is similar to the efficiency of **germanium (Ge)** $M_2 = 250$ arb. units in the long infrared at the wavelength 10.6 microns. Consequently, a material suitable for the application in the infrared should possess the figure of merit as high as $M_2 > 50\,000$ arb. units. Practically all used so far infrared materials have the diffraction efficiency lower to a factor of 50-100 [1-18].

As recently found, the crystalline compounds on base of mercury, thallium, lead and tellurium possess the magnitudes of the acousto-optic figures of merit of the order $M_2 = 1\,000 - 250\,000$ arb. units. In this respect, these materials are superior to the majority of used acousto-optic materials. This statement was confirmed in a few papers related to the subject [10, 13,15,18]. It is likely that the new acousto-optic crystals will find applications in modern instruments of light beam control. Unfortunately, utilization of the crystals in acousto-optic instruments was not so wide because it was and it still is restricted by lack of these materials on the market. The problem may be solved if laboratories capable of growth and characterization of the new crystals are stimulated by support of interested customers. According to the Contractor’s opinion, the new infrared acousto-optic materials may, for example, be grown in Universities of counties situated in Eastern Europe. In particular, the crystals may be obtained in the Laboratories that belong to the ex-USSR countries.

Based on the Contractor’s experience and knowledge, he carried out a thorough search in the Internet and executed a detailed analysis of data with the goals of finding scientific groups capable of the growth, fabrication and characterization of new crystals

including those transparent in the long infrared. Direct contacts with known experts on crystal growth, visits of the Contractor to laboratories, his discussions at scientific conferences (in Russia and Poland) and at a seminar organized for the purpose in one of the Universities outside Russia (in Dnepropetrovsk, Ukraine) resulted in the information on the subject of interest.

Division of Solid State Physics at National University of Dnepropetrovsk, Ukraine

The Division of Solid State Physics at the National University of Dnepropetrovsk (Ukraine) has for many years been known for growth and characterization of crystalline materials. Among others, the Division was specialized in fabrication of compounds including **tellurium** and **lead**. As found from a private communication during a one day visit of the Contractor to the University, the crystals in Dnepropetrovsk are grown by the traditional Chokhralsky method, i.e. from a melt [1].

One of the Laboratories of the University (Head of the Laboratory is Dr. Sergei Akimov) is known for growth and fabrication of **tellurium dioxide (TeO_2)**. The crystals are grown large in size and with perfect optical quality. However, the specialists of the laboratory have no experience in growth of the single crystals of **tellurium (Te)** and the single crystals of **calomel (Hg_2Cl_2)**.

Two other Laboratories of the University (Heads of the Laboratories are Dr. Anatoly M. Antonenko and Dr. Mikhail D. Volnyansky) are growing **paratellurite** as well as the variety of single crystals based on **lead (Pb)**. For example, the laboratory grows **lead molybdate (PbMoO_4)** widely used in Acousto-Optics [1]. Recently they grew the unique acousto-optical material **double lead molybdate (Pb_2MoO_5)**. This material is a double axis crystal that is promising for the application in the imaging acousto-optic filters operating in the visible light and also in the middle infrared region of spectrum. **Double lead molybdate** may not be recommended for the application in the

long infrared. However, it is likely that other efficient crystalline materials representing the family of lead crystals, e.g. **lead bromide (PbBr₃)** [15] may be grown and fabricated in the University.

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Institute of Crystalline Materials in Kharkov, Ukraine

The Institute of Crystalline Materials (Single Crystal Materials) in Kharkov, Ukraine is known for development of technology of growth and characterization of crystals applied in Optics and Laser Technology. The particular specialization of the Institute is large in size crystals possessing perfect transparency with respect to optic, especially to laser radiation. The extremely large size of the crystals provides application of the materials in optical devices with linear apertures of about a few inches and larger (dozens of inches).

The materials grown in the Institute are obtained by means of the known technology of crystal growth from a solution [1]. For example, the fabricated crystals are **cesium chloride (CsCl)**, **potassium chloride (KCl)** and others. The crystals are transparent in a very wide spectral range of optical radiation starting from the wavelengths in the ultraviolet shorter than 0.4 microns and up to 20-30 microns in the long infrared. The crystals may be used for fabrication of plates serving as optical windows in laser setups. These materials may also be utilized for fabrication of large in size dispersion prisms used in spectroscopy, etc.

The above mentioned materials, as well as many other grown in the Institute, are transparent in the long infrared region of spectrum. However, the crystals possess

relatively low values of the acousto-optic figure of merit M_2 . Therefore, the crystals may not be considered as promising for the acousto-optic imaging filter applications. Nevertheless, based on the opinion of the Contractor, data on the materials grown in Kharkov are worth including in the Report.

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Institute of Physical Optics in Lviv, Ukraine

The Institute of Physical Optics in Lviv, Ukraine as well as Lviv National University, Ukraine for many years have been known as the scientific centers of the country, where scientists and specialists grew unique crystalline materials based on **mercury (Hg)**, **thallium (Tl)**, **selenium (Se)**, **arsenic (Ar)** and on other heavy-metal and rare-earth elements. The Contractor in the Internet could not find data on the present activities of the Institute and the University. However, a detailed survey of scientific literature on the subject revealed a publication (thesis) of as much as 3 authors representing the Institute of Physical Optics.

The members of the scientific team of the Lviv Institute, in particular, M.V.Kaidan, A.V.Zadorina and A.S.Andrushchak together with their colleague from Poland A.V.Kityuk published a paper “*Photoelastic and acoustooptical properties of Cs_2HgCl_{14} crystals*”. The new material based on **mercury (Cs_2HgCl_{14})** belongs to the family of mercury crystals, which the crystal of **calomel** also belongs to. It means that a technology of growth of the mercury material, that is to a great extent similar to **calomel (Hg_2Cl_2)**, **mercury bromide (Hg_2Br_2)** and **mercury iodide (Hg_2I_2)**, is known to the authors of the paper. Therefore, it is likely to conclude that the team of scientists from the Institute of

Physical Optics in Lviv will be capable to develop the technology of growth of the infrared acousto-optic materials on base of mercury.

Address for communication:

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79005 Lviv, Ukraine

Technical University of Czestochowa, Poland

As mentioned above and found from the carried out analysis of scientific literature, Dr. A.V. Kityuk from the Technical University in Czestochowa, Poland was the co-author of the Ukrainian scientists in their joint thesis and later in their paper “*Photoelastic and acoustooptical properties of Cs_2HgCl_{14} crystal*” submitted in 2003 to the Western journal “Applied Optics”. It is most likely that growth of the crystal on base of **mercury Cs_2HgCl_{14}** was carried out not in Poland but in Ukraine. Nevertheless, it was reasonable to include in the Report the name of the Polish co-author and the address of his University in Czestochowa.

Address for communication:

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**Institute of Physical Research of Armenian Academy of
Sciences in Ashtarak-2, Armenia**

During the USSR times, Armenia was known as one of the Republics, where crystalline materials were grown for applications in Optics and Laser Technology. The

Institute responsible for the technology was the Institute of Physical Research of Armenian Academy of Sciences. The Institute was situated in Ashtarak-2, Armenia. In particular, the scientists from Armenia grew the well-known acousto-optic crystal **lead molybdate (PbMoO₄)**. It means that the Armenian physicists have the facilities to fabricate crystalline materials on base of **lead (Pb)**. The expert on the crystalline materials, which include **lead (Pb)** and **molybdenum (Mo)**, is Dr. Eduard S. Vartanyan.

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Institute of Physics in Prague, Czech Republic

It was found that the single crystals of **calomel (Hg₂Cl₂)** suitable for laser applications were first grown in Czechoslovakia (now Czech Republic) by Dr. Cesmir Barta. Later in the eighties, Dr. Barta examined physical properties of the material in the laboratories of the Institute of Crystals in Moscow, Russia [16,17]. The crystal was first grown in the Institute of Physics of the Academy of Sciences of the Czech Republic in the capital of the country Prague. Large size crystals with perfect optical quality were also grown in the Institute of Crystals, Russian Academy of Sciences [16,17].

At present, the Department of Optical Crystals at the Institute of Physics in Prague is headed by Dr. Milan Vanecek. The Department is known for growth of optical crystals intended for applications in Laser Technology, Non-Linear Optics, Electro-Optics and Acousto-Optics. The physicists from Czech Republic grow materials such as **halides** including **lead (Pb)** and **mercury (Hg)**.

It was found by the Contractor from a private communication with Dr. Milan Vanecek that Professor Cesmir Barta “has retired some years ago”. However, his son Cesmir Barta, Jr. is interested in the crystals such as **calomel** and continues the research initiated by this father. Dr. Vanecek also provided the Contractor with the following electronic address of Prof. C. Barta and C.Barta Jr. bartabbt@atlas.cz .

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<http://www.fzu.cz/departments/optcryst>

E-mail address of Cesmir Barta Jr: bartabbt@atlas.cz

See also: <http://google.com> ; Google Search for “BBT Materials Processing” .

Activities of the Contractor

1. The Contractor participated in the International conferences on Acousto-Optics in Poland and St. Petersburg. He had talks on the subject of the Report with many well-known international specialists in the field of Acousto-Optics, Electro-Optics and Physics of Crystals.
2. The Contractor visited Ukraine (the University of Dnepropetrovsk) to negotiate with his colleagues and to participate in a seminar related to applications of the optical crystals in Laser Technology, Electro-Optics and Acousto-Optics.

3. The Contractor had fruitful discussions on the subject with the Russian experts on crystalline materials from M.V.Lomonosov Moscow State University, the Institute of Crystals of Russian Academy of Sciences, Moscow and the A.F.Ioffe Physical-Technical Institute in St. Petersburg.
4. The Contractor executed a thorough analysis of scientific literature and corresponding data in the Internet.

Conclusion

It may be concluded that the most interesting and well-equipped laboratories capable of growth of the infrared crystals are situated in Ukraine. These laboratories are known for the sounding results on the growth of the crystals utilizing mercury, lead and tellurium. As for the single crystals of calomel, it seems most reasonable to contact the specialists from Czech Republic, in particular, Prof. Cesmir Barta who was the first to grow and fabricate large size samples of calomel.

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