Track 1: Infrared Physics and Technology

Sep. 18, Room 105A	
Presider: Weida Hu, Shanghai Institute of Technical Physics, CAS	
14:00-14:30 (Keynote)	**Recent hotspots and innovative trends of infrared photon detectors** Zhenhua Ye, Key Laboratory of Infrared Imaging Materials and Detectors, Shanghai Institute of Technical Physics, Chinese Academy of Sciences, China
14:30-14:50 (Invited)	**Innovative path to improve the performance of InAs/GaSb type-II superlattice photodetectors** Donghai Wu, Zhichuan Niu, Institute of Semiconductors, Chinese Academy of Sciences, Center of Materials Science and Optoelectronics Engineering, University of Chinese Academy of Sciences, China
14:50-15:10 (Invited)	**Recent progress of infrared photodetectors driven by local field** Peng Wang, Shanghai Institute of Technical Physics, CAS
15:10-15:30 (Invited)	**The study of condensed matter spectroscopy on ferroelectric oxides** Zhigao Hu, East China Normal University
15:30-15:45	Coffee break
Presider: Fansheng Chen, Shanghai Institute of Technical Physics, CAS	
15:45-16:05 (Invited)	**Innovative optical payloads and big data technologies support for the realization of SDGs** Fansheng Chen, Shanghai Institute of Technical Physics, CAS
16:05-16:25 (Invited)	**InP/InGaAs shortwave infrared Single-Photon avalanche detectors** Chen Liu, Yunnan University
16:25-16:45 (Invited)	**Polarization-Sensitive photodetectors based on 2D layered semiconductors** Zhongming Wei, Institute of Semiconductors, CAS
16:45-16:55	ESIT2022-0829-6 **Spatial description theory as a complementary of the semiconductor transport equation for HgCdTe single-carrier avalanche infrared photodetector** Runzhang Xie, Shanghai Institute of Technical Physics, CAS
16:55-17:05	ESIT2022-0814-5 **CdTe/PbTe heterojunction grown by molecular beam epitaxy for high-Performance mid-wavelength infrared photovoltaic detectors** Yao Wang, Zhejiang University

17:05-17:15	ESIT2022-0815-12 **Research on High Gain-bandwidth Product Mid-wavelength Infrared HgCdTe Avalanche Photodiodes** Hao Xie, Shanghai Institute of Technical Physics, CAS
17:15-17:25	ESIT2022-0822-1 **Study of 5μm pixel pitch InGaAs detector** Yu Tian, Shanghai Institute of Technical Physics, CAS
17:25-17:35	ESIT2022-0820-4 **Test and analysis of multi-spectral infrared radiation features of the tank vehicle under camouflage** Zengwei Wang, Shanghai Institute of Technical Physics, CAS
17:35-18:30	Poster Session
18:30-20:30	Banquet
Sep. 19, Room 105A	
Presider: Donghai Wu, Institute of Semiconductors, CAS	
8:30-9:00 (Keynote)	**Progress in monolithic optoelectronic devices composed of 2D materials** Jianbin Xu, Chinese University of Hong Kong
9:00-9:20 (Invited)	**New photo-thermoelectric detectors: from infrared to terahertz** Yating Zhang, Tianjin University
9:20-9:40 (Invited)	**Narrow-gap 2D semiconductors for infrared and terahertz optoelectronics** Kai Zhang, Suzhou Institute of Nano-Tech and Nano-Bionics, CAS
9:40-9:50	ESIT2022-0524-1 **Simulation of SAGCM structure InGaAs/InP SPAD Using COMSOL multiphysics** Rui Yang, Huazhong Institute of Electro-Optics
9:50-10:00	ESIT2022-0805-3 **Bandwidth characterization and optimization of MWIR HgCdTe e-APDs** Liqi Zhu, Shanghai Institute of Technical Physics, CAS; ShanghaiTech University
10:00-10:10	ESIT2022-0801-2 **Complete and robust energy conversion by sum frequency generation based on Invariant Engineering** Congfu Zhang, Xi'an Institute of Optics and Precision Mechanics, CAS

10:10-10:25	Coffee break
Presider: Kai Zhang, Suzhou Institute of Nano-Tech and Nano-Bionics, CAS	
10:25-10:45 (Invited)	**Mid-infrared chalcogenide-silicon hybrid integrated photonics** Hongtao Lin, Zhejiang University
10:45-11:05 (Invited)	**Si based GeSn material and devices** Chuanbo Li, Minzu University of China
11:05-11:25 (Invited)	**Enhancing graphene detector performance at near infrared region with organic heterojunction** Jun Wang, University of Electronic Science and Technology of China
11:25-11:45 (Invited)	**Optoelectronic devices based on near infrared colloidal quantum dots** Wenhan Cao, ShanghaiTech University
11:45-11:55	ESIT2022-0810-3 **Subwavelength thin-film stack metamaterials: theory and applications** Zhengji Wen, Shanghai Institute of Technical Physics, CAS
Presider: Peng Wang, Shanghai Institute of Technical Physics, CAS	
13:30-13:50 (Invited)	**HgCdSe semiconductors for applications in next generation infrared detectors** Wen Lei, University of Western Australia
13:50-14:10 (Invited)	**High-mobility narrow-bandgap III-V nanowires for infrared detectors** Zaixing Yang, Shandong University
14:10-14:30 (Invited)	**High performances two dimensional materials based photodetector** Yongzhe Zhang, Beijing University of Technology
14:30-14:40	ESIT2022-0814-8 **Room-temperature operating PbSe infrared photoconductive detector arrays** Ziyang Ren, Zhejiang University
14:40-14:50	ESIT2022-0806-11 **Structural design and fabrication of hollow optical fiber for transmitting mid-infrared and visible light** Shuoying Yu, East China Normal University
14:50-15:00	ESIT2022-0821-18 **Study on Reset Time Extended CDS forlow noise hyperspectral infrared focal plane readout circuits** Shuang Wu, Shanghai Institute of Technical Physics, CAS

15:00-15:10	ESIT2022-0821-21 **Design and simulation of Anti-reflecting nanostructure for Visible shortwave infrared focal plane array detector** Xiaoyuan Yu, Shanghai Institute of Technical Physics, CAS
15:10-15:25	Coffee break
Presider: Jiaming Hao, Fudan University	
15:25-15:55 (Keynote)	**The performance of the HOT LWIR interband cascade detectors** Martyniuk Piotr, Military University of Technology
15:55-16:15 (Invited)	**HgTe colloidal quantum dots: from synthesis to infrared photodetectors** Xinzheng Lan, Huazhong University of Science and Technology
16:15-16:35 (Invited)	**High-speed type-II superlattice photodetectors** Baile Chen, ShanghaiTech University
16:35-16:45	ESIT2022-0822-24 **The key technology of rapid refrigeration and precise temperature of cryogenic optical infrared camera** Hui Geng, Shanghai Institute of Technical Physics, CAS
16:45-16:55	ESIT2022-0812-6 **The magic of III-Vs** Yonggang Zhang, Shanghai Institute of Technical Physics, CAS
16:55-17:05	ESIT2022-0815-15 **Developments and characterization of HgCdTe e-APDs at SITP** Huijun Guo, Shanghai Institute of Technical Physics, CAS
17:05-17:15	ESIT2022-0815-9 **In-situ ellipsometric study on composition-dependent short-wave HgCdTe in the process of molecular beam epitaxy growth** Liao Yang, Shanghai Institute of Technical Physics, CAS
17:15-17:25	ESIT2022-0819-12 **Study on surface pretreatment of CdZnTe substrates for MBE HgCdTe films** Yangrong Liu, Shanghai Institute of Technical Physics, CAS
17:25-17:35	ESIT2022-0820-12 **Observation of sunspots at He I 10830Å using a low-noise InGaAs infrared detector** Baicheng Sun, Shanghai Institute of Technical Physics, CAS
17:35-17:45	ESIT2022-0821-7 **Overview of the development of astronomical infrared detectors** Yongsheng Xiang, Yunnan Normal University

Recent hotspots and innovative trends of infrared photon detectors

Zhenhua Ye
Key Laboratory of Infrared Imaging Materials and Detectors, Shanghai Institute of Technical Physics, Chinese Academy of Science, China

Infrared detection technology usually works in the passive sensing mode and contains the advantages of long acting-distance, good anti-interference, excellent penetration of smoke and haze, and all-day operation, which has been widely used in space remote sensing, military equipment, astronomical detection and other aspects. So far, second-generation and third-generation infrared photodetectors have been deployed widely. High-end third-generation infrared photodetectors have been gradually promoted to practical application. Fourth generation and more forward-looking research including new concept, new technology, new device has been proposed. This presentation focuses on the research status of infrared technology at home and abroad, emphatically introducing the hot spots and development trends of infrared photodetectors. Firstly, the concept of SWaP3 is introduced due to tactical ubiquity and strategic high performance. Secondly, the high-end third-generation infrared photodetectors with ultra-high spatial resolution, ultra-high energy resolution, ultra-high time resolution and ultra-high spectral resolution are reviewed. Technical characteristics and implementation methods of ultimate-performance infrared detectors are analyzed. Then, the fourth-generation infrared photodetector based on the artificial micro-structure is discussed. The realization approaches and technical challenges of multi-dimensional information fusion such as polarization, spectrum and phase are mainly introduced. Lastly, highly innovative trends of future detectors are discussed according to upgradation from on-chip digitization to on-chip.

Innovative path to improve the performance of InAs/GaSb type-II superlattice photodetectors

Donghai Wu, Zhichuan Niu
1Institute of Semiconductors, Chinese Academy of Sciences, China
2Center of Materials Science and Optoelectronics Engineering，University of Chinese Academy of Sciences, China

Since its proposal by Sai-Halasz and Esaki in the 1970s, InAs/GaSb type-II superlattice(T2SL) material has been extensively studied and appears to be an excellent candidate for giving breakthroughs in infrared technology. InAs/GaSb T2SL material has many advantages such as its unique band structure engineering capability, innovative design of device structure, Auger recombination suppression, large carrier effective mass and excellent material uniformity. With the development of molecular beam epitaxy (MBE) growth technology and the maturity of GaSb substrate, infrared photodetector based on InAs/GaSb T2SL material has experienced a rapid development over the past decade. High performance focal plane arrays (FPA) from short-wavelength (SWIR) to very long wavelength (VLWIR) infrared spectral bands have been demonstrated and its performance has reached a comparable level with the state of the art HgCdTe detectors. As one research group from Institute of Semiconductors, CAS, we are devoted to develop high performance InAs/GaSb T2SL photodetectors. With constant efforts during the past ten years, many important breakthroughs have been made including focal plane array from SWIR to VLWIR and SWIR/MWIR、MWIR/LWIR、LWIR/LWIR dual band focal plane array. In this report, we will review part of the past achievements and present some of our recent breakthroughs.

Recent progress of Infrared photodetectors driven by local field

Peng Wang
Shanghai Institute of Technical Physics, Chinese Academy of Sciences

In the past decades, infrared (IR) photodetectors have been widely applied in remote sensing, medicine, communication and many other important fields. The smaller size, lighter weight, lower power, higher performance and lower price are expected in the next generation IR detection system. In recent years, many new types of advanced IR photodetectors with extraordinary designs, operating modes and materials come to the fore quickly. Here, we will introduce the progress and challenges of IR technology and give a report on our progress in the development of novel IR photodetectors.

The study of condensed matter spectroscopy on ferroelectric oxides

Zhigao Hu
East China Normal University

The studies of lattice structure and phase transition of matter and phonon-electron coupling property are of fundamental interests in condensed matter physics and material science. The structure characteristics could determine the variety of functionalities and some potential applications of material. Many mature characterization techniques have been used to probe the lattice structure and phase transition so far, such as X-ray diffraction, Neutron scattering technology, temperature dependence of dielectric constant, spectroscopic ellipsometry (SE), infrared spectroscopy (IR) and Raman scattering, etc. IR and Raman scattering spectroscopies are complementary and highly sensitive to small distortions of the structural (ferroelectric-paraelectric phase) or non-structural (ferromagnetic-paramagnetic phase) transition on molecular scale. Simultaneously, SE could determine the dielectric functions and optical transition behaviors of materials. These condensed matter spectroscopic methods can provide many significant physical evidences on the structure property, such as phonon and soft mode behavior, dielectric function, optical transition, etc.

The performance of the HOT LWIR interband cascade detectors

Martyniuk Piotr
Military University of Technology

This talk presents an interband cascade photodetector performance designed for longwave infrared range (LWIR) and high operating temperature (HOT) conditions. The device was developed and fabricated based on the type-II superlattice (T2SLs) "Ga-free" InAs/InAsSb to include active layer, contact layers and tunneling regions. The detector reached detectivity, D* ~ 3×107 cmHz1/2/W for temperature, T = 300 K and LWIR ~ 10 μm.

InP/InGaAs Shortwave Infrared Single-Photon Avalanche Detectors

Chen Liu
Yunnan University

InP/InGaAs single-photon avalanche diodes (SPADs), which combine the advantages of short-wavelength infrared detection, single-photon performance, sub-nanosecond response time, and miniaturization, have been widely employed in fields such as quantum key distribution, eye-safe time-of-flight laser ranging, non-line-of-sight imaging, and time-resolved photoluminescence. At present the InP/InGaAs SPADs have been well developed and produced as commercial products, and the performance is still being continuously optimized to obtain lower dark counts, higher maximum count rate and higher operation temperature in Europe and the United States. There are distinct performance improvement on the domestic InP/InGaAs SPADs concerning the device specification and stability. This paper first analyzes the development of the InP/InGaAs SPADs, and introduces some research work on the InP/InGaAs SPADs including the design, processing and performance measurement.

Polarization-Sensitive Photodetectors based on 2D Layered Semiconductors

Zhongming Wei
Institute of Semiconductors, Chinese Academy of Sciences

Two dimensional (2D) materials have been attracting wide interest due to their peculiar structural properties and fascinating applications in the areas of electronics, optics, biology, and catalysis. As the promising substitutes for the gapless graphene, transition metal dichalcogenides (TMDCs, such as MoS_2, WS_2, etc.) which also have layered crystalline structure with strong in-plane bonding but weak interlayer action (van der Waals force) show natural band gaps. Photodetectors with high polarization sensitivity are in great demand in advanced optical communication. Here, we demonstrate that photodetectors based on 2D layered GeSe, $GeSe_2$ and GeAs, which are extremely sensitive to polarized light (from visible to the infrared), due to its reduced in-plane structural symmetry. The polarimetric image sensor based on GeSe also showed high performance.

Progress in Monolithic Optoelectronic Devices Composed of 2D Materials

Jianbin Xu
Chinese University of Hong Kong

Innovative optical payloads and big data technologies support for the realization of SDGs

Fansheng Chen
Shanghai Institute of Technical Physics, CAS

Narrow-gap 2D Semiconductors for Infrared and Terahertz Optoelectronics

Kai Zhang
Suzhou Institute of Nano-Tech and Nano-Bionics, CAS

Narrow-gap semiconductors like III-V/II-VI materials and their superlattices boost the infrared (IR) and terahertz (THz) technologies and play a critical role in the fields of security inspection, bio-medical imaging, free-space communication, gas detection, and so on. Nowadays, conventional IR and THz devices encounter great challenges referring to the complex structures and expensive epitaxy growth, incompatible with silicon chips, etc. The rising of two-dimensional (2D) materials, with the advantages of atomic thickness, van der Waals integration and fantastic physical characteristics, paves the way for the evolution of advanced optoelectronics. For this end, we have paid our continuous effort on the growth and band engineering of novel narrow-gap 2D semiconductors and their applications in IR & THz devices, especially for lasers and photodetectors.

Mid-infrared chalcogenide-silicon hybrid integrated photonics

Hongtao Lin
Zhejiang University

Mid-infrared (MIR) range (2-20 μm) is a significant wave band that plays an important role in various applications, including thermal imaging, spectroscopic sensing, medical diagnosis, communication, industrial environmental monitoring. High-performance waveguide-integrated MIR photonic devices are promising for MIR optical communication networks and on-chip optical sensing systems. In this talk, we will present our recent works on the integrated silicon and chalcogenide photonic devices for the 2-micron wavelength range, which include high speed waveguide integrated Te photodetectors, novel inverse design devices, etc.

Si based GeSn materials and devices

Chuanbo Li
Minzu University of China

With the quick developments of Si integrated circuits (ICs), traditional electric interconnect cannot meet the demands of bandwidth and low power consumption. Optical ineterconnect has many advantages, such as high speed, high bandwidth, and low power consumption. Therefore, people greatly demand Si-based optical interconnect for chip-to-chip and on-chip data transmissions. Although Si is good material for microelectronic, its indirect bandgap characteristic limits its application in optical devices. One of the key points is to integrate the direct materials on Si. Several experimental results have proven that new IV materials SnGe materials would transform from an indirect semiconductor to a direct one at a Sn concentration of approximately 7%–8%. However, the epitaxy of high-quality GeSn alloy on Si substrate is extremely difficult given the large lattice mismatch between Si and GeSn (>4.2%). To obtain high-quality GeSn epitaxy on Si, the low-temperature strategy is commonly used to grow Ge virtual buffer, which has been proven to improve the quality of the GeSn alloy remarkably. Growing low-defect GeSn materials on the Si substrate remains a huge challenge. In this talk, a new strategy to grow defect-free GeSn alloys with a Sn content of 5.26% directly on Si substrates by Sn self-catalyzed molecular beam epitaxy (MBE) growth will be presented. Sn concentration changes linearly with Ge deposition temperature and can reach 5.26% using the proposed approach. The GeSn heteroepitaxial has been proven to be of good crystalline quality by TEM. The largest defect-free area can reach 3 μm × 10 μm, whereas the smallest one can be reduced down to nanoscale by adjusting the experimental conditions. The growth of GeSn on patterned substrate and the application of the GeSn in photodetection application are also discussed.

Enhancing graphene detector performance at near infrared region with organic heterojunction

Jun Wang
University of Electronic Science and Technology of China

Graphene indicates promising potential in fabricating phototransistor and photo- detector due to its unique band structure with prominent optoelectronic and charge transportation properties. However, inferior light absorption rate of single atomic layer graphene limits photodetector performance. The graphene/ semiconductor hetero- junction is an effective strategy to break the intrinsic limit absorption of graphene and enhance phototransistor performance including Quantum dots enhanced structure, stacked graphene heterojunction structure, graphene planar structure, dual photogating phototransistor, waveguide-integrated enhanced and bilayer enhanced structure. In this report, we introduced several methods to enhance detection performance of graphene detector at near infrared region using organic heterojunction structure. High device detectivity, fast response speed, and multi-function adjusting graphene devices were obtained with the graphene/organic heterojunction structure.

Optoelectronic devices based on near infrared colloidal quantum dots

Wenhan Cao
ShanghaiTech University

Semiconductor quantum dots are zero-dimensional nanoparticle structures whose excitons are confined in three spatial directions. Interestingly, these nanoparticles can produce significant and efficient photoluminescence and electroluminescence effects under the excitation of external fields. Therefore, not only are quantum dots widely used in the field of biomedical engineering, especially for optoelectronic sensing and detection. But also, they provide important measurement and characterization tools for various fields such as nanotechnology, materials science, biology and surface science. Here, we combine colloidal near-infrared quantum dots with flexible polymeric substrates and realized measurements and detection based on the interplay of the spatial distribution of quantum dot nanoparticles and the external electric fields, to better facilitate potential adaptation to wearable optoelectronic devices. Firstly, by observing the corresponding Boltzmann distribution of the quantum dot particles in aqueous solution corresponding to the non-uniform electric field created by the interdigitated electrodes that are confined in a fluidic cell, we quantify and measure the polarizability of the single quantum dot particle, which enables us to inversely obtain the electric field intensity to realize the sensing capability. This gives us important information for analyzing and predicting the collective behavior of quantum dot particles in response to a customized external electric field. At the same time, in order to improve the understanding of manipulation of the movement of the colloidal nanoparticles using electric fields, the unique local electric field intensity and geometry induced by the anisotropy of various particle shapes that could be synthesized using seed mediated methods is studied, which provides a helpful reference for designing manipulation electrodes in a different but three-dimensional way. Then, a directed self-assembly of nanoscopic quantum dot particles starting from the uniform and even distribution under a specially designed external electric field is constructed to end up forming a macroscopic hierarchical cellular phase structure for the first time, which provides new possibilities for the preparation of complex flexible micro-nano photoelectric sensing structures and building energy storage devices. The formed structure features a percolating network with numerous voids that resembles the structure of soap bubbles while the interconnect materials here are quantum dots instead of soap liquid. Finally, through the combination of near-infrared quantum dots array and flexible substrates, and by the use of fluorescence resonance energy transfer phenomena, where of emission spectra of the quantum dots can be found changing drastically when donor and acceptor quantum dot nanoparticle are getting close enough, we propose the construction of a high-throughput, resolution and large field-of-view, ultrafast imaging system, which provides an effective method and instrumentation that can be applied to the imaging of large scale integrated circuits and the examination of biomedical and biological samples, and very importantly, novel flexible wearable detectors.

HgCdSe semiconductors for applications in next generation infrared detectors

Wen Lei
University of Western Australia

The rapid development of infrared (IR) imaging applications requires next generation IR detectors and their focal plane arrays to have features of lower cost, larger array format, and higher operating temperature. However, current state-of-the-art CdZnTe-based photovoltaic HgCdTe IR detectors are seriously limited by their higher cost, smaller array format size, and lower operating temperature (usually 77K). HgCdSe, a material having similar infrared capabilities to HgCdTe, is close to being lattice-matched to GaSb substrates, which are readily available as epi-ready substrates with features of low cost, large wafer size (up to 6 inch diameter) and low defect density (as low as 500 cm^{-2} in terms of etch pit density). The successful growth of device quality HgCdSe on GaSb would address the primary challenges confronted by current HgCdTe detector technology. In addition, HgCdSe belongs to the family of materials with lattice parameters close to 6.1Å, including ZnTe, GaSb, and InAs, which makes possible the nBn detector structures as well as the monolithic integration of detector devices capable of sensing different wavelength bands on a single chip. In this work, we will report our recent progress on developing high quality GaSb-based HgCdSe semiconductors for fabricating next generation infrared detectors with features of lower cost, larger array format, and higher operating temperature. High quality HgCdSe epilayers are grown on GaSb (211)B substrates with a XRD (X-ray diffraction) FWHM (full-width at half-maximum) as small as 55 arc sec *via* molecular beam epitaxy (MBE). The growth temperature window (~ 20°C) for achieving high quality HgCdSe epilayers is found to be much wider than that for HgCdTe (~ 5°C), which makes high quality MBE growth of HgCdSe more accessible to industry manufacture. The as-grown $Hg_{1-x}Cd_xSe$ samples have a range of x-values (x= 0.37 to 0.18) and cut-off wavelengths (λ_c= 3.9 mm to 10.4 mm at 80K), and show typical n-type semiconductor behaviour. At a measurement temperature of 80K, the as-grown HgCdSe samples with x=0.18 present a cut-off wavelength of 10.4 mm, an electron mobility as high as 1.3×10^5 cm^{2}V^{-1}s^{-1}, a background electron concentration as low as 1.6×10^{16} cm^{-3}, and a minority carrier lifetime as long as 2.2 ms. These values of XRD FWHM, electron mobility and minority carrier lifetime represent a significant improvement over previous studies of MBE-grown HgCdSe reported, and are comparable to those of corresponding CdZnTe-based HgCdTe materials. This high material quality is primarily due to the nearly lattice-matched epitaxial growth of HgCdSe on GaSb, as well as optimised growth conditions and thermal cleaning processes. In addition, the photoconductor detectors based on these HgCdSe materials also present encouraging device performances. These preliminary results indicate that GaSb-based HgCdSe materials can meet the basic material quality requirements for fabricating high performance infrared detectors, although further effort is required to reduce the background electron concentration to <10^{15}cm^{-3}. The results of this study show the great potential of GaSb-based HgCdSe materials for making next generation infrared detectors with features of lower cost, larger array format size and higher operating temperature.

High-mobility narrow-bandgap III-V nanowires for infrared detectors

Zaixing Yang
Shandong University

As a typical p-type III-V semiconductor, GaSb holds a narrow bandgap of 0.72 eV and a high hole mobility of 1000 cm^{2}V^{-1}s^{-1}, showing promising applications in next-generation high-performance room-temperature infrared (IR) detectors and p-type building blocks in the modern chips. However, controllable growth of high-quality thin GaSb NWs with high mobility is the key point for achieving high-performance IR detectors. Here, a simple and low-cost growth method of surfactant-assisted chemical vapor deposition has also been developed for the controllable growth of GaSb NWs. When configured into NWs array IR detector, the fabricated device exhibits a photo-responsivity of 61 AW^{-1}, and a fast response with the rise and decay time constants of 221 and 380 μs, respectively, under the illumination of 1550 nm infrared light.

High performances two dimensional materials based photodetector

Yongzhe Zhang
Beijing University of Technology

Photodetection on intensity, polarization and frequency of lights are significant and widespread in modern society scientific research and industrial production. The current instruments are usually bulky and expensive, especially for the polarization and frequency probing. Two-dimensional (2D) materials based optoelectrical devices have attracted lots of attention in next generation of high-performance optoelectronics integrated applications due to the perfect dangling bond-free surface, external field tunability and natural anisotropy. This provides more opportunities to achieve multi-dimensional light detection upon low cost, low power consumption and ultra-miniaturized size. We hence put forward a series of 2D heterogeneous integration design based on energy band engineering and external field modulation. First, a concept of in memory sensing is implemented, where highly sensitive detection and storage for UV light are realized. Secondly, switchable photoelectrical response mechanism is developed, which enables the on-chip full linear polarimetry. Thirdly, electrically tunable interlayer exciton absorption is explored, based on which an ultra-miniaturized near infrared spectrometer with footprint <10 μm is demonstrated.

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HgTe colloidal quantum dots: from synthesis to infrared photodetectors

Xinzheng Lan
Huazhong University of Science and Technology

HgTe colloidal quantum dots (CQDs) promise good applications as infrared photodetectors in terms of their widely-tunable photoresponse and good compatibility with Si electronics for device integration. The applications of HgTe CQD, however, are limited by the use of aggregated CQDs. We developed a ligand-engineered approach that successfully addresses this issue and produces well-separated HgTe CQDs. This approach first employs strong-binding alkyl thioalcohol ligands to enable the synthesis of well-dispersed HgTe cores, followed by a second growth process and a final post-ligand modification step enhancing their colloidal stability. The resultant monodisperse HgTe CQDs are available in a wide size range, from 4.2 to 15.0 nm with sharp excitonic absorption fully covering short- and mid-wave infrared regions, together with a record electron mobility up to 18.4 $\mathrm{cm^2V^{-1}s^{-1}}$. Photodetectors with a 1.7 μm cutoff absorption edge show a room-temperature detectivity of 3.9×10^{11} Jones.

High-speed type-II superlattice photodetectors

Baile Chen
ShanghaiTech University

High-speed extended short wavelength infrared (eSWIR)/mid wavelength infrared (MWIR) photodetectors have many important applications such as frequency comb spectroscopy, next generation optical fiber communication, and others. In this work, I will report high-speed photodetectors with type-II superlattice as an absorber for eSWIR and MWIR detection.

New photo-thermoelectric detectors: from infrared to terahertz

Yating Zhang
Tianjin University

Terahertz wave, as the intersection of microwave and infrared, is the transition frequency band between electronics and photonics. It has a wide range of important applications, due to the advantages of high penetration, low photon energy and large electrical bandwidth, where terahertz detectors play an important role. However, the performance of terahertz detectors is limited by low responsivity, low working temperature, or low response speed. Recently, many new thermoelectric materials have been used as working materials for terahertz detection. Those new materials include two-dimensional materials, carbon nanotubes, three-dimensional graphene, topological alloys and perovskite. Especially, the addition of perovskite and three-dimensional materials has brought breakthroughs in the performance. Since 2020, our research group has reported a series of terahertz detectors based on perovskite and 3D graphene, achieving quite good performance. The MAPBI3 detector has a response of 273 mA/W to 2.52 THz and a response time of 76 ns; 3D graphene detector showed wide response range from ultraviolet to terahertz, with response time of 43 ms, 50mA/W @2.52THz

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Spatial description theory as a complementary of the semiconductor transport equation for HgCdTe single-carrier avalanche infrared photodetector

Runzhang Xie*; Weida Hu
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The infrared photodetector is very important for 24 hours remote sensing in military applications. As well as civilian applications such as medical imaging and weather forecasting. In recent years, the application of space lidar, high-speed optical communication, infrared quantum communication, and high sensitivity and low noise detection shows the high demand for low power dissipation, high gain, and high signal-to-noise ratio infrared photodetectors. One promising technique is the narrow bandgap avalanche photodetector. Especially the MCT single carrier avalanche photodetector, which has very high gain, low excess noise factor, low operating bias voltage, and high speed at the same time. With the carefully designed structure introduced below, the MCT avalanche photodiode could work at higher temperatures as well.

Avalanche process in the MCT is very complex. Following only the avalanche theory designed for semiconductors with a relatively wide bandgap is not accurate enough. A new theory should be built based directly on the dominant microscopic processes of MCT. The transport of carriers in the semiconductor is described by the semiconductor transport equation, which is derived from the Boltzmann transport equation. There are four assumptions in deriving the semiconductor transport equation.

First, the time scale of interest is much larger than the mean free time. This assumption still holds. And the time scale of interest is at most to the order of sub-nanosecond.

Second, the scattering should be local both in time and space. Alloy scattering and other scattering provide a large-angle change of momentum and change the trajectory of electrons enormously, this will introduce scattering dependent scattering event into the system, which is history-dependent scattering. Thus, the scattering is not local in time and space. This assumption could be deleted if the spatial coordinate of every carrier is specified.

Third, the scattering should be weak. The reason is the same as in the second assumption, as well as the solution.

Last, the external field should be small enough. In an avalanche photodiode, the electric field and the derivative of the intensity of the electric field are very large to achieve high electron acceleration efficiency. This assumption could be deleted if the spatial coordinate of every carrier is specified.

For the calculation of the excess noise factor, we only need to calculate the probability distribution function of the multiplication. Because the dark and light multiplication is calculated separately, the excess noise factors of light and dark excess noise factor could also be derived separately.

In conclusion, Avalanche in narrow-bandgap semiconductors is more sensitive to carrier energy and direction. As mentioned above, many assumptions in the semiconductor transport equation are not satisfied in describing narrow-bandgap semiconductors, especially HgCdTe, avalanche process. This is the result of that the method in the classical theory of the semiconductors transport equation describing a group of carriers that is no longer suitable. Based on the abstraction of APD measurement, the spatial description theory swaps the roles of temporal- and spatial- coordinates in the semiconductor transport equation and constructs an avalanche theory suitable for narrow-bandgap semiconductors, especially HgCdTe.

ESIT2022-0814-5

CdTe/PbTe heterojunction grown by molecular beam epitaxy for high-Performance mid-wavelength infrared photovoltaic detectors

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Objective and purpose: Mid-infrared (MIR) detectors play a pivotal role in aerospace, greenhouse gas detection and many other fields. For a photodetector, both sensitivity and response time are critical parameters for application scenarios. It is known that photodetectors based on II-VI compound semiconductor (such as HgCdTe) and III-V compound semiconductors (such as IbSb and InAs/GaSb SLs), show high detectivity and high-speed at low temperature such as 77 K. However, at room temperature their performance sharply deteriorates. PbTe and PbSe are IV-VI compound semiconductors with narrow and direct band gaps, which were widely used in traditional MIR detectors for long history, but low speed of the IV-VI compound detectors limited their application scenarios. Recently, we have realized a two-dimensional electron gas (2DEG) system with high concentration of electrons and high mobility at interface of II-VI/IV-VI compound semiconductor heterostructures (such as CdTe/PbTe and ZnTe/PbTe). It is revealed that fewer scattering centers exist in the naturally formed 2DEG of heterojunction than the 2DEG implemented by extrinsic doping, which renders high mobility of carriers in the unique 2DEG system. MIR photodetectors with high-speed and high sensitivity based on CdTe/PbTe heterojunction have been developed.

Methods:

Film Deposition: High-quality CdTe/PbTe heterostructure films were carried out on freshly cleaved (111) oriented BaF2 in a solid-state MBE system. A CdTe compound effusion cell was used for CdTe growth. A PbTe compound effusion cell and an additional Te effusion cell were used for PbTe growth. 3μm PbTe was deposited first at a growth rate of 1.0μm/h as the PbTe/Te flux ratio was 7. Then 100nm CdTe was deposited at a rate of 0.60μm /h. The streaky reflection high-energy electron diffraction (RHEED) patterns and high-resolution X-ray diffraction (XRD) patterns were observed which illustrates the good quality of CdTe/PbTe heterojunction. After film deposition, the device was fabricated by those steps: (i) wet etch a conductive channel as a 600μm ×800μm rectangle; (ii) deposit Cr/Cu by the magnetron-sputtering method and employ lift-off to form the electrode; (iii) A 10-min annealing at 150°C is used to diffuse the Cu into the 2DEG channel to form ohmic contact; (iv) deposit insulation layer on part of the CdTe surface; (v) deposit Cr/Au masking layer by magnetron-sputtering and lift-off method. A measurement system is employed for photocurrent response spectra, which is consisted of SiC blackbody light source, SRS-SR540 chopper, Zolix Omini-λ 300 grating monochromator, SRSSR570 preamplifier and SRS-SR830 lock-in amplifier.

Results: RHEED and XRD results indicate the high quality of the CdTe/PbTe film grown by MBE. The response spectrum of our detector covers 2 ~ 4 μm, and the peak detectivity is as high as 4 × 109 Jones at room temperature. Measured impulse responses and the noise power spectra at various low temperatures indicate that our detector performed excellently at low temperatures as well. At 180K, the highest peak detectivity of 1.7×1011 Jones is achieved, also with an extremely fast response time.

Conclusion: In our work, MBE was utilized for high-quality CdTe/PbTe heterostructure growth. CdTe/PbTe heterostructure was applied to fabricate MIR photodetectors with a masking layer to introduce a lateral photovoltaic effect. The fast relaxation mechanism of photogenerated carriers in PbTe and the high mobility property of the 2DEG at the CdTe/PbTe interface are employed for the extremely fast response time with high peak detectivity.

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Research on High Gain-bandwidth Product Mid-wavelength Infrared HgCdTe Avalanche Photodiodes

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HgCdTe avalanche photodiodes (APD) have been demonstrated to be one of the most promising paths for low flux and high speed applications, such as free space laser communication and hyper spectral imaging. In free space laser communication and hyper spectral imaging applications, the number of photons is detected decreases rapidly, and the acceptable data rate is limited by the following two factors: one is the possible bandwidth to achieve photon discrimination accuracy, the other is the sufficient output power of the laser within a very narrow pulse width. High-performance HgCdTe electron avalanche photodiodes (e-APD) detectors have been demonstrated due to its considerable high internal gain and low excess noise. Besides, the bandwidth of the device is determined by the response time, which is mainly resultant of i) the diffusion time of minority carriers in the absorption region, ii) the transit time of carriers generated by the avalanche process in the multiplication region and iii) the RC time constant. A number of well-known infrared detector research institutions such as DRS and CEA/Leti have carried out in-depth theoretical and experimental research on the bandwidth of HgCdTe APD devices, and obtained focal plane devices with a bandwidth of 200 MHz~4 GHz, which have been successfully used in the lunar laser communication demonstration (LLCD) and is expected to open a new horizon of applications in quantum optics and deep space optical telecommunications.

In the earlier years, Emmons formulated the response time theory of avalanche photodiodes that the bandwidth of the transit-limited decreases as the gain increases when the gain (M) is more than the inverse of hole-electron ionization coefficient ratio (1/k). Therefore, the bandwidth of HgCdTe e-APD has been theoretically predicted to be independent of the gain, own to its strongly dominant electron multiplication (quite low k-factors), which show the capacity to obtain high gain-bandwidth products. However, when the photocurrent is high, a large number of electrons exist in the depletion region, and the electrical field in the depletion region might collapse due to the space charge effect, thus limiting the increase of the gain-bandwidth product. The experimental results also proved that the device bandwidth actually decreases with the increase of the gain while the bias voltage and photocurrent exceed a certain value. This work studied the effect of the light injection dose on the electric field, gain and bandwidth of the device, and the structure of the device was optimized by simulation. Finally, a Mid-wavelength Infrared HgCdTe e-APD device whose bandwidth doesn't decrease with the increase of gain is fabricated, which lays the foundation for a record high gain-bandwidth product device in the future.

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Study of 5μm Pixel Pitch InGaAs Detector

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Short-wave infrared detectors are widely used in medical, defense and industrial fields. Infrared detector made of lattice matched In0.53Ga0.47As/InP has the advantages of high quantum efficiency, high sensitivity and other advantages in the short-wave infrared band. In particular, the InGaAs detector still has good performance at room

temperature, which can reduce the limitations of refrigeration equipment and make it have great advantages in miniaturization and low cost . Decreasing the pixel pitch of the detector is not only beneficial to reduce the size, weight, power consumption and cost of the detector system, but also conducive to improve the imaging spatial resolution and operating temperature, thus increasing the system functionality and the value of the imaging system in a given space. However, as the pixel pitch of facial plane arrays continues to decrease, when the diffusion length of carriers generated by incident light is greater than the pixel pitch of pixels, the detector array will generate large dark current and crosstalk, which will lead to the reduction of MTF, and finally the image sensor imaging quality deteriorates. The fabrication of ultra-small pixel focal plane detectors requires not only the exploration of fabrication technology, but also solve the challenge that the crosstalk between pixels increases as the pixel pitch decreases. This paper combines the features of low dark current of plane-type detector and low electrical crosstalk of mesa-type detector, innovatively introduces a micro-mesa structure detector. The micro-mesa structure detector fabrication process was explored, including the micro-mesa isolation trench fabrication process, the isolation trench etching process and the micro-mesa passivation process, then successfully fabricated 5μm pixel pitch micro-mesa InGaAs infrared detector test structures. By designing the crosstalk test structures, the crosstalk signal of the pixel to its nearest and next nearest 4 pixels was tested by using a blackbody radiation source, and the crosstalk suppression effect of the micro-mesa structure was investigated. The experimental results show that the crosstalk signal is 37.5 mV for the nearest 4 pixels and 38.3 mV for the next nearest 4 pixels of the planar device; when the isolation trench formed by etching (about 1.3μm) is deeper than the PN junction formed by diffusion(about 1.1μm), the crosstalk signal is 2.36 mV for the nearest 4 pixels and 3.8 mV for the next nearest 4 pixels, the crosstalk signal between pixels decreases by one order of magnitude than that of plane-type device. When the depth of the isolation trench formed by etching (about 0.7μm) is shallower than that of the PN junction formed by diffusion, the crosstalk signal strength of the micro-mesa device is comparable to the crosstalk signal of the plane-type device. That is, the isolation trench between pixels can effectively suppress crosstalk, but the isolation trench depth must exceed the PN junction depth. The dark current characteristics of micro-mesa type devices are further investigated, and the experimental results show that the dark current increases due to the material damage introduced by etching the pixel isolation trenchs . The dark current density of the 5 μm pixel pitch planar device is 1.14E-7A / cm2@-0.1V, which of the micro-mesa type device is 3.33E-6A/cm2@-0.1V, increases about 29 times than that of plane-type device. The paper also designed micro-mesa test structures with different isolation trench widths to investigate the dark current characteristics versus the etched isolation trench width, and the experimental results show that the device dark current is proportional to the trench width until the trench etching touches the area of the diffusion junction, where the dark current increases dramatically due to the exposure of the PN junction. The results of the paper provide a theoretical basis for the fabrication of 5μm pixel pitch InGaAs focal plane array (FPA) detectors.

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Simulation of SAGCM Structure InGaAs/InP SPAD Using COMSOL Multiphysics

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InGaAs/InP single photon avalanche photodiode (SPAD) is important for quantum communication, and LIDAR applications in the near-infrared (NIR) wavelength range, between 0.9 μm and 1.7 μm. Compared with other optoelectronic devices, SPAD has two main advantages: high quantum efficiency and high detection efficiency. In this study, the design and simulating of a separate absorption, grading, charge, and multiplication (SAGCM) sturcture InGaAs/InP SPAD were conducted by using COMSOL multiphysics. The electric-field distribution was studied under the given thickness and dopant concentration of each layer of the SPAD. It was found that the edge pre-breakdown of planar-type SPAD resulted from the intense electric field at the junction bend can be prevented from happening by using gaussian type dopant distribution profile. The punch-through voltage and the breakdown voltage were also focused. The results show that the punch-through voltage and the breakdown voltage was 55 V and 65V respectively. In addition, the electric field nonuniformity of the avalanche area increases greatly after the bias voltage exceeded the punch-through voltage.

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Bandwidth Characterization and Optimization of MWIR HgCdTe e-APDs

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Mid-wavelength infrared (MWIR) avalanche photodetectors (APD) detectors have attracted intensive interests due to the applications in chemical sensing, military and astronomical identification. Recently, the emergence of high-speed free-space optical (FSO) communication and dual frequency comb spectroscopy require the MWIR devices to operate with high 3 dB bandwidth, meanwhile maintaining high responsivity and low noise. In the earlier years, Emmons formulated the avalanche photodiodes response time theory that the bandwidth of the transit-limited decreases as the gain increases when the gain (M) is more than the inverse of hole-electron ionization coefficient ratio (1/k). This also implies that for the devices with lower k-factors, the bandwidth would be compromised at higher gains. Therefore, a high gain-bandwidth product is expected for Hg1-xCdxTe APDs with a composition x less than 0.5 due to the very low impact ionization of holes and high mobility of electrons. S. Pes et al. have also demonstrated an extended short-wavelength HgCdTe devices (lambda = 2.9 μm) with 450 MHz bandwidth for long-range free-space optical communication. Otherwise, the bandwidth characteristics of III-V pin and APDs have been demonstrated to exhibit excellent performance. However, the bandwidth of HgCdTe MWIR APD has been rarely reported so far.

The primary purpose of this work is to characterize and explore the high-speed performance of MWIR Hg0.69Cd0.31Te e-APD. The device with a 20 μm diameter shows a low dark current, high gain and low excess noise. The dark current is around 10-13 A in the low-bias range. A significant avalanche gain can be observed, which gradually increases and reaches up to 1356 under − 11.4 V. The experimental excess noise value F 1.3 is less than the theoretical limit of McIntyre. A high responsivity of 1.48 A/W at 4.5 μm wavelength is also demonstrated under zero bias. Here, a lateral-diffusion length of about 5.2 μmis found by characterizing the area-dependent responsivity of the devices. The response bandwidth of the devices is 635 MHz under − 1 V, which is mainly limited by the electron lateral diffusion process. Under lower bias below − 1 V, the bandwidth slightly increases with reverse bias. That is due to the increase of depletion region, causing a reduction of lateral diffusion time. As the reverse bias increases, the gain of the APD increases, leading to a slight decrease of bandwidth. On the other hand, the bandwidth decreases as the photocurrent increases, which could be due to the space charge effect. The RC-limited bandwidth of 6.5 GHz is extracted from the small signal equivalent circuit model. The series resistance Rs is extracted to be 586 ohm, which is relatively high, and may be due to the unoptimized Indium bump bonding process. Moreover, the depletion region thickness can also be estimated from the extracted junction capacitance by assuming the planar-junction device to be a vertical cylindrical capacitor and a parallel plate capacitor. To alleviate the slow lateral-diffusion process, an upside-down p-i-n structure is proposed to achieve a high gain-bandwidth product of the MWIR APD device. It indicates that over 30 GHz bandwidth and 1THz gain-bandwidth product can be realized with a 2 μm intrinsic region.

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Complete and robust energy conversion by sum frequency generation based on Invariant Engineering

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Infrared detection is a critical technique in many fields, such as in quantum optics, new light sources, holographic imaging, biological imaging and Sensing. Conventional infrared detection technology requires the use of semiconductor detectors in the infrared waveband, but semiconductor materials are difficult to overcome the sensitivity caused by thermal noise. Therefore, nonlinear optical frequency upconversion technology can be used as an alternative for infrared detection. This technology converts the target frequency to near-infrared or visible frequency, avoiding the technical difficulties of mid-far infrared detector. We propose an analytical method to achieve complete energy conversion in sum frequency generation based on Lewis-Riesenfeld invariants theory， which is named quasi-adiabatic (QA) single control parameter model ,and can achieve "shortcuts to adiabaticity" (STA) during frequency upconversion by designing the coupling coefficient and nonlinear crystal polarization period. In this way, the coupling coefficient is considered as single control parameter and the phase mismatch is a variable related to the coupling coefficient and propagation distance. By combining the Lewis-Riesenfeld invariants theory with the optimal control theory, the optimal schemes are robust against the different system perturbations respectively. This means these optimal schemes allow us to achieve a conversion efficiency of almost 100% at any crystal with wider wavelength bandwidth. Further, considering the crystal length L =1 mm as an example for numerical calculation, it shows that our scheme can provide efficient broadband sum frequency generation in the 2.6 μm - 3.6 μm wavelength range with a spectral bandwidth approaching to 400 nm bandwidth.

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Subwavelength thin-film stack metamaterials: theory and applications

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Subwavelength thin-film stack metamaterials, as a special group of metamaterials, have attracted much attention owing to their subwavelength thickness, ease of fabrication, low-cost and large-area fabrication capacities, etc. In this talk, the recent research progress of the theory and applications based on subwavelength thin-film stack metamaterials is reviewed. We first focus on the overview of the theoretical background and the newly developed techniques for subwavelength thin-film stack metamaterials. Then, we highlight the progress of recent applications, including structural colors, photoluminescence (PL) enhancement, thermal emitter, and infrared stealth, etc. Finally, the future opportunities and challenges for further research on the subwavelength thin-film stack metamaterials are also addressed.

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Room-temperature operating PbSe infrared photoconductive detector arrays

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Objective and purpose: Infrared focal plane arrays (IRFPAs) and linear detector arrays(LDAs) have been widely applied in the atmosphere monitoring, infrared imaging in space and military use. Currently IRFPAs based on HgCdTe, QWIP, and InSb materials have been fully investigated. However, because of the small bandgap and high background noise, it's necessary to cryogenically cool these IRFPAs to enhance the contrast in the infrared scene, which will increase cost and sacrifice the size of devices as a result of low operating temperatures. Lead salt semiconductor (PbSe, PbS and PbTe) is another type of infrared semiconductor material with narrow and direct bandgap which has been used for fire warning and gas analysis, etc. Detector arrays based on these materials have advantage of low cost of fabrication and room-temperature operation, so it's important to investigate the fabrication and imaging of IRFPAs and LDAs based on these semiconductors.

Methods of Fabrication and imaging: To fabricate 8×8 focal plane arrays and 64×2 linear arrays, we used a series of micro-nano fabrication processes which can be introduced as follows: (i) deposition of 200nm thick silicon dioxide(SiO2) passivation layer on the surface of PbSe; (ii) lithography of 8×8 cells' patterns; (iii) dry etching exposed area of SiO2 passivation layer by ICP method; (iv) wet etching photosensitive area of PbSe; (v) etching of the contact area and deposition of 200nm gold(Au) as a contact layer; (vi) deposition of 300nm SiO2 as an insulation layer in the intersection of longitudinal and traverse Au contact layer; (vii) etching of contact area and deposition of a 200nm Au contact layer. Fabrication process of PbSe LDAs is similar to that of IRFPAs, though there is no need to deposit an insulation layer as no intersection area exists. After the device has been fabricated, photoelectric performance was characterized. In our imaging system, a high-temperature solder tip was used as an imaging object and an optical lens was placed between object and detector. Through selecting different pixel of IRFPAs driven by a step motor and reading out the detector signal from external circuits, we obtained an infrared image of the solder tip. We also performed the imgaing experiment of LDAs in which the tip was moved step by step to obtain a complete image.

Results: The photoelectric performance of 8×8 IRFPAs was characterized using a blackbody with uniform illumination on the detector arrays. All pixel responsivity and noise equivalent temperature difference (NETD) were estimated and gave an average value of 110mA/W and 32mK, respectively. The responsivity uniformity of IRFPAs was calculated to be 0.18, which shows favorable uniformity, and characterization also gave an average detectivity of 5.5×109 cmHz1/2W-1 at room temperature. The images from LDAs and IRFPAs have been obtained, both of them gave a high-contrast IR image of the solder tip.

Conclusion: Through micro-nano fabrication process, we have fabricated 8×8 focal plane arrays and 64×2 linear arrays successfully, indicating the possibilities of fabricating 32×32 or larger scale IRFPAs; and the imaging system gave a high contrast image of the object, which would pave the way for investigating large-scale IRFPAs based on lead salt semiconductor.

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Structural design and fabrication of hollow optical fiber for transmitting mid-infrared and visible light

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Mid-infrared light is widely used in the field of laser medical treatment. As an important way for transmitting mid-infrared light, hollow optical fibers have the advantages of no end refection, good heat dissipation and small divergence. However, the existing mid-infrared hollow optical fibers still need to overcome the problems of high preparation costs, non-visibility and other issues. In our work, two facile ways are proposed to fabricate the hollow optical fiber for transmitting mid-infrared and visible light based on following common and low-cost materials: polytetrafluoroethylene (PTFE) tube, ultraviolet (UV) gel, polymethylmethacrylate (PMMA) optical fiber and acrylonitrile butadiene styrene (ABS) plastic. A PTFE/UV silica glass tube-based dual-core hollow optical fiber and a PMMA/ABS plastic-based hollow optical fiber are designed respectively to obtain the hollow optical fiber which possesses low cost, facile fabrication method and can simultaneously transmit mid-infrared and visible light. The fabrication procedure and transmission performance were also explored in this work.

For PTFE/UV silica glass tube-based dual-core hollow optical fiber, low-cost PTFE and UV gel were used as the low-refractive index layers. To obtain the dual-core optical fiber sample, the Ag/AgI hollow optical fiber was nested in the PTFE-coated silica glass tube, and they were connected by the UV gel filled in the gap. In this dual-core optical fiber, the silica glass annulus with an inner diameter of 1 mm and a thickness of 0.35 mm was used to transmit visible laser, and the transmission loss changed from 0.74 to 1.22 dB/m as the bending angel increased from 0° to 40°. The CO$_2$ laser beam was delivered through the Ag/AgI hollow optical fiber with an inner diameter of 700 μm and the transmission loss went up from 0.85 to 1.22 dB/m as the bending angle increased from 0° to 90°. The research results show that the PTFE/UV silica glass-based dual-core hollow optical fiber has low manufacturing cost and is capable for transmitting high-quality visible beams and CO$_2$ laser beams, which means that they have application potential in medical fields such as laser surgery.

For PMMA/ABS plastic-based hollow optical fiber, PMMA plastic optical fiber and ABS plastic were chosen as the main materials because of their high flexibility and low cost. To obtain the PMMA/ABS plastic-based optical fiber sample, the output end of ABS plastic capillary hollow optical fiber and PMMA plastic optical fibers were integrated. Among them, ABS plastic capillary hollow optical fiber was used to transmit CO$_2$ laser and PMMA plastic optical fibers are tightly wrapped around the ABS plastic capillary hollow optical fiber to transmit visible light. The optical transmission performance of the hollow optical fiber was tested. For the ABS plastic capillary hollow optical fiber with an inner diameter of 1.35 mm, the transmission loss of CO$_2$ laser went up from 0.74 to 1.22 dB/m as the bending angle increased from 0° to 120°. For the PMMA plastic optical fibers, the visible light transmission illumination could reach 1171 lux. The research results show that this hollow optical fiber has the characteristics of low preparation cost and high flexibility, and the mid-infrared laser and visible light laser beams can be transmitted independently, which is expected to build laser surgery medical equipment.

The results show that both kinds of hollow optical fibers have the characteristics of low fabrication cost and can transmit mid-infrared CO$_2$ laser and visible light at the same time. Therefore, they provide new ideas for solving the problem of non-visibility and can be good candidates in the field of laser medical treatment.

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Test and analysis of multi-spectral infrared radiation features of the tank vehicle under camouflage

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The tank is an important military weapon and carrier of the armies of various countries, and an important embodiment of a country's military strength. The tank moving in the ground background can generate strong infrared radiation due to the high temperature part, forming its own infrared characteristics, which is very easy to be detected and recognized by the infrared detector. The acquisition of infrared characteristic data of the tank and its land environment, such as temperature distribution, radiance, radiation intensity and other characteristic parameters, is very important for the detection and positioning of the tank, the development of anti-tank guidance weapons, the research of tank stealth defense and infrared suppression. The research on multi-spectral infrared radiation characteristics of ground targets is one of the hot spots in the infrared field. In this work, the multi-spectral infrared radiation features of tank vehicles after camouflage were experimentally studied. The main purpose is to evaluate the camouflage effect of the multi-spectrum camouflage shelter against ground infrared radiation and infrared reconnaissance. Experimental tests were carried out on two T-59 tank vehicles. These two T-59 tank vehicles are arranged in the same field of view under the same background, and one of them is covered by the multi-spectrum camouflage shelter. The test equipment includes visible light camera, medium wave infrared thermal imager, long wave infrared thermal imager and atmospheric environment measurement equipment. The changes of radiance, radiation flux, gray scale value and radiation temperature of each observation target and climate environment factors within 24 hours were recorded. Climate and environmental factors include air temperature, humidity, wind direction, wind speed, air pressure and visibility. Observation targets include a tank, a square cabin vehicle, a tank with camouflage shelter, a square cabin vehicle with camouflage shelter, grass and blackbody. The thermal characteristics of the front and rear ends of the two tanks are of concern. According to the experimental test data, the medium and long wave infrared characteristics of two tank vehicles in cold and thermal static states were analyzed. In the cold static state, the tank does not start, while in the thermal static state, both tanks are started and left for 30 minutes. The results for the cold static state show that the radiation temperature change trend of the tank with camouflage shelter is the closest to that of the grassland background, and the radiation temperature peaks at almost the same time, while the tank without camouflage shelter reaches a higher radiation temperature peak at another time. When the radiation temperature is low, the temperature difference between the tank without camouflage shelter and the grass background is small, while the temperature difference between the tank with camouflage shelter and the grass background is large. The change of radiation flux and radiance of each observation target is almost consistent with the change of radiation temperature. The observation azimuth of the target has a certain impact on the camouflage effect, but the overall change trend is still consistent. The radiation temperature changes collected by the long wave infrared camera and the medium wave infrared camera are almost the same. In general, the temperature difference between the tank with camouflage shelter and the grassland background is small, and has a good camouflage effect. However, the results of thermal static state show that the camouflage effect of the tank with camouflage shelter is not significant.

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Design and Simulation of Anti-reflecting Nanostructure for Visible Shortwave Infrared Focal Plane Array Detector

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The typical In0.53Ga0.47As/InP photodetector with a spectral response of 900nm-1700nm is widely used for applications as telecommunication, remote sensing, astronomical observation, geography imaging, homeland security. With the benefit of substrate-removal processes and wafer-bonding technology, the spectral response of InGaAs image sensor can extend to 400-900nm. However, quantum efficiency of such a device in visible spectrum is quite low, (nomally < 0.4). when compared with the silicon-based counterpart. Recently, optical metasurface is considered as a new breakthrough to improve the performance of InGaAs photodetector in the whole Vis-SWIR wavelength range. Based on Mie scattering, sub-wavelength scale nano-semiconductor has been demonstrated as anti-reflection film due to the outstanding performance on manipulating optical field. Here we present a comprehensive study for designing the optical metasurface on the backside-illuminated InGaAs PIN focal plane array (FPA). With the precisely optimized parameters, the integration of periodic nanostructures aims at effectively suppressing the reflectivity in visible spectrum, in other words increasing the transmittance of light from the back-illuminated side.

The incident light interacting with the InP layer can be divided as three parts, the part of light absorbed by the layer, reflected by the layer, and transmitting through the layer. Simulation results show that bare InP layer is highly reflective and absorptive over the entire visible wavelength range, which impedes incident light to be converted into electric signal. For a practical PIN FPA. the thickness of InP contact layer should be established in the range from 10nm to 200nm. The transmittance was highly sensitive to the InP contact layer, which means ultra-thin InP epilayer should be applied to a Vis-SWIR InGaAs FPA. With transmittance improved in visible spectrum, the part of light which is resonated by nanostructure can transmit through the InP layer to be absorbed by photodetector. Transmittance of visible spectrum of InP also indicates that resonant center wavelength of nanostructure should be chosen at the visible wavelength which have relatively high transmittance.

According to Mie theory, dielectric sub-wavelength scale nanoparticles can possess strong scattering resonances. For example, researches demonstrated that subwavelength nanoparticles can generate strong resonant light scattering under white light illumination and in SWIR. Well-designed Si nanostructure array can possess strongly substrate-coupled Mie resonances, yielding almost zero total reflectance over the entire spectral range from the ultraviolet to the near-infrared. Additionally, Fabry–P´erot resonances is also included in explaining the mechanism of anti-reflecting in nanostructures. TiO$_2$, ZnO are also proved effectively capturing and redirecting the lights through the excitation of optical resonances. To improve response signal of the visible light, advanced nanostructure should be integrated on the InP layer, with appropriate aspect-ratio of nanostructures to generate Fabry–P´erot resonances in visible light range from 400nm-600nm.

In this work, reflectivity and transmittance of InP layer integrated with designed Si$_3$N$_4$ sub-wavelength nanostructures are simulated using Lumerical FDTD. We choose the auto non-uniform with mesh accuracy as 2. The boundary condition in x and y direction is set as periodic, while PML is chosen in z direction. The simulated wavelength is ranging from 400nm to 1700nm with 100 frequency points. According to Mie scattering and Fabry–P´erot resonances theory, the Si$_3$N$_4$ sub-wavelength nanostructures are designed at different center resonance wavelengths and simulated with different thicknesses of InP layer. The simulated reflectivity of the designed nanostructures, compared with the case which coated the surface of InP layer with single anti-reflecting layer, dramatically decreases from 0.3 to 0.05 at 450nm wavelength. The transmittance of InP layers integrated designed nanostructure is also simulated with different InP layer thicknesses. Simulation result shows that, compared to single-layer anti-reflecting coating, the transmittance of 10nm InP layer integrated with designed nanostructure improves from 0.54 to 0.75 at 450nm.

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The key technology of rapid refrigeration and precise temperature of cryogenic optical infrared camera

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The background radiation of opto-mechanical structure is an important factor affecting the sensitivity of infrared cameras, so cryogenic optics usually used to reduce the background photon flux and improve the performance of them. At present, the thermal control scheme of refrigerator combined with heat pipe and other cold chains is mostly used in infrared cameras. The transmission process of this scheme is prone to heat leakage, resulting in a waste of resources, the low cooling rate cannot meet the demand of rapid response, and the low temperature control accuracy is easy to affect the imaging quality. Therefore, the development of fast refrigeration and high precision thermal control technology is one of the key problems to be solved urgently in the low temperature optics of infrared camera. Based on the key technologies of infrared payload of a certain type of high-speed flight platform, this study carried out the research of cryogenic optics of infrared camera. In order to achieve fast response within 200s and high-precision temperature control less than ±1K of the optical and mechanical structure with all-optical path. In this research, the breakthrough design of open throttling refrigeration system is proposed, which is integrated with the optical and mechanical structure. The key points and difficulties in the thermal control design of the infrared camera for rapid cooling were analyzed in detail according to the characteristics of opto-mechanical structure and the space heat flux. The open J-T throttling system is combined with the infrared opto-mechanical structure directly, which avoids the heat leakage of cold chain, and also improves the difficulty of working medium selection and flow field design. Firstly, the working medium with significant temperature drop after throttling is screened in the cooling temperature zone. Then, the suitable working medium is selected in the system combining open J-T throttling and complex optical system based on the infrared optical characteristics of the working fluid, such as the absorption rate and refractive index in the infrared band. The complex spatial position and heat load distribution of the opto-mechanical structure increase the difficulty of realizing the uniform temperature cooling of the infrared cryogenic optical system. Therefore, a multi-lattice injection refrigeration method is proposed. The flow field of the optical path is optimized by CFD simulation to realize the effective distribution and rational utilization of the cooling capacity, and the high-efficiency thermal protection, thermal isolation and other temperature control technologies are used to reduce the loss of cooling capacity. The J-T throttle low temperature optical test system with primary precooling is designed. The test results show that the system has a significant cooling effect, and the temperature is rapidly reduced by 110K in 200s. Thermal analysis results show that the working medium at low temperature with the surface by convection heat transfer between the mirror, optical components, temperature uniformity and stability can meet the design requirements within the 200s, quickly reduce the temperature to 180k, the temperature gradient is less than 1K, the maximum temperature fluctuation is less than±1K, realize the complex internal and external thermal environment under the low temperature optical fast cooling and high precision temperature control. This study will provide important research ideas and theoretical basis for refrigeration and thermal control of infrared camera with high response speed.

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The magic of III-Vs

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III-V compound semiconductors have abundant features for various electronic, optoelectronic and photonic applications, all arise from variform magic combination of group III and group V elements, resulting in ever-changing characteristics. In this paper, diversified ternaries, quaternaries and quinaries are presented geometrically based on the binaries of arsenide, phosphide and antimonide, mainly concerned of their bandgap, lattice constant and the match domain on different substrates. The features of nitride and dilute nitride, bismide and dilute bismuth, as well as boride, are also discussed briefly. An overall observation of whole III-Vs may contribute to the comprehensive understanding of their latent capacity and sustainable development, along with a lot of challenges.

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Developments and Characterization of HgCdTe e-APDs at SITP

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The impact ionization coefficients of electrons and holes are significantly different in HgCdTe materials. HgCdTe Avalanche Photodiodes (APDs) have been demonstrated to be a quasi single carrier multiplication mechanism in short-wavelength, medium-wavelength, long-wavelength infrared detectors for cut-off wavelengths from 1.3 μm to 11 μm corresponding to compositions xcd from 0.7 to 0.2, which has the remarkable characteristics of high gain, high bandwidth and almost no excess noise. HgCdTe APDs will play a key role in active/passive detection, 2D / 3D imaging, infrared weak signal detection and high spatial and temporal resolution detection, which has become an important development direction of the third generation infrared imaging detectors. At present, the international HgCdTe avalanche detector focal plane arrays have entered the practical and commercial stage, but our country is still in the advanced research stage. Therefore, in order to narrow the gap with the international level, General scientific problems such as simulation and structure design of HgCdTe PIN structure electronic avalanche devices, preparation of materials and chips for low noise and high gain PIN structure avalanche devices, and performance evaluation methods of avalanche single element devices and focal-plane array devices have been studied systematically in Shanghai Institute of Technical Physics in recent years. The structure of HgCdTe e-APD devices with low noise and high gain was designed. Based on the P-type HgCdTe film materials grown by liquid phase epitaxy on CdZnTe substrate, the basic technologies of materials and chips were optimized, and the key technologies such as chip surface passivation, PIN junction width and carrier concentration distribution process control were broken through. The HgCdTe APD single element and focal plane array devices for cut-off wavelength from 2.55 μm to 5.30 μm corresponding to compositions xcd from 0.29 to 0.45 were developed. Performance metrics such as response gain, dark current, gain-normalized dark current density (GNDCD), quantum efficiency, noise, excess noise factor, and noise equivalent photon (NEPh) are evaluated for both single element and focal plane array devices. The gain of single element short-wavelength HgCdTe APD for 2.55 μm cut-off wavelength is about 31 at 25V reverse bias, and GNDCD is about 1.57×10^{-7}A/cm^2 at gain of 10. 50 μm pitch 128×128 array HgCdTe

APDs for cut-off wavelengths 4.88 μm corresponding to compositions xcd 0.307 were fabricated, whose GNDCD is less than 1×10-7A/cm2 at 8V reverse bias, gain reaches 700 at 10V reverse bias, quantum efficiency is 61.8% at1.06 μm wavelength, the blind element rate is 2.16% and the average excess noise factor is 1.66 at average gain of 113 for all pixels. A 50 μm pitch 128×128 array HgCdTe APDs with xcd=0.294 was manufactured, whose gain reaches 1570 at 9.8V reverse bias, quantum efficiency is 67.41% at1.06 μm wavelength, the average excess noise factor is 1.25 at average gain of 133, noise equivalent photon is 11.57 at average gain of 113. The gain and dark current characteristics of medium-wavelength HgCdTe APDs for compositions xcd from 0.28 to 0.33 were analyzed by experiments and simulations. By thinning the absorption region thickness, the response bandwidth of Hg0.79Cd0.31Te APD reaches 635MHz under 1V reverse bias. Moreover, the medium-wavelength focal plane of 128×128 array and 320×256 array are demonstrated the imaging, and the low noise, high sensitivity and fast imaging characteristics of HgCdTe APDs under linear avalanche gain are verified. The above research results lay a substantial theoretical and technical foundation for further obtaining a three-dimensional infrared HgCdTe avalanche imaging detector with larger scale, lower avalanche noise and high speed recognition.

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In-situ ellipsometric study on composition-dependent short-wave HgCdTe in the process of molecular beam epitaxy growth

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Hg1-xCdxTe is a ternary semiconductor formed by tellurium, cadmium and mercury mainly through ionic bond, and the band gap can be adjusted by modulating the alloy composition x, which is considered as the preferred material for high performance infrared photodetectors and imaging focal plane array (FPA) detectors. In order to meet the application needs of high spatial and spectral resolution images for infrared detection system, advanced HgCdTe FPA devices are developing along the direction of large-scale, multi-dimensional, high-speed and intelligent. Therefore, higher requirements are put forward for heterojunction HgCdTe with complex compositional gradients, such as multi-color detectors, avalanche photodiodes and HOT detectors.

One of the technical challenges of multi-dimensional integrated HgCdTe growth by molecular beam epitaxy (MBE) lies in the in-situ extraction, characterization and precisely control of a series of parameters such as alloy composition, surface roughness, substrate temperature and film thickness at a relatively low substrate temperature of about 180°C. Reflection high-energy electron diffraction (RHEED) is a good option, however, it can cause irreversible surface damage on HgCdTe material which has been observed by many research groups. Spectroscopic ellipsometry (SE) is an optical measurement method with characteristics of non-contact, high precision, high sensitivity and non-damage, which has been proved to be extremely sensitive to the optical properties of II-VI compounds. In-situ SE technology can realize longitudinal composition integrated structure design, real-time monitoring and evaluation of performance parameters during the epitaxial process, and therefore will promote the research and development of HgCdTe heterojunction with complex component distribution and doping profiles. For HgCdTe, the critical point (CP) energy E1 is in the visible wave range, which ensures the high sensitivity of ellipsometry detection, especially for xvalue of 0.2-0.3.

In this work, real time monitoring of short-wave HgCdTe deposited by MBE is reported. By successfully building a brand-new parameterized composition-dependent optical constant library, optical properties of HgCdTe epitaxial films and CdTe buffer layers, composition of HgCdTe and surface roughness can be acquiesced by in-situ SE during the epitaxy growth process. Verified by the conclusion of Fourier transform infrared spectroscopic (FTIR), feasibility and stability of in-situ SE is confirmed, and a routine reproducibility measurement accuracy Δx~ 0.0015 is obtained. This work will be conducive to establish the relationship between thin film property parameters and epitaxy growth parameters, in which case the growth parameters can be adjusted according to the feedback of film property characterization, so as to improve the performance of HgCdTe films and FPA detectors.

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Study on Surface Pretreatment of CdZnTe Substrates for MBE HgCdTe Films

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Cadmium zinc telluride (CZT) is a promising material as a suitable substrate for epitaxial growth of lattice-matched mercury cadmium telluride (MCT) films. Molecular beam epitaxy growth of MCT requires high quality surface substrate. However, CZT has soft and brittle feature, which is easily to form mechanical damage layer during lapping and polishing process. In order to remove this damage layer, surface pretreatment process before molecular beam epitaxy growth is necessary. In the article, a novel bromine based polishing solution is proposed. The solution can significantly reduce surface defects and roughness of CZT substrate after chemical polishing which is essential for the subsequent epitaxy of HgCdTe. Results on surface pretreatment of CdZnTe which is used for MCT growth are reported. Both chemical polishing and thermal treatment were evaluated. As-received 20mm × 30mm CZT substrates were rinsed by methanol to get rid of grease and dirt. After that, bromine based solution was used to eliminate scratches from front chemical mechanical polishing process. Then the substrates were rinsed by methanol and deionized water and dried by N2. Some substrates were loaded into Riber 32P MBE system, the others were loaded into Riber Compact21 MBE system which had been equipped with spectroscopic ellipsometer (SE). After degassing in loading chamber, the substrates were transferred to growth chamber to go though high temperature deoxidation process with extra Te flux. The deoxidize temperature was determined by infrared thermometer and spectroscopic ellipsometer. The whole thermal treatment was monitored by reflection high-energy electron diffraction (RHEED) and real time substrate roughness was tested by spectroscopic ellipsometer. The roughness and surface quality of CdZnTe substrate after chemical polishing were tested by atomic force microscopy (AFM) and optical profilometer. Surface defect were analyzed by optical microscope and laser scanning confocal microscope. The surface roughness (Ra) of about 1nm was achieved in measuring area of 1nm × 1nm. The surface roughness root-mean-square (rms) of 10nm was achieved in measuring area of 150um × 120um. The surface defect was less than 1000 cm^{-3}. The oxide layer and Te-rich layer started to eliminate at about 150°C along with substrate increasing roughness measured by spectroscopic ellipsometer. Extra Te flux was useful to stabilize the surface roughness during thermal process.

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Observation of sunspots at He I 10830Å using a low-noise InGaAs infrared detector

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The activity of the Sun is closely related to human life. The tiny irregularity of its activity will have a great impact on the Earth. Therefore, it is crucial to real-time monitor and predict the Sun activity using the absorption spectra of the Sun in the near-infrared band such as TiO, He I, Fe I and so on. The New Vacuum Solar Telescope (NVST) is the new generation of ground-based solar observing devices in China, in which He I 10830 Å is the main spectral line for measuring the magnetic field structure at the corona of the Sun. Generally known that the properties of infrared detectors such as the chip array scale, the dark current and readout noise are vital to the sensitivity and spatial resolution in spectra observations. The infrared response materials evolve from PbS and InSb to InGaAs and HgCdTe with the scale from single pixel to 1024 × 1024 and 2048 × 2048 array. In this paper the near-infrared detectors for the solar magnetron measuring in the world were introduced. Then the properties infrared detectors by ourselves and the solar imaging were recommended. With the support of NASA and NSF, Teledyne Imaging Sensors developed two HgCdTe infrared detector arrays for solar magnetic field observation, TCM8600C and H2RG, which have a quantum efficiency greater than 80%, a readout noise design of less than 70 electrons. The 1.6-meter solar telescope (GST) at Great Bear Lake Solar Observatory successfully developed the Infrared Imaging Magnetometer (IRIM), which was later upgraded to the Near Infrared Imaging Spectrometer (NIRIS). With these two devices, GST has achieved impressive results in small-scale magnetic reconnection, solar chromosphere and solar flares, opening a new era of accurate magnetic field measurement in the near-infrared band and opening a door for the world solar infrared astronomical observation. Yunnan Astronomical Observatory (YAO) and Yunnan Normal University firstly developed the solar imaging and spectra observation at He I 10830Å by NVST equipped high-dispersion spectrometer in China. A reflection solar infrared imaging light path is established, which can observe the image of the sunspot by means of the high-performance 640×512 InGaAs focal plane array (FPA) with high quantum efficiency operated at 77K. Compared with the dominate HgCdTe detectors in astronomical observations, InGaAs FPA has certain advantages in terms of detection rate, uniformity and stability in a high background radiation and low contrast situation. In the Lyot filter with the bandpass of 0.5 Å at He I 10830Å, the solar radiation is much weaker so that a high signal-to-noise ratio infrared detector is needed to observe the structure of the sunspot. In addition, an effective data processing method is needed to extract the details of the sunspot from the raw images. In this work, the readout noise, the dark current and of the infrared detector are large and uniform, resulting in the structure of the signal-to-noise ratio of 640×512 InGaAs focal plane array (FPA) are discussed. The resolved sunspot image at He I 10830Å using InGaAs FPA can be firstly obtained all over the world which will be compared with the image captured by HgCdTe FPA from Great Bear Lake Solar Observatory. The established infrared observation system can be used to continue the study of infrared magnetic field observation at Fe I 1.565 μm, which is an important spectral line for detecting the low-level vector magnetic field of the solar photosphere, and can combine the sensitivity and spatial resolution of solar magnetic field measurement at the same time.

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Overview of the development of astronomical infrared detectors

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This paper introduces the significance and development of infrared astronomy, mainly concerns the infrared detec-

tors applied to the telescopes. Firstly, the astronomical requirements for infrared detector indicators were analyzed. We summarize the performance parameters of astronomical infrared detectors such as the dark current, readout noise and image element size in recent decades. Then we recommend 640×512 InGaAs array fabricated by Yunnan Astronomical Observatory (YAO) for near infrared imaging and spectrometer. The Hubble Space Telescope's second-generation infrared detector has an array size of 256 × 256, an image element size of 40 μm, a wavelength range of 0.8-2.5 μm, a dark current of 0.1e^-/s, and a readout noise of 25 e^-. The Hubble Telescope has brought mankind into a whole new astronomical era, which gives us a glimpse of places in the universe that no human has ever reached or seen before. The average quantum efficiency of the 16 detectors of the VISTA IR camera was measured to be (J, H, K)=(90, 96, 92)%, the average dark current was 1.2e^-/(pixel·s), and the average readout noise was 20.9e^-. VISTA's focal plane has 64 megapixels and consists of 16 Raytheon VIRGO 2K×2K HgCdTe LPE arrays, all read out simultaneously by the standard ESO IR control electronics for a total of 256 simultaneous readout channels. The entire focal plane can be read out in less than 1 second. By comparing the main indexes of each astronomical infrared detector, it can provide the development direction for the infrared detector used for astronomical observation, which is an important guidance for the localization of astronomical infrared detectors. YAO have researched near infrared detectors and camera for years, which is help to observe the sunspot activity and measuring the magnetron field at the corona. After testing by photon curve transfer method, we found that the dark current of the 640×512 InGaAs array developed by our team can be as low as 64 e^-/(pixel·s), and the average readout noise of the image element is 25.4 e^-. This shows that the technical level of the prototype is leading in China. However, in comparison with foreign astronomical infrared detectors, there is still a big gap. For example, the HgCdTe Near Infrared Camera (NIR Cam) carried in the James Webb Space Telescope (JWST) can have dark currents as low as 0.001e^-/s for the short wavelength channel (0.6-2.3 μm) and 0.035e^-/s for the long wavelength channel (2.4-5.0 μm), with readout Noise down to 5.9 e^- for the short wavelength channel (0.6-2.3 μm) and 8.6e^- for the long wavelength channel (2.4-5.0 μm). With its outstanding performance, JWST has obtained higher resolution images of galaxies, newly certifying several galaxies located in the early universe. China's infrared astronomy started late, the units used by the astronomical infrared detectors mostly introduced foreign low-end products, far from the requirements of domestic astronomical observation, so the need to improve the domestic infrared detector research and development capabilities. Although the development of domestic infrared detectors significantly behind the U.S. and Europe, but in recent years has been catching up with the trend, some of the performance has been advanced alongside Europe. The HgCdTe NIR detector array developed by the Shanghai Institute of Technology Physics, Chinese Academy of Sciences has a dark current ≤ 1600 e^-/(pixel·s) and a device amplifier noise ≤ 150 e^-when cooled by liquid nitrogen. In the future, we should try to break the technical barriers of infrared detectors and realize the benign iterations of developing, testing, correcting, improving and developing again for domestic astronomy-specific infrared detectors.

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Study on Reset Time Extended CDS forlow noise hyperspectral infrared focal plane readout circuits

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The optical signal received by the hyperspectral remote sensing infrared detector is very weak. In order to adapt to this low irradiation characteristic, the low noise performance of the readout circuit is particularly important. At present, most of the hyperspectral short wave infrared focal plane readout circuits use the input stage of the

capacitive transimpedance amplifier (CTIA) combined with the correlated double sampling (CDS) structure to achieve the target that the number of noise electrons is less than 50. However, the influence of CDS capacitor reset time trand the time interval between two samples tdon the noise performance of the circuit is rarely analyzed, and the design of the circuit for controlling these two durations is also lacking. The analysis and control of these time intervals is of great significance to improve the noise performance of the circuit. In this paper, the Reset Time Extended CDStechnology (RTECDS) for low-noise hyperspectral infrared focal plane readout circuit is proposed. The function of CDS reset duration, the sample time interval and noise is obtained and simulated. A pixel circuit consists of low-noise CTIA input stage and CDS with adjustable reset timeis designed. A new method is proposed to simulate the noise performance of the circuit.

In this paper, the /first-order low-pass filter/-/delay subtractor/-/sample and hold/ model of pixel circuit is created, and the limitation of tris analyzed in consideration of the parasitic characteristics of MOS transistor; By using autocorrelation function and Dirac comb function, the influence of td on output noise power spectral density is analyzed, and the function of tdand the noise power density S(w) are obtained. The relationship between ratio γ of td to the sampling period Tsand normalized noise power density are simulated by MATLAB. The simulation results show that the noise power spectral density increases with γ. In a constant sampling period, extending the CDS reset time means reduced td, which will decrease γ thus resulting in lower noise.

Based on the analysis above, a low noise readout pixel circuit is designed in this paper, which adopts /cascode/ type CTIA with high gain and low noise performance; Unlike other designs where the CDS reset time is determined by the external clock, the CDS reset time of this work can be adjusted by 4-bits digital code, with a time span of 0 ~ 30 us.

A new CDS noise simulation method is proposed for this circuit. Considering that the working sequence of the circuit has multiple reset and sampling processes, the noise contribution of the sampled output is simulated using Spectre transient noise analysis. And the input noise is calculated according to the noise components. The circuit is designed for a 0.18um CMOS technology, the power supply voltage is 3.3V, and the output swing of CTIA is 2.4V. By extending the reset time of CDS, the number of noise electrons reaches 24.42 which is better than 50.11 without CDS and 34.45 without extending the reset time. The design of Reset Time Extended CDS can improve the noise performance of hyperspectral readout circuit and can be widely used.