HgCdTe and Other Infrared Material Status in the Ukraine

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This is the first article to explain and illustrate the HgCdTe and other infrared (IR) material status in the Ukraine. It develops the background needed to understand the what and where of IR physics, devices, and materials, but does not pretend to be a comprehensive treatment of the subject as some data still remain classified.

Key words: HgCdTe, infrared (IR) materials, thermoelectric coolers

INTRODUCTION

Now that the Cold War is over, some of the resources of the former Soviet Union (SU) National Institutions that have played a major role in assuring the SU security, are increasingly available for nondefense high-technology research and development. They face the challenge of redefining their role as a result of the significantly diminished demand for their weapons-related capability. The knowledge developed in these labs and plants may offer an opportunity for international cooperation. Such technology development and transfer would be clearly of mutual interest and dual benefit to both scientists and developers in the Commonwealth of Independent States (CIS) and international scientific community.

By participating in SU large scale defense and civilian programs, Ukranian scientists and engineers have successfully developed various types of efficient optoelectronic devices for the infrared (IR) which are known in the West only as "made in Russia." Now after SU's collapse, this large European country looks like a blank white spot on the world "photonic devices and materials" map. This is the first article to explain and illustrate the HgCdTe and other IR material status in the Ukraine. It develops the background needed to understand the what and where of IR physics, devices, and materials, but does not pretend to be a comprehensive treatment of the subject as some data still remain classified.

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STATE OF DEVELOPMENT

Science

The Institute of Semiconductor Physics (Kyiv)[1] is generally believed to be a leader in this area. Although the institute's interest is primarily in the fundamental interaction of light with matter, the radical shift was made in recent years toward practical applications of the light emitting and detection in a new generation of photonic devices. Contrary to the traditional approach exploiting low temperature IR detectors, the main thrust in this section deals with new research to raise the operating temperature of narrow gap semiconductor (NGS) devices and to demonstrate the physical principles and parameters of related nonorthodox IR light emitting diodes (LEDs).

It is difficult to obtain a high injection level in NGS (for example, by contact injection or by photoexcitation) because of a small lifetime ($\tau<10^{-8}$ s), a high efficiency of nonlinear Auger recombination and a high value of intrinsic carrier density ($n_i \geq 10^{16}$ cm^{-3}). For these reasons NGS IR devices are cooled either thermoelectrically or by small Stirling-cycle devices which keep temperatures between 70 and 200K. In most cases, these cooling devices drive up the system cost beyond a commercially viable price, particularly in the civilian field. The requirement for cooling does not appear to be fundamentally necessary. Auger recombination-generation processes can be suppressed and the need for cyrogenic operation reduced or even eliminated by operating the devices in the nonequilibrium mode where the carrier densities are below their thermal equilibrium values.

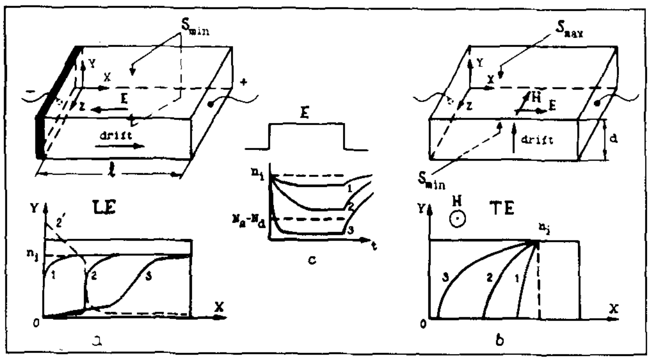

Fig. 1. (a) Longitudinal (p^+-p junction from the left), and (b) transverse carrier exclusion in the slab with near-intrinsic conductivity and lateral contacts. Below: (a) 1–3, carrier distribution along the crystal at $V_3 > V_2 > V_1$; 2'–E distribution along the crystal; (b) carrier distribution across the crystal at $E_3 > E_2 > E_1$; and (c) time dependence of nonequilibrium carrier concentration in the excluded region.

There are two simple ways to decrease carrier densities in NGS with intrinsic conductivity.[2] The first approach is the contact exclusion occurring when reverse voltage bias is applied to an antiblocking contact (n^+–n or p^+–p junction). As a result of longitudinal minority carrier drift along the current lines to an opposing contact, an extended region of bipolar exclusion appears. If the opposite contact is ohmic, the minority carrier density may be reduced below the equilibrium density over much of the sample volume. The second way is realized if a crystal with ohmic contacts is exposed to crossed electric (E) and magnetic (H) fields (magnetoconcentration effect, MCE). In this case, the Lorentz force causes transverse carrier drift toward the lateral face of the crystal slab, and the whole volume of the crystal becomes the region of exclusion, except for a narrow surface layer near the face to which the carriers drift (Fig. 1). In InSb and HgCdTe (MCT) the longitidunal exclusion region may be as large as 100 µm at room temperature wherein the carrier density is decreased almost a hundredfold becoming less than the density of uncompensated impurities. As a result, exclusion effects dramatically change optical, electric, and photoelectric properties of the crystals.

First of all, the decrease in electron and hole density ($n,p<n_i$) is accompanied by a decrease in the power of spontaneous radiation, $P<P_0$ (P_0 is equilibrium thermal radiation value), in the range of band-to-band transitions $\omega > E_g/\hbar$ (E_g-bandgap)—negative lumines-

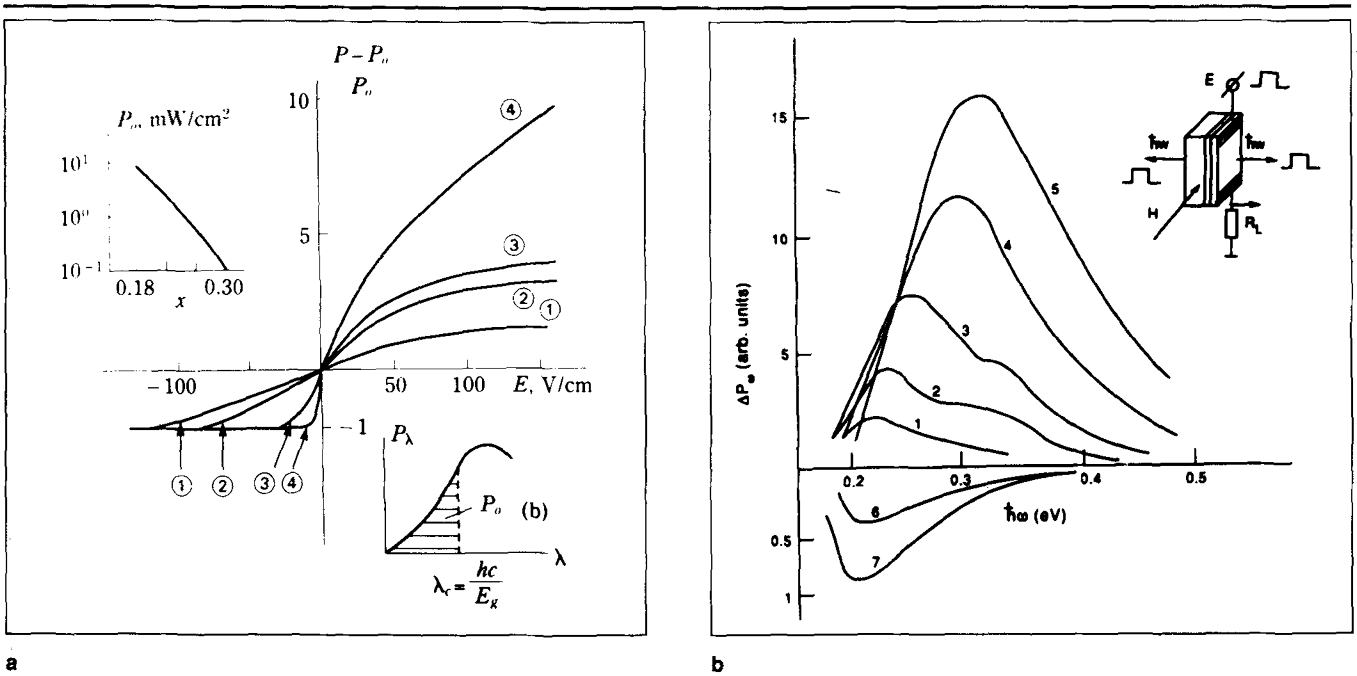

Fig. 2. (a) Field dependences of the fractional change in integral emissive power of MCE MCT emitters at T = 300K. H = 10 kOe, x: 1-1'–0.20; 2-2'–0.22; 3-3'–0.28; 4-4'–0.30. 1-4—positive luminescence, 1'-4'–negative luminescence. Insertions show: left: maximal negative luminescence power (P_0) vs x at 300K; right: spectral distribution of black body emission; cross-hatched part corresponds to the negative luminescence power in the spectral range of interband transitions. Note: an essential qualitative aspect of negative luminescence is that it cannot exceed the magnitude of equilibrium emission, since the absolute radiant emission cannot be reduced below zero. (b) Spectral characteristics of luminescence of varying gap MCT at room temperature and H = ± 10 kOe. E, V/cm; 1.6–20; 2–40; 3.7–80; 4–160; 5–240. Positive luminescence: 1–5, negative luminescence: 6–7. Inset: diagram of MCE transverse carrier exclusion experiment.

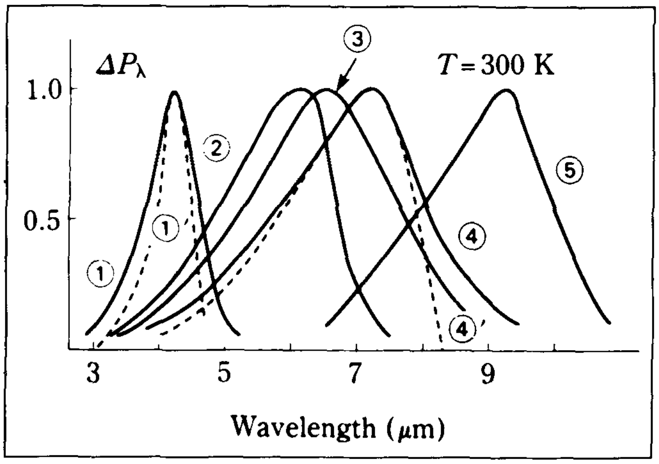

Fig. 3. Difference emission spectra of MCE MCT emitters at T = 300K. H = 10 kOe, E = 1 V/cm; x: 1–0.30, 2–0.22, 3–0.215, 4–0.20, 5–0.18. 1', 4'–theory.

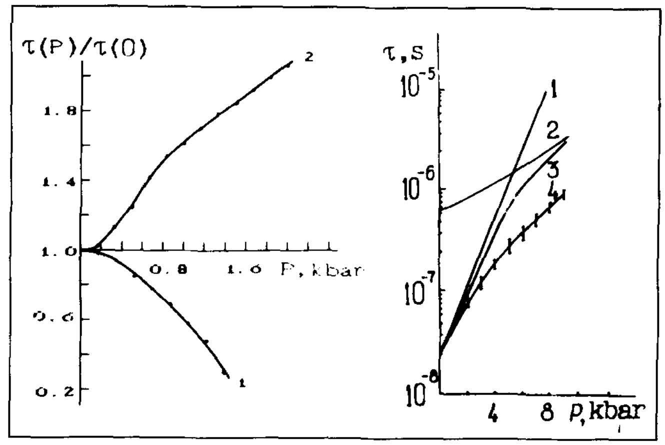

Fig. 4. Relative carrier lifetime vs pressure. Left—uniaxial pressure, 1–τ_R for MCT (x = 0.29) at T = 150K, 2–τ_A for MCT (x = 0.2) at T = 100K. Right—hydrostatic pressure, 1–τ_A, 2–τ_R, 3–$\tau^{-1} = \tau_A^{-1} + \tau_R^{-1}$, 4–experiment for InSb at T = 300K.

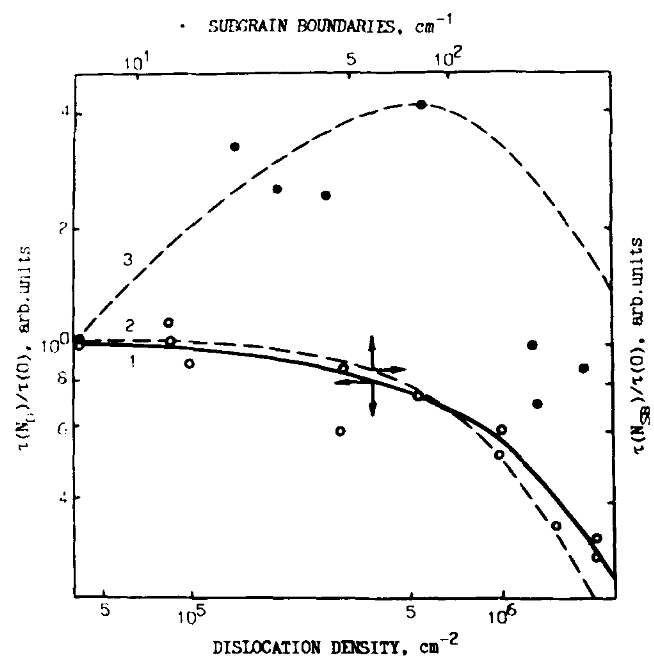

Fig. 5. Relative carrier lifetime vs dislocation density N_d (1–calculation, open circles–experiment) and subgrain boundary value N_{SB} (2–$[V_{Hg}] = 10^{15}$ cm^{-3}, 3–$[V_{Hg}] = 10^{13}$ cm^{-3}) for MCT (x = 0.2) at T = 77K.

cence.[3] In the limiting case of large-signal exclusion, the recombination radiation is fully suppressed: the radiation deficit equals the equilibrium value P_0 ($\Delta P = P - P_0 \approx -P_p$). The maximal power of negative luminescence is determined by integrating the formula for the Plank spectral distribution over the interval $E_g \leq \hbar\omega \leq \infty$ (Fig. 2). Because of this, the negative luminescence power in $Hg_{0.8}Cd_{0.2}Te$ at 300K is estimated to be 10 mW cm^{-2} whereas it does not exceed 1 mW cm^{-2} for InSb. The negative luminescence has been investigated in detail for InSb and MCT crystals and films as well as for MCT epistructures.[4–6] As a result, the most important features of this phenomenon are established and unorthodox high-temperature InSb and MCT IR sources (Fig. 3) for those applications requiring stable, reliable sources of low power IR energy have been developed.[7]

The radiative cooling effect[8] induced by the exclusion region (when the crystal pumps thermal energy from its surroundings and does not radiate back) is also under study. A maximal temperature differential as high as $\Delta T = 3$K at room temperature has been achieved using excluded MCT thin film as a cooling body.

The Auger generation suppression results in the appearance of a region of negative differential conductivity (N-type) in I-V characteristics.[9] Experimentally, this region is detected as the appearance of oscillations at the flat tops of current pulses through the material. The oscillation frequency depends on E, and the amplititude attains 50% of the current mean value. The latter corresponds to a pulse power up to 100 W.

The exclusion effects occurring in photogenerated electron-hole plasmas cause a significant decrease of the photoresonse time which is not accompanied by a decrease in the responsivity because the crystal resistivity in the dark is increased.[10]

An alternative way to suppress the Auger processes in NGS and to improve the performance of IR devices is to employ pressure. Auger (τ_A) and radiative (τ_R) carrier lifetime calculations within the Kane model, with allowance for uniaxial pressure along <100> of HgCdTe, shows that the hole effective mass in the upper of two valence subbands decreases (E_g is not affected by uniaxial pressure practically).[11] As a result, τ_A increases and τ_R decreases, as it is shown in Fig. 4. Such a redistribution between radiative and nonradiative channels could result in increases of both the quantum efficiency of radiative recombination ($x \geq 0.2$, $T \geq 150$K) and responsivity of the IR detectors ($x \leq 0.2$, $T \leq 100$K). On the contrary, hydrostatic pressure induces a marked increase of E_g followed by an increase in τ_A and τ_R. Calculation and experiments show[12] that for InSb crystals (T = 300K) radiative recombination increases from 6 to 25%, whereas, the response time of photodetectors increases by 30 times when the 8 kbar pressure is applied (Fig. 4). Also hydrostatic pressure impact at negative and positive luminescence parameters in MCT heterostructures seems to be attractive for practical applications.[13] Naturally, a shift of emission and photosensitivity toward short wavelengths occurs.

Finally, the impact of structural and point defects on the electronic and optical properties of MCT as well as NGS material characterization are typical examples of the work permanently conducted by institute scientists at Kyiv. Figure 5 demonstrates the MCT carrier lifetime dependence on the dislocation density and subgrain boundary value. It shows that dislocations provoke a lifetime decrease, whereas the subgrain boundaries, acting as point defect getters, promote the photosensitivity rise of materials.[14]

IR MATERIALS

Presently, there are two Ukranian enterprises which have been significant SU-wide suppliers of electronic and photonic materials for 20 years, the titanium and magnesium plant at Zaporozhye[15] and the pure metals plant at Svitlovodsk.[16]

The titanium and magnesium plant at Zaporozhye delivers large quantities of low-cost Si (bulk material and wafers) and Ge (doped and undoped crystals) as well as the Ge-based optic accessories for IR applications. It has the capabilities to manufacture, by various crystal-growth techniques, Si and Ge mono- and polycrystals which satisfy the different needs of the semiconductor and optoelectronic industry.

As-grown Czochralski, dislocation-free, Si monocrystals (ingots) with different doping levels (ρ = 0.01–40 Ω cm for n-type and ρ = 0.005–40 Ω cm for p-type) can be delivered with a diameter up to 150 mm. Carbon concentration does not exceed $3 \cdot 10^{16}$ cm^{-3}, and the spatial nonuniformity of dopants is less than 5%. Floatng zone technique-grown Si monocrystals (ρ = 0.1–2 $\cdot 10^4$ Ω cm for n-type and ρ = 0.1–4 $\cdot 10^4$ Ω cm for p-type) with a diameter up to 105 mm and carbon or oxygen concentrations less than $1 \cdot 10^{16}$ cm^{-3} are also available. Also, there are polycrystalline Si cylindrical ingots available (d = 800 mm, h = 70 mm).

The present production ability of dislocation-free zone-refined Ge polycrystals (ρ = 48 Ω cm) as well as Ge crystals for optical accessories (ρ = 5–40 Ω cm, n-type) with diameters from 10 to 420 mm is estimated as 5 ton/year. In addition, $GeCl_4$ and GeO_2 are also available.

The pure metals plant at Svitlovodsk supplies with high uniformity, low carrier concentration single crystal HgCdTe as well as liquid phase epitaxially (LPE) grown p-HgCdTe/CdTe structures (0.185 < x < 0.300,

Table I. HgCdTe Wafers (Polished)

Molar content, x	0.190–0.240 0.240–0.320
Conductivity	n,p
Carrier concentration at 77K, cm^{-3}	n-type–$7 \cdot 10^{13}$ – $1 \cdot 10^{15}$ p-type–$1 \cdot 10^{15}$ – $1 \cdot 10^{17}$
Carrier mobility at 77K cm^2/V·s	n-type–$3 \cdot 10^4$ – $2.5 \cdot 10^5$ p-type–≥200
Surface, cm^2	0.25–4.0
Thickness, mm	0.7–1.0

Table II. Gallium Arsenide Ingots

Method: LEC	**Semi-Insulating (i-GaAs)**	**Conductive (n/p-GaAs)**		
Ingot diameter, mm	52±0.5 78.2±0.5	52±0.5		78.2±0.5
Crystal orientation	<100>, <111>	<100>,	<111>	
Conductvity type		n	n	p
dopant	None or Cr	Te	Si	Zn
Crystal annealing	As atmosphere, 950°C, 2.5 h			
Car. concentration, 10^{17} cm^{-3}		1–5	1–8	5–200
Resistivity, 10^7 Ω·cm	1–10			
Carrier mobility	>4000 cm^2 V^{-1} s^{-1}			
Disl. density, cm^{-2}	<$8 \cdot 10^4$ <$1.5 \cdot 10^5$	$8 \cdot 10^4$		<$1.5 \cdot 10^5$

Table III. Si-Doped GaAs EPI-Wafers

Method: Liquid Phase Epitaxy	**Application: Infrared Light Emitting Diodes**		
Diameter, mm		35–40	
Orientation		<100>	
Structure type	p-GaAs:Si	n-GaAs:Si	n-GaAs
Dopant	Si	Si	Sn
Carrier concentration, cm^{-3}	$1 \cdot 10^{16}$–$1 \cdot 10^{18}$	$1 \cdot 10^{16}$–$5 \cdot 10^{17}$	(0.5–1.5)$\cdot 10^{17}$
Layer thick, μm	50–70	5–35	360–380
Emiss. max. λ, μm		0.9–0.98	p-GaAs (Si)
Emiss. pow. of 1 mm dia. mesa-str., I = 100 mA		>4.5 mW	n-GaAs (Si)
			n-GaAs(Sn)
Voltage drop at I = 100 mA		<1.5 V	

$p_o = 5 \cdot 10^{15}$ to $2 \cdot 10^{16}$ cm^{-3}, $\mu_p \geq 300$ cm^2/v $\cdot$ s at T = 77K). Most standard wavelengths are available (Table I). Ultrahigh purity Cd, Te, Hg starting materials are also available.

GaAs (polycrystalline, semi-insulating, conductive, Si-doped EPI-wafers, multilayer GaAs/AlGaAs EPI-wafers)[17] and InAs single crystals with diameters ranging from 25 to 81 mm, both n- and p-type, and CdTe ($\rho = 10^8\ \Omega \cdot$ cm, dislocation density $\leq 10^5$ cm^{-2}) are available for immediate shipment (see Tables II–IV). Monocrystalline Si (Sn, As, P, B-doped) dislocation-free ingots of diameters 78, 100, 125 mm with parameters similar to that of SEMI standard can be also delivered.

Also, researchers and tehcnologists at the Institute for Single Crystals at Kharkiv[18] have succeeded in developing the technology of A^2B^6, alkali halide and sapphire crystal growth. As an example, bulk ZnSe single crystals (d←63 mm, h = 50 mm, $\rho = 10^{10}\ \Omega$ cm) and wafers are practically transparent within the 1–15 μm spectral range (k = 0.002 cm^{-1}). This material's laser beam damage threshold exceeds 15 kW/cm^2 for a 0.5 mm diameter beam, and the value of half-wave voltage at 10.6 μm is 160 kV. The wafers can be covered with antireflecting, reflecting, or highly protective (diamond films) coatings. KCl, NaCl, KBr, and KCl-KBr single crystals can be grown with d = 60–500 mm and maximal bubble size ≤0.2 mm. MgF_2, CaF_2, BaF_2, LiF ceramics of various forms and sized are also available.

New materials for IR devices are also under development by researchers at the University of Chernivtsy.[19] They have been developing the technology of $Cd_xMn_{1-x}Te$ and $Cd_xMn_yHg_{1-x-y}Te$ crystal growth for several years, and now have a production facility for it. The technologies developed (zone-melting, LPE, and vapor phase epitaxy [VPE]) provide high cross-sectional homogeneity and low structural defect concentrations both in 12–30 mm diameter ingots and epitaxial structures. These materials' resistance to degradation over time seem to be superior to those achieved for HgCdTe.[20] The parameters of interest at 80K are $\mu_n \geq 2 \cdot 10^6$ cm^2/V s (x = 0.16), $\mu_n \geq 6 \cdot 10^5$ cm^2/V s (y = 0.07), $n_o = 10^{15}$–10^{16} cm^{-3}, spectral range λ = 9–14 μm. Photoresistors, photodiodes, and photoelectromagnetic (FEM) detectors based on these materials are at the experimental stage. This group also believes they have demonstrated the first InSb-InBi superlattices (10–1000Å) grown with laser induced technology.

DEVICES

To date, Rythm Optoelectronics (RO)[21] at Chernivtsy is probably the major supplier of photodetectors with total wavelength coverage from ultraviolet (UV) to near IR. The company has more than 20 years' experience in the design and manufacture of silicon (p-n, p-i-n, avalanche photodiodes, 0.20–1.1 μm, ordinary, UV enhanced, built-in interference filters, transimpedance amplifier modules), germanium (p-n and avalanche photodiodes, 0.5–1.7 μm) as well as lead chalcogenides (PbS, PbSe photoresistors operating at room temperature or thermoelectrically cooled, 0.8–5.0 μm) single and multi-element (1 . . . 256) devices with the highest detector performance. Full in-house capabilities for design, fabrication, and test of customized devices are available. As an example, Tables V and VI provide a more detailed look at the lead

Table IV. Multilayer GaAs/AlGaAs EPI-Wafers

Method: Liquid Phase Epitaxy	Application: "Red" Light Emitting Diodes			
Diameter, mm	35–40			
Orientation	<100>			
Structure type	n+-AlGaAs	n-AlGaAs	p-AlGaAs	p+-GaAs
Dopant	Te	Te	Zn	Zn
Carrier Concentration 10^{17} cm^{-3}	5–20	1–3	8–20	50–200
Layer Thickness, μm	15-25	15–25	10–25	350–450
Emiss. max., λ, μm	0.65–0.68			
Light power of 0.35 × 0.35 mm chip at I = 100 mA	type A: > 300 cd type B: > 600 cd			

n+-AlGaAs(Te)
n-AlGaAs(Te
p-AlGaAs(Zn)
p+-GaAs(Zn)

Table V. Lead Chalcogenide Photodetectors

Device Parameters	PbS		PbSe	
	T = 293K	T = 195K	T = 293K	T = 195K
Spectral range, μm	0.8–3.0	0.8–3.5	1.0–4.5	1.0–5.0
λ_{max}, μm	2.5±0.2	2.8±0.2	3.5±0.3	4.0±0.3
Time constant, μs	~200	~2000	~5	~30
Dark resistance, MΩ	~0.5	~5	~1	~10
Responsivity, V/W	(3–8)·10^4	(1–5)·10^5	(2–7)·10^4	(2–7)·10^5
$D^*_{\lambda max}$, 10^{10}cm Hz$^{1/2}$ W^{-1}	3–10	50	0.3–1.2	2–8
at mod. frequqncy, Hz	1000	70	1000	1000

Table VI. Silicon Photodiodes (T = 20°C)

PD Type	Spectral Range, μm	Dark Current pA/mm^2	Capacitance at V_p, pF/mm^2	Responsivity at λ,A/W
UV enhanced	0.2–1.1	≤10 at 10 mV	≤12 at 10 mV	≥0.08 at 0.62 μm 0.62 at 0.63 μm
Low Noise	0.4–1.1	≤100 at 10V	≤1.8 at 10 V	≥0.3 at 0.63 μm
Threshold responsivity enhanced	0.4–1.1	≤20 at 10 V	≤1.5 at 10 V	≥0.32 at 0.63 μm
Common-use	0.4–1.1	≤1 at 10 mV	≤12 at 10 mV	≥0.4 at 0.63 μm

Table VII. Thermoelectric Module Parameters

Module Type	ΔT_{max} °C	Q_{max} W	I_{max} A	V_{max} V	Base mm × mm	Height mm	Cooled Surface mm × mm
TE02-1	95	0.48	0.3	5.0	6.0 × 9.0	9.0	2.48 × 4.2
TE02-3	80	55.0	7.5	12.0	40.0 × 40.0	7.0	40.0 × 40.0
TE02-4	80	32.0	4.8	12.0	40.0 × 40.0	7.0	40.0 × 40.0
TE02-5	98	1.5	5.0	0.9	8.0 × 12.0	6.8	5.0 × 6.0
TE02-6	95	0.3	4.6	0.2	6.0 × 8.0	5.5	2.0 × 4.0
TE02-7	98	0.48	2.0	0.7	12.0 × 12.0	6.8	2.0 × 4.0
TE02-8	98	2.2	2.5	2.8	12.0 × 15.0	6.8	5.0 × 8.0
TE03-2	109	0.3	3.0	5.0	15.0 × 20.0	12.5	2.0 × 10.0
TE03-3	110	0.52	1.2	3.0	8.5 × 5.0	10.0	3.0 × 3.0
TE03-4	109	1.6	7.5	1.1	12.0 × 1.0	12.5	2.0 × 2.0
TE03-5	110	1.6	2.5	3.2	14.0 × 14.0	12.5	2.0 × 6.0
TE03-6	108	1.7	0.06	1.7	4.0 × 4.0	12.5	0.8 × 0.8
TE04-1	118	1.45	2.0	6.0	21.0 × 20.0	22.0	8.0 × 12.0
TE04-2	118	4.9	5.0	7.0	18.0 × 20.0	20.0	5.0 × 20.0
TE04-3	119	6.7	3.7	12.0	27.4 × 41.0	21.3	9.5 × 14.5
TE04-4	110	0.68	0.9	0.7	12.4 × 16.3	11.65	4.1 × 8.0
TE04-7	115	0.81	1.0	7.5	12.5 × 16.4	13.7	3.0 × 7.3
TE05-1	125	0.8	1.0	8.0	16.0 × 25.0	15.0	4.0 × 10.0
TE04-9	120	1.1	1.2	6.5	15.4 × 19.0	16.6	2.6 × 8.5
TE06-1	133	0.3	1.1	4.6	12.4 × 10.0	12.5	5.5 × 5.5

ΔT_{max} –max. temperature differential between base (T = 300K) and cooled surface (vacuum, no thermal load).
Q_{max}–cooled surface thermal loat at $\Delta T = 0$. I_{max} and V_{max}–current voltage supply.

chalcogenide and silicon detector parameters.

The RO's near-term goal is to become the major "eyes" supplier for the unmanned satellite program started by the National Space Agency. RO is also considering expanding its activity toward longer wavelength devices based on MCT, Ge(Hg), and Pt-PtSi.

The Research and Production Corporation Termoprylad[22] at Lviv has nearly 40 years of extensive experience in the development and production of efficient devices for remote and contact temperature (–35°C to +5000°C) measurements. To date, manufacturing capability exists for the production of analog and digital resistor thermometers, thermoelectric temperature transducers (thermocouples), as well as IR-pyrometers based on PbS, PbSe, Si, Ge, LiNb, and operating within the 0.5–14 μm spectral range.

Also, a multilayer thin film (100–200Å) superconducting tunnel junciton IR-bolometer operating as 0.3–5K has been developed at the institute for low temperature physics and engineering[23] at Kharkiv. The device is equipped with a compact cryogenic system (no extermal pumping, remote control) and is ready for use in zero-gravity conditions. Basic device parameters (spectral range 2.0–30 μm, NEP = $1.4 \cdot 10^{-15}$ W/Hz$^{1/2}$, $\tau = 3 \cdot 10^{-3}$ s) allow its use in satellite photometers and radiometers as well as at low background radiation metrological facilities (background emission power $\geq 10^{-12}$ W cm^{-2}) operating in this institute. In addition, a three-range (3–5 μm, 8–10.5 μm, 5–13 μm) space radiometer (satellite orbit height ≈70 km) based on cooled MCT 3 × 128 array detector modules is now at the experimental stage.

High sensitive and fast response pyroelectric detectors (TGS, $LiTaO_3$) can be delivered from the Institute of Physics at Kyiv.[24] This broadband (1–50 μm) detector series combines both low-noise performance ($3 \cdot 10^{-10}$ W/Hz$^{1/2}$) and high bandwidth (50 MHz) at room temperature. These detectors can be optimized for radiometry, IR gas analysis, Fourier transform infrared (FTIR) spectroscopy as well as for measuring laser power and energy (minimal energy ~10^{-10} J and pulse duration –10^{-9} s).[25] Reportedly, these devices have been in use on "meteor"-type satellites, the interplanetary station "Phobos," and on the orbital station "Mir."

A family of efficient single and multistage (up to nine) thermoelectric coolers for commercial and scientific applications have been developed by researchers from the Institute of Thermoelectricity at Chernivtsy.[26] Made with bismuth telluride materials, these devices can be used in IR focal plane detector arrays. Maximum current ratings range from 0.06 to 7.5Å and a maximum temperature differential of 70 to 133°C is possible.[27] Table VII provides a more detailed look at these device parameters. Custom designs are also available upon request.

Ukranalyt R&D Company in Kyiv[28] produces both efficient multilayer IR interface filters and multipath optical cells for two wavelength coverages (2–8 and 8–14 μm). The filters can be delivered with $T_{max} \geq 50\%$ trasmittance at λ_o for 2–8 μm and $T \geq 40\%$ for 8–14 μm spectral ranges. The relative halfwidth $\frac{\Delta\lambda_{0.5}}{\lambda_0}$ does not exceed 2.2–4%. When illuminated with IR noncoherent light the multipath cells provide up to a 25 m long beam traveling length and more than a 70 m path when illuminated with an IR laser. Based on these optical components, the company has developed the IR gas analyzers for air monitoring and vehicle exhaust gas analysis.

GOVERNMENT GUARDIANSHIP

Government support in this area is growing and helping. In its declared overall strategy, the government plans to balance spending on civilian and defense programs. However, the switch from defense to a civilian focus is happening slower than anticipated for several reasons. First, private companies have exhibited little interest in the electronic and optoelectronic business. Secondly, the times seem to favor small science, not big physical projects, and thirdly, the national roadmap aimed to remedy the situation and to improve the worldwide competitiveness of the Ukranian optoelectronics industry has not been developed yet.

All in all, the State Committee on Science and Technology is permanently funding as many as 30 scientific projects to develop efficient semiconductor lasers, IR LEDs and two-dimensional focal plane area detectors. Some of these projects are concerned with fibreoptics and optical storage components.

The National Academy of Sciences assistance in financing practically all aspects of fundamental studies such as new materials (primarily narrow-gap semiconductors and semimetals), new generations of photonic devices, fundamental aspects of radiation-substance interaction, should be mentioned also. The number of grants dealing with different aspects of IR physics and devices reportedly exceeds a hundred. Finally, after the government decision to fix civilian R&D funding for FY 1995 at 1.7% of gross domestic product, the future of Ukranian IR science is not seen as being in doubt.

The National Space Agency follows more application-oriented goals. Their task is clearly formulated: the family of Ukranian satellites (the first one is to be launched by 1996) have to be equipped with domestic-made IR-systems.

The Department of Conversion concern is to focus on the IR optoelectronic technologies as key dual-use technologies with improtant enabling applications in both the defense and civilian areas and to turn many of the fundamental laboratory developments into manufacturable products. The strategic and commercial forces at work are similar to those that grew the optoelectronics industry in North America, Europe, and Japan—defense, scientific research, medicine, ecology, and industrial modernization. Naturally, economic factors and a shift away from defence contracts raise more questions than answers.

CONCLUSIONS

The results presented indicate that the IR photonics status in the Ukraine is quite comparable to that achieved in other countries. On the contrary, the cost of acquiring, processing, and producing the IR photons in this country is now so cheap as to be almost free. These two circumstances appear to provide the basis for understanding both the scientific and commercial opportunities of cooperation with Ukranian scientists and developers.

In the author's opinion, the top high-growth economy in Europe at the turn of the century will be the Ukraine, this European China. Clearly, the status of Ukranian IR photonics constitutes a promising opportunity for the international community. Ukranian semiconductor materials and optoelectronic devices could capture a significant portion of the semiconductor market in the near future, but the serious doubt exists that any Ukranian group will jump to international market alone (no domestic high-technology expertise exists, only a few of this products are suitable for export market). The question is who will be that entrepreneur to join Ukranian developers and producers in this jump. It is costly and risky, but the potential rewards are alluring.

What is envisioned now is a series of long-term, large-scale international programs that would be difficult for others to tackle because of their size, complexity, and long-term nature as well as "work for others" in small science application-oriented and dedicated projects. While this may seem dire, the picture is not as bad as it may look at first. Isn't it nice to have a choice? The stakes are high. In conclusion, the author's goal is not simply to ride the crest of this wave, but to be one of the forces driving this process forward.

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