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STRUCTURAL AND ELECTROPHYSICAL PROPERTIES OF MnHgTe LAYERS OBTAINED BY LASER ASSISTED DEPOSITION

Abstract: $Mn_xHg_{1-x}Te$ (x=0.1-0.13) layers were grown on (111) CdTe substrates by laser assisted deposition; they were characterized by electron diffraction, microprobe analysis, and Hall effect measurements. *

Introduction

The narrow gap semimagnetic semiconductors have been intensively investigated due to their many unique properties. Particularly, MnHgTe (MMT) solid solutions have already been applied successfully for preparation of high quality infrared detectors [1,2].

In order to produce infrared-sensitive devices it is important to obtain high quality MMT layers. Nowadays, several techniques for growing of MMT layers have been reported, such as liquid phase epitaxy on MnCdTe [3] and CdTe [4,5] substrates, and organometallic vapour phase epitaxy on GaAs substrates with buffer CdTe layers [6,7] at relatively high growth temperatures.

For low temperature (below 300K) techniques of growing MMT layers, it is available information only on molecular beam epitaxy on GaAs substrates [8,9]. Laser-assisted deposition (LADA) is also a low temperature vacuum deposition, which has been used to grow epitaxial layers of CdHgTe, CdTe, HgTe and HgTe/CdTe superlattice at substrate temperature (Ts) of 180, 350, 185, and 250°C, respectively [10-14].

†Deceased

In this paper, results on growth and characterization of MMT layers on CdTe (111) substrates by LADA are reported for the first time. Single crystal n-type MMT layers were grown at temperatures ranging from 180 to 200°C. The influence of the thermal treatment on the electro-physical properties of MMT layers has been studied. After two-stage thermal annealing at Hg overpressure, MMT layers have been established to remain as those of the n-type conductivity at 77 K with mobility and carrier concentration values in the range of (1.3-3.3)$\cdot 10^4$ cm^2/Vsec and (0.5-3.3) $\cdot 10^{17}$ cm^{-3}, respectively.

Experimental

A simple, schematic drawing of the LADA apparatus used for epitaxy of MMT layers on CdTe substrates is shown in Fig.1. It consists of a pulsed laser and a vacuum chamber. An acoustooptical Nd:YAG laser is used as an external power source for evaporating the source material. It was operated in the free oscillation mode. Typical operating conditions were: 14, 28, and 56 Hz repetition rate with an average power of 0.2-0.45 W. The beam was focused into a 0.05 cm diameter spot on the source surface. A pair of galvanometric mirrors was used to scan the laser beam over the source material with a linear rate of 1.25 cm/sec. The vacuum chamber was backed by the oil-diffusion pump with residual pressure in the low 10^{-7} Torr range.

The condensation of MMT was carried out onto (111) CdTe substrates. The substrates were loaded into the vacuum chamber after etching in bromine-methanol solution. Single-crystal $Mn_xHg_{1-x}Te$ wafers of average composition of x=0.14 were used as the source material. Prior to growth, the surface of source material was mechanically polished and etched in bromine-methanol solution. The MMT layers were grown at Ts ranging from the room temperature to 250°C.

The layer structure has been investigated by means of reflection high electron energy diffraction. Chemical composition of MMT layers was determined by electron-beam microprobe analyser DC-130°C. Mobility and carrier concentration measurements have been made using four-probe method, and the magnetic field of 0.3 T.

Results and discussion

The LADA grown layers have been known to be characterized by structural defects formed mainly by „spitting" from the source material [10,11]. The growth parameters were chosen so that spitting-effect would be minimum and a deposition rate would be in the range of 4-5 μm/h. It has been achieved at repetition rate of 14 Hz with average power of 0.35 W and source material-to-substrate distance of 4 cm. The deposition rate has been established to be almost independent of Ts under these growth parameters.

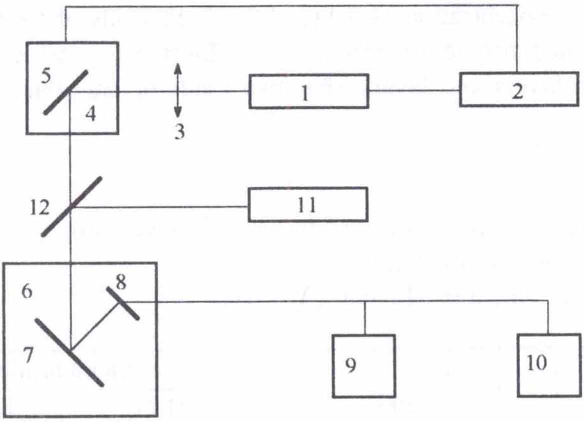

Fig.1. Schematic drawing of LADA apparatus

1 - Nd:YAG laser; 2 - pulse generator; 3 - focused lens; 4 - dielectric mirror; 5 - scanner; 6 - vacuum chamber; 7 - laser evaporated source; 8 - substrate; 9,10 - system for determination and stabilisation of Ts; 11 - power measuring unit; 12 - half-transparent mirror

From chemical composition analysis it has been revealed that Mn content in MMT layers is in conformity with the average Mn content in the source material. The Mn, Hg, and Te distributions were established to be uniform over the thickness and surface of the layer.

On the basis of the investigation of the peculiarities of MMT layer structure formation it should be pointed out, that at low substrate temperatures (Ts<150°C) layers have polycrystalline structure. The oriented growth of crystallites with preferred (111) orientation parallel to substrate (111) is observed at 150<Ts<180°C. The epitaxial growth of MMT layers is achieved at 180<Ts<200°C. Microtwins and stacking faults are the main structural defects of MMT layers. At Ts>200°C the structural perfection of MMT layers decreases, und at Ts>230°C they have polycrystalline structure again, due to the Hg loss from the layer built up on the substrate.

As-grown MMT layers were n-type with carrier concentration of $(0.6\text{-}3)\cdot10^{17}$ cm^{-3} and mobilities of $(0.3\text{-}2.8)\cdot10^{3}$ $cm^{2}/Vsec$ at 77 K. The MMT layers were submitted to two-stage isothermal treatment at Hg overpressure which includes short-time (30-40 min) high-temperature annealing at 400°C and low-temperature annealing at 210°C during 24 h. Furthermore, MMT layers were submitted to one-stage isothermal treatment at 210°C at Hg overpresure during 24 h for decreasing of the carrier concentration [4,5,11]. After both kinds of treatment MMT layers remained n-type of conductivity. Electrophysical characteristics of As-grown layers and layers after two kinds of annealing are reported in Table 1.

Table 1
Electrophysical characteristics of $Mn_XHg_{1-X}Te$ layers grown by LADA
d - $Mn_XHg_{1-X}Te$ layer thickness;
x - manganese content in $Mn_XHg_{1-X}Te$ layers

N	x	d	Ts	after growth		after annealing			
						210°C		400/210°C	
		μm	°C	m_{77} cm²/Vs	R_{77} cm³/ql	m_{77} cm²/Vs	R_{77} cm³/ql	m_{77} cm²/Vs	R_{77} cm³/ql
MK-4	0.101	2.1	150	$3.2\cdot10^2$	20.5	$1.8\cdot10^3$	4.0	$9.2\cdot10^3$	23.8
MK-5	0.123	2.2	190	$7.1\cdot10^2$	48.4	$5.3\cdot10^3$	7.3	$1.4\cdot10^4$	18.3
MK-8	0.128	2.0	200	$2.8\cdot10^3$	94.6	$2.0\cdot10^4$	106.2	$3.3\cdot10^4$	85.2
MK-6	0.133	2.1	230	$1.8\cdot10^3$	102.5	$7.2\cdot10^3$	14.4	$1.9\cdot10^4$	31.5

x was calculated from $E_g(x,T)$ dependence [1]. E_g was determined by means of the transmision measurement at the room temperature using the SPECORD 75 IR spectrophotometer.

As it can be seen, carrier concentration of MMT epilayers almost does not change after annealing, but their mobilities appreciably increase by 6-7 times and up to 1-1.5 order of magnitude after isothermal and two-stage treatment, respectively (Fig.2). The latter is caused by annealing of layer structural defects that give rise to an increase of carrier mobility.

Conclusions

The investigation of MMT layers grown by LADA has shown that single crystal layers can be obtained at the narrow range of substrate temperatures from 180 to 200°C. They have n-type conductivity with carrier concentration of $(0.6\text{-}3)*10^{17}$ cm^{-3} and mobilities of $(0.3\text{-}2.8)\cdot10^3$ cm^2/Vsec at 77 K. Thermal annealing at Hg overpressure almost does not change carrier concentration. The abrupt increase of electron mobility is achieved only after two-stage treatment of MMT layers at Hg overpressure.

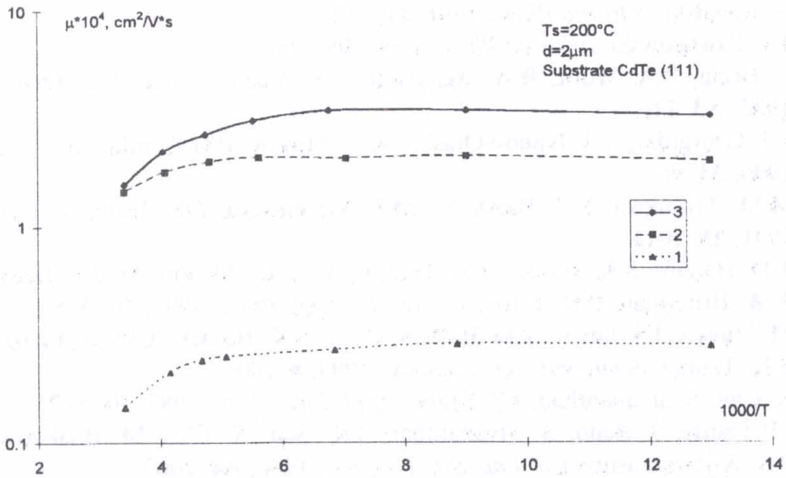

Fig.2
Hall mobility versus reciprocal temperature for MMT layer:
as-grown (1), after isothermal one-stage annealing (2), and after two-stage annealing (3) at Hg overpressure

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Struktura i właściwości elektrofizyczne warstw MnHgTe uzyskanych za pomocą laserowego napylania

Streszczenie: Warstwy MnHgTe uzyskano na bazie (111) substratów CdTe w procesie laserowego napylania; scharakteryzowano je za pomocą dyfrakcji elektronowej i mikroanalizy oraz pomiarów efektu Halla.