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In this contract which has been awarded to EPIR Ltd. two tasks were assigned. The first one was related to the evaluation of the cost HgCdTe epitaxial layers grown by Molecular Beam Epitaxy (MBE) on various substrates. The substrates which were supposed to be considered are CdTe, CdZnTe and GaAs. In addition, EPIR has also analyzed the cost on silicon substrates since Si is currently considered to be the most important substrates for IR photodiode technology. The second task was related to the feasibility of growing a few HgCdTe epilayers by MDE with at least one exhibiting standard specifications.

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EVALUATION OF THE FEASIBILITY AND THE COST OF HgCdTe EPITAXIAL LAYERS GROWN BY MOLECULAR BEAM EPITAXY ON CdTe, CdZnTe AND GaAS SUBSTRATES

DARPA CONTRACT MONITORED BY AFOSR
CONTRACT #F49620-90-C0062

Final Report
July 15, 1990 - January 14, 1991

Principal Investigator
Dr. Jean-Pierre Faurie
President, EPIR Ltd.

INTRODUCTION

In this contract which has been awarded to EPIR Ltd. two tasks were assigned. The first one was related to the evaluation of the cost HgCdTe epitaxial layers grown by Molecular Beam Epitaxy (MBE) on various substrates.

The substrates which were supposed to be considered are CdTe, CdZnTe and GaAs. In addition, EPIR has also analyzed the cost on silicon substrates since Si is currently considered to be the most important substrate for IR photodiode technology.

The second task was related to the feasibility of growing a few HgCdTe epilayers by MBE with at least one exhibiting standard specifications.

TASK I

In the first part of the contract the total cost per cm^2 to produce an MBE-grown HgCdTe epitaxial wafer suitable for the industrial manufacture of an IR photodiode detector array has been estimated. The different parameters which have been taken into consideration to do the estimation are the following:

1. **$Hg_{1-x}Cd_xTe$ PHYSICAL SPECIFICATIONS FOR IR PHOTODIODES DETECTOR ARRAY**
2. **FIXED EXPENSES**
   2-1 MBE MACHINE COST
   2-2 MBE MAINTENANCE COST
   2-3 SALARIES
3. **PRODUCTION RELATED EXPENSES**
   3-1 SUBSTRATE COST
   3-2 GROWTH COST
4. **OVERHEAD AND GEA**
5. **YIELD**

In this report fixed expenses, overhead and G & A have been calculated on a yearly basis, whereas production related expenses have been calculated per run.

1. $Hg_{1-x}Cd_xTe$ PHYSICAL SPECIFICATIONS FOR IR PHOTODIODES DETECTOR ARRAY

cadmium composition	$x = 0.22 \pm 0.002$
	$\sigma_x/\bar{x} \leq 1\%$
cutoff wavelength	$\lambda_c = 10.4 \pm 0.28$ µm at 77K
thickness	= 10µm

Concerning the uniformity in composition the best results obtained in a monowafer MBE machine have published by M.D. Lange, S. Sivananthan, X. Chu and J.P. Faurie, Appl. Phys. Lett. 52, 978 (1988). They have shown that a composition uniformity of $\sigma_x/\bar{x} \leq 0.7\%$ can be achieved by MBE for $\bar{x} = 0.22$ on a 2-inch diameter substrate. Therefore in the estimate it will be considered that IR photodiode compositional uniformity can be achieved in a monowafer MBE machine on a 2-inch diameter substrate.

Concerning the multiwafer MBE machine no results have been so far reported. However, preliminary experiments carried out in the Microphysics Laboratory have shown that compositional uniformity $\sigma_x/\bar{x}$ of less than 0.6% can be achieved over 3-inch. Therefore, in the estimate it has been considered that suitable uniformity for IR photodiode can be achieved on 3 substrates of 2-inch diameter processed at the same time.

For comparison an estimate has also been established for a 5-inch silicon substrate. A composition uniformity $\sigma_x/\bar{x}$ of 2.4% has been found in these preliminary results. Even though this result is not fully satisfactory for a composition x = 0.22 it is quite suitable for a composition x = 0.33.

2. FIXED EXPENSES

2-1 MBE MACHINE COST

This cost has been calculated for the following configurations.

<u>configuration I</u> (1 x 2")	monowafer (2-inch or 3-inch) type RIBER 2300 which includes one MBE chamber, one introduction module and one transfer module. This configuration is suitable for the growth on lattice matched substrates such as CdZnTe, CdTeSe or even CdTe.
<u>configuration II</u> (1 x 2" +)	monowafer MBE machine with the transfer module designed to evaporate CdTe. This configuration is suitable for the growth on non-lattice matched substrates such as GaAs or Si because a several micrometer thick (5µm has been selected in this report) CdTe buffer layer has to be grown prior to the growth of HgCdTe. The growth of the buffer layer requires between 5 to 10 hours.
<u>configuration III</u> (3x 2" +)	multiwafer MBE machine type RIBER OPUS 45 (3 x 2-inch wafers, 3-inch, 4-inch or 5-inch wafer), comprising one MBE chamber, one evaporation chamber, and one introduction module. The multiwafer machine has been designed in such a way that compositional uniformity on each of the three 2-inch substrates grown simultaneously will be identical to the uniformity

obtained on a single 2-inch wafer in the monowafer machine. Preliminary results related to HgCdTe compositional uniformity obtained in this machine are, as stated earlier, very encouraging.

2-1 MBE MACHINE COST

Configuration I -	(1 x 2")	$750,000
Configuration II -	(1 x 2" +)	$900,000
Configuration III -	(3 x 2")	$1,500,000

In the estimate the cost of the MBE machine will be amortized over 5 years

2-2 MBE MAINTENANCE COST

According to qualified sources including the Microphysics Laboratory, which has eight years experience in this domain, ten percent of the total cost of the MBE machine represents a safe estimate as yearly maintenance expenses for an extensive use of the machine corresponding to 3 shifts. The maintenance cost has to be prorated to the number of shifts.

	1 SHIFT	2 SHIFTS	3 SHIFTS
(1 x 2") MBE machine	$25,000	$50,000	$75,000
(1 x 2"+) MBE machine	$30,000	$60,000	$90,000
(3 x 2") MBE machine	$50,000	$100,000	$150,000

2-3 SALARIES

A MBE machine can operate 24 hours per day. In this estimate only identical HgCdTe epilayers with well-defined characteristics are considered. For routine growth, in order to insure the control of the growth itself, the basic characterization and the result interpretation, it has been estimated that

One Shift requires the presence of one qualified technician plus one scientist (Ph.D. level)

Two Shifts require the presence of 2 technicians plus 1.5 Ph.D.
Three Shifts require the presence of 3 technicians plus 2 Ph.D's

Basic salaries are

Ph.D. salary	$50,000
Technician salary	$35,000

1 Shift	1 Ph.D. + 1 T	$85,000
2 Shifts	1.5 Ph.D. + 2 T	$145,000
3 Shifts	2 Ph.D. + 3 T	$205,000

3. PRODUCTION RELATED EXPENSES

3-1 SUBSTRATE COST

In this estimate we will consider CdZnTe substrates of 3 x 3cm^2 since this is the largest area commercially available which can be used on a 2-inch substrate holder. 2-inch diameter substrates for GaAs and Silicon substrates and 5-inch diameter for Si substrates have also been selected.

Current substrate prices are:

CdZnTe	3 x 3cm^2	(211)B: $900, (111)B: $720.00
GaAs	2-inch	$130
Si	2-inch	$2
Si	5-inch	$20

3-2 GROWTH COST

The two most expensive items related to the growth are the mercury and the liquid nitrogen (LN_2). The purest mercury (9N) which is currently used cost $0.25 per gram. When the growth occurs at 190°C the mercury consumption is of 15g/micrometer of HgCdTe in configuration I and II and of about 28g/micrometer of HgCdTe in configuration III. Since the HgCdTe thickness is of 10µm, the mercury related cost per run will be of $37.5 in configuration I and II compared to $70 in configuration

iii. CdTe related cost is also high when a 5µm thick CdTe buffer layer has to be grown prior to HgCdTe. The cost associated to the growth of the buffer layer is about twice the cost associated to the growth of the HgCdTe epilayer. Tellurium purity is 7N and CdTe purity is 6N+. The following table gives the cost of the growth without LN_2.

COST OF THE GROWTH PER RUN (WITHOUT LN_2)

	CONFIGURATION I	CONFIGURATION II	CONFIGURATION III	
			(without buffer layer)	(with buffer layer)
Chemicals	$10.00	$10.00	$10.00	$10.00
Mercury	$37.50	$37.50	$70.00	$70.00
Tellurium	$4.00	$4.00	$16.00	$16.00
Cadmium Telluride	$4.00	$12.00	$16.00	$48.00
TOTAL	$55.50	$63.50	$122.00	$154.00

Liquid nitrogen (LN_2) is also part of growth cost but its estimate requires the determination of the number of run per day and per year because the mercury trap has to be kept cold 24 hours/day every day of the year except during mercury removal. This part obviously represents a fixed expense.

First of all let us determine the duration of a run. The duration of a run is growth rate dependent. The growth rates that we have selected are suitable for a growth of high quality epilayers; they are:

CdTe:	0.72µm/hour
HgCdTe:	2.4µm/hour

In configuration II and III the buffer layer can be grown when HgCdTe epitaxial layers are growing, therefore only the time to transfer is taken into account.

DURATION OF A RUN

	CONFIGURATION I	CONFIGURATION II	CONFIGURATION III
Cleaning & mounting	1h	1h	0.5h
Loading	0.5h	0.5h	0.5h
in situ cleaning	0.5h	0.5h	0.5h
Transfer between growth chamber		0.5h	0.5h
Growth of HgCdTe	5h	5h	5h
Unloading	1h	1h	1h
TOTAL TIME	8h	8h 30	8h
Number of possible runs per day	3 runs	2.5 runs	3 runs

Taking into account the experience of the Microphysics Laboratory the mercury removal which takes two days should be carried out every 10 runs. Therefore it is reasonable to project 200 working days i.e. a maximum, corresponding to 3 Shifts, of 600 runs/year for configuration I & III and 500 runs/year for configuration II. The amount of $16,000 represents a yearly average of the LN_2 cost based on 200 working days with 200 runs. This cost can by analyzed as follows:

Fixed Expense:	Cryo shroud 1 (mercury)	24h x 250 days = 6000h
Growth Related: Expense	Cryo shroud 2 & 3	10h each per run i.e. 10h x 2 x 200 runs=4000h
Total	10,000h which gives a LN_2 cost per hour of $1.6	

Therefore the LN_2 cost in configuration I can be expressed by the following equation:

Cost per year: $1.6 (6000 + 20x)
Cost per run: 9600/x + 32 where x = number of runs/year

In configuration II two cryo shrouds are cold during CdTe growth (duration: 7h) [5µm/0.72µm/h] i.e. 14h of LN_2 have to be added for each run.

LN_2 cost per year: $1.6 (6000 + 34x)
cost per run: 9600/x + 54.4

In configuration III the LN_2 consumption in the cryoshroud operating during the growth is about 1.5 times the consumption in the monowafer MBE machine.

-WITHOUT BUFFER LAYER

LN_2 cost per year: $1.6 (6000 + 35x)

LN_2 cost per run: 9600/x + 56

-WITH BUFFER LAYER (5µm thick)

Cost per year: $1.6(6000 + 51x)

Cost per run: 9600/x + 81.6)

Therefore the total cost of the growth per run is approximated to

	Cost per run	Cost per year
CONFIGURATION I:	88 + 10,000/x	88x + 10,000
CONFIGURATION II:	118 + 10,000/x	118x + 10,000
CONFIGURATION III:	178 + 10,000/x	178x + 10,000
CONFIGURATION III (WITH BUFFER LAYER):	236 + 10,000/x	236x + 10,000

4. OVERHEAD AND G & A

The cost is established on a yearly rental basis. It does depend on the number of Shifts for several items such as insurance, salary overhead, services, and G & A. It has been estimated as follows:

			1 SHIFT	2 SHIFT	3 SHIFT
4-1	SPACE				
	CLEAN ROOM	600 sqft	$20,000	$20,000	$20,000
	LABORATORY	1000 sqft	$10,000	$10,000	$10,000
	OFFICE	500 sqft	$5,000	$5,000	$5,000
	TOTAL		$35,000	$35,000	$35,000
4-2	PROPERTY AND CASUALTY INSURANCE		$15,000	$20,000	$25,000
4-3	RETIREMENT (10% of Total Direct Labor)		$8,500	$14,500	$20,500
4-4	PAYROLL TAXES (10% of TDL)		$8,500	$14,500	$20,500
4-5	SERVICES (Telecommunications)		$6,000	$9,000	$12,000
4-6	SHIPPING - HANDLING		$4,000	$6,000	$8,000
	TOTAL		$42,000	$64,000	$86,000
	G & A				
4-7	OFFICE EQUIPMENT LEASE		$10,000	$10,000	$10,000
4-8	SECRETARIAL WORK & BOOK KEEPING		$30,000	$40,000	$50,000
4-9	ACCOUNTING		$10,000	$10,000	$10,000
	TOTAL				
			$50,000	$60,000	$70,000
GRAND TOTAL			$127,000	$159,000	$191,000

5. YIELD

Since no information has been reported about the yield, in this estimate it has been taken equal to one. It is obvious that the yield should be lower than one. Therefore, the cost reported in the following tables have to be divided by the yield. Since the yield depends on the epilayer specifications any hypothesis is difficult to make without experimental data.

6. COST

Summary of fixed expenses and growth related cost along with estimated cost per run, per wafer and per cm^2 of HgCdTe epitaxial layer grown by MBE on CdTe, CdZnTe, GaAs and Si substrates in three different growth chamber configurations are given in Table I, II and III.

TABLE I

Configuration I

HgCdTe MBE epilayer is 10μm thick

SUBSTRATE	CdZnTe(211)B - 3 x 3cm^2			CdZnTe(111)B - 3 x 3cm^2		
NO. OF RUNS PER YEAR	200	400	600	200	400	600
FIXED EXPENSES (K$):						
MACHINE	150	150	150	150	150	150
MAINTENANCE	25	50	75	25	50	75
SALARIES	85	145	205	85	145	205
OVERHEAD	127	159	191	127	159	191
LN_2	10	10	10	10	10	10
TOTAL (K$)	397	514	631	397	514	631
FIXED COST PER RUN ($)	1985	1285	1052	1985	1285	1052
GROWTH RELATED COST PER RUN ($):						
SUBSTRATE	900	900	900	720	720	720
LN_2	32	32	32	32	32	32
GROWTH	56	56	56	56	56	56
TOTAL	988	988	988	808	808	808
COST PER RUN ($)	2973	2273	2040	2793	2093	1860
COST PER WAFER ($)	2973	2273	2040	2793	2093	1860
COST PER CM^2 ($)	330	253	227	310	233	206

TABLE II

Configuration II

CdTe buffer layer is $5\mu m$ thick
HgCdTe epilayer is $10\mu m$ thick

SUBSTRATE	CdZnTe(211)B - 3 x 3cm^2			CdZnTe(111)B - 3 x 3cm^2		
NO. OF RUNS PER YEAR	167	333	500	167	330	500
FIXED EXPENSES (K$):						
MACHINE	180	180	180	180	180	180
MAINTENANCE	30	60	90	30	60	90
SALARIES	85	145	205	85	145	205
OVERHEAD	127	159	191	127	159	191
LN_2	10	10	10	10	10	10
TOTAL (K$)	432	554	676	432	554	676
FIXED COST PER RUN ($)	2587	1664	1352	2587	1664	1352
GROWTH RELATED COST PER RUN ($):						
SUBSTRATE	130	130	130	2	2	2
LN_2	54	54	54	54	54	54
GROWTH	64	64	64	64	64	64
TOTAL	248	248	248	120	120	120
COST PER RUN ($)	2834	1912	1600	2707	1784	1472
COST PER WAFER ($)	2834	1912	1600	2707	1784	1472
COST PER CM^2 ($)	142	96	80	135	89	74

TABLE III

Configuration III

CdTe buffer layer grown on GaAs or Si is 5μm thick
HgCdTe epilayer is 10μm thick

SUBSTRATE	CdZnTe(111)B 4 x 9cm^2			GaAs(100) 3 x 2-inch			Si(100) 3 x 2inch			Si(100) 5-inch		
NO.OF RUNS PER/YEAR	200	400	600	200	400	600	200	400	600	200	400	600
FIXED EXPENSES (K$):												
MACHINE	300	300	300	300	300	300	300	300	300	300	300	300
MAINTENANCE	50	100	150	50	100	150	50	100	150	50	100	150
SALARIES	85	145	205	85	145	205	85	145	205	85	145	205
OVERHEAD	127	159	191	127	159	191	127	159	191	127	159	191
LN_2	10	10	10	10	10	10	10	10	10	10	10	10
TOTAL (K$)	572	714	856	572	714	856	572	714	856	572	714	856
FIXED COST PER RUN ($)	2860	1785	1427	2860	1785	1427	2860	1785	1427	2860	1785	1427
GROWTH RELATED COST PER RUN ($):												
SUBSTRATE	2880	2880	2880	390	390	390	6	6	6	20	20	20
LN_2	56	56	56	82	82	82	82	82	82	82	82	82
GROWTH	122	122	122	154	154	154	154	154	154	154	154	154
TOTAL ($)	3058	3058	3058	626	626	626	242	242	242	256	256	256
COST PER RUN ($)	5918	4843	4485	3486	2411	2053	3102	2027	1669	3116	2041	1683
COST PER WAFER ($)	1480	1211	1121	1162	804	684	1034	676	556	3116	2041	1683
COST PER CM^2 ($)	164	135	125	58	40	34	52	34	28	25	16	13

TASK II

In the second task of this contract six HgCdTe epitaxial layers have been grown by Molecular Beam Epitaxy and characterized using FTIR and Hall technique. Among the six layers it was expected to have one exhibiting at low temperature the following characteristics:

composition: $x = 0.225 \pm 0.01$
conduction type: n or (p)
carrier concentration: $N_D - N_A$ or $(N_A - N_D) \leqslant 5 \times 10^{-15}cm^{-3}$
electron (hole) mobility: $\mu_e \geqslant 1 \times 10^5 cm^2 v^{-1} s^{-1}$; $(\mu_h \geqslant 300 cm^2 v^{-1} s^{-1})$

These layers have been grown on CdTe (211)B oriented substrates. The substrate's quality has been investigated using X-ray diffraction. From this screening only substrates exhibiting a FWHM of less than 30 arc sec have been selected. The composition and thickness of HgCdTe epilayers have been determined using FTIR.

LAYER THICKNESS AND COMPOSITIONAL UNIFORMITIES

No change in either thickness nor in composition has been observed on epilayers as large as $2 \times 2cm^2$. The precision of these measurements using FTIR is of ± 0.2%. Therefore it is confirmed that when the substrate is rotating during the epitaxial growth of HgCdTe by MBE in a RIBER 2300 machine, the standard deviations for thickness $\sigma t/\bar{t}$ and composition uniformity $\sigma x/\bar{x}$ are lower than 0.2% for a size up to $2 \times 2cm^2$.

COMPOSITION REPRODUCIBILITY

Although the purpose of these growth was not to establish a statistic about composition run to run reproducibility, it is interesting to see that 4 out 6 layers have cadmium composition x within the targeted composition range of 0.225 ± 0.01 (Table IV and V).

TRANSPORT PROPERTIES

All the as-grown layers exhibit a n-type conductivity (Table IV and V). Four out of six layers have low temperature electron mobilities exceeding $10^5 cm^2 v^{-1} s^{-1}$ especially for EPI 1 and EPI 2. Five out of six layers have carrier concentration

TABLE IV

Characteristics of the as grown HgCdTe epilayers:

Substrate	sample	x	t (μm)	300 K		77 K		23 K	
				cc (cm^{-3})	μ_e (cm^2/v.s)	cc (cm^{-3})	μ_e (cm^2/v.s)	cc (cm^{-3})	μ_e (cm^2/v.s)
CdTe(G)	EPI 1	0.19	9.5	6.6×10^{16}	1.6×10^{4}	5.5×10^{15}	2.8×10^{5}	5.2×10^{15}	5.2×10^{5}
CdTe(G)	EPI 2	0.19	21.4	7.3×10^{16}	1.4×10^{4}	4.5×10^{15}	4.3×10^{5}	3.1×10^{15}	7.2×10^{5}
CdTe(G)	EPI 3	0.225	2.2	3.3×10^{16}	7.3×10^{3}	1.3×10^{16}	6.4×10^{4}	1.2×10^{16}	1.1×10^{5}
CdTe(II-IV)	EPI 6	0.215	9.7	4.7×10^{16}	1.0×10^{4}	5.9×10^{14}	6.3×10^{4}	4.3×10^{14}	1.3×10^{5}

TABLE V

Characteristics of as grown and annealed HgCdTe epilayers:

Substrate	sample	x	t(μm)	300 K		77 K		23 K	
CdTe	EPI 4	0.22	12.8	cc (cm^{-3})	μ_e(cm^2/v.s)	cc (cm^{-3})	μ (cm^2/v.s)	cc (cm^{-3})	μ (cm^2/v.s)
As Grown				5.6×10^{16}	6.7×10^{3}	9.2×10^{14}	2.8×10^{4}	8.2×10^{14}	2.1×10^{4}
n-type annealing				5.0×10^{16}	9.5×10^{3}	4.1×10^{15}	7.8×10^{4}	4.0×10^{15}	1.2×10^{5}
p-type annealing				n-1.9×10^{16}	3.7×10^{3}	p-7.5×10^{16}	380	p-1.0×10^{16}	400
Substrate	sample	x	t(μm)	300 K		77 K		23 K	
CdTe	EPI 5	0.235	11.25	cc (cm^{-3})	μ_e(cm^2/v.s)	cc (cm^{-3})	μ (cm^2/v.s)	cc (cm^{-3})	μ (cm^2/v.s)
As Grown				1.7×10^{16}	6.6×10^{3}	1.7×10^{14}	3.1×10^{4}	1.4×10^{14}	5.4×10^{4}
n-type annealing				3.5×10^{16}	5.1×10^{3}	7.4×10^{15}	4.2×10^{4}	6.8×10^{15}	6.6×10^{4}
p-type annealing				n-9.1×10^{15}	2.8×10^{3}	p-2.2×10^{16}	408	p-2.1×10^{15}	600

lower than $5x10^{15}cm^{-3}$ at 77K or below. EPI 3 has a carrier concentration in the low 10^{16} cm^{-3} range but it might be thickness related since this layer is very thin (2.2 µm). At 23K five out of six layers show a carrier concentration in the 10^{14} cm^{-3} range which seems to indicate that they are compensated since for EPI 4 and EPI 5 the mobility at 23K for such a carrier concentration should be above $10^{5}cm^{2}v^{-1}s^{-1}$.

ANNEALING

In order to address the suitability of these layers for IR photodiodes we have annealed EPI 4 and EPI 5 in order to convert both of them n- and p-type. N-type annealing was carried out under isothermal conditions at 400°C for 10 minutes followed by a 250°C 27 hours annealing. P-type annealing was carried out like the n-type annealing followed by a 250/50°C 24 hours anneal. It should be pointed out that these steps were not part of the task assigned in this contract. In addition these annealing procedures are not conventional procedures. EPIR has worked out specific anneals for these MBE grown layers.

The results presented in Table (V) are very interesting. First, the two layers do convert n and p which is very encouraging. The n-type anneals show that the residual donor level in these MBE layers is in the mid $10^{15}cm^{-3}$ range which is acceptable for IR diodes but should be decreased for MIS structures. The origin of this residual donor background is not clear yet and EPIR is currently investigating this point. It might be due to impurities coming from the substrate and/or from the effusion cell material. Te atoms in antisite might also play a role. Anyway both carrier concentration and electron mobilities are suitable for IR detection.

The p-type anneal has been carried out under conditions for which acceptor level is higher than the residual donor level found after isothermal anneal. Therefore it is expected to have a carrier concentration above $5x10^{15}cm^{-3}$. Hole mobilities are above 300 $cm^{2}v^{-1}s^{-1}$. These p-type layers are also suitable for IR photodiode fabrication.

CONCLUSION

Table I, II, and III show the cost per run, the cost per wafer and most important the cost per cm^2 of MBE HgCdTe layers grown on various substrates in different MBE machine configurations. For comparison $1cm^2$ of LPE grown HgCdTe on CdZnTe substrate is currently sold at $1,000.

In the second task of this program 6 HgCdTe epilayers have been grown by MBE. Four out of six have a cadmium composition within the targeted range and all of them exhibit transport properties suitable for IR photodetection. In addition, two of them have been annealed and have been converted n- or p-type as expected which is a very good sign about the quality of these layers.

On such a small number of runs it is not wise to determine a yield but the least that can be said is that getting 67% of the layers within the composition range is very encouraging from a production point of view.

A rough estimate shows that if such a yield is confirmed by a systematic investigation the cost per cm^2 on CdZnTe substrate will in the worst case of 200 runs per year (See Table I) of $330/0.67 = $495 i.e. half the selling price of LPE layers.

By taking a more realistic approach of a 400 runs per year growth in configuration III on CdZnTe substrate (See Table III) the cost would be of $135/0.67 = $203 which is a very competitive price. For HgCdTe grown on alternate substrates such as GaAs and above all Si the cost is incredibly low as it can be seen in Table III.

The cost estimate along with these preliminary experiments show that MBE is indeed an epitaxial technique which must be considered for the manufacturing of HgCdTe material. EPIR Ltd. has been founded for this purpose.