Vapour–liquid–solid-assisted growth of cadmium telluride nanowires and their field emission properties

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Cadmium telluride (CdTe) nanowires were grown on silicon substrate (100) by thermal evaporation method. The synthesised CdTe nanowires were characterised by X-ray diffraction, field emission scanning electron microscope, energy-dispersive analysis of X-ray, and photoluminescence techniques. The field emission characteristics have been investigated at room temperature. The *J–E* and *I–t* characteristics were measured in a planar diode configuration at the base pressure of 1×10^{-8} mbar. Turn-on field defined for the emission current density of 0.1 μA/cm^2 has been found to be 2.2 V/μm and on the application of high applied electric field of 7.8 V/μm maximum current density of 210 μA/cm^2 has been achieved. The *I–t* measurement has been studied at the preset of 1 μA emission current for the duration of 3 h. Overall nature of emission current has been seen to stable for duration of the measurement. To the best of the authors' knowledge, this is a first report on field emission study of CdTe nanowires.

1. Introduction: One-dimensional (1D) nanostructures gain importance as a building block for future electronic devices. Nanowires are one of the potential candidates from 1D nanostructure for electronic devices due to its high aspect ratio and nanometric dimension [1]. Cadmium telluride (CdTe) is one of the important II–VI semiconducting chalcogenide material with direct bandgap of 1.45 eV [2]. Owing to direct optical transmission CdTe is employed in the application of photovoltaic applications as well as in gamma ray and infrared detectors and also in electronic and optoelectronic devices [3]. The quantum confinement effect appears in the nanoparticles of the CdTe by controlling size and which offers the wide bandgap energy for the visible spectrum [4]. The various techniques such as solvothermal [5], hydrothermal [6], solution-based synthesis [7] and electrochemical [8] are used for the synthesis of CdTe nanowires.

Field emission is purely quantum mechanical phenomenon, where electrons are emitted from the surface of nanomaterials under the action of the strong electrostatic field. Field emission is geometry dependent phenomenon. For best field emitter, the requirements are low turn-on field, high current density and stable electron emission over long periods. It is achieved by controlling the morphology or electronic properties of the synthesised materials in the nanodimension. Various investigations show that semiconducting nanowires are the good field emitters [9–11]. That is just by controlling the dimension of materials at nanoscale the electron emission characteristics can enhance.

In this Letter, we report the synthesis of CdTe nanowires on silicon (Si) (100) substrate by vapour–liquid–solid (VLS) route. Owing to the synthesis of CdTe nanowires on Si substrate, it can be directly used for electronics applications.

2. Experiment: The position controlled growth of CdTe nanowires done by VLS route on gold (Au)-coated Si (100) substrate in the horizontal tube furnace. A layer of Au (about 3 nm in thickness) as a catalyst was coated on Si substrate by sputtering. Highly pure 50 mg CdTe powder (99.99%, Sigma Aldrich) was filled in the quartz boat and was placed in the middle of the horizontal quartz tube furnace. In a quartz tube at a distance of 22, 23 and 24 cm, the Au-coated Si substrate was kept downstream of the gas flow from the centre. The Si substrate was first degreased in an ultrasonic bath with acetone for 20 min and a thin layer of Au film was coated by sputtering. Before reaction the purging of quartz tube by argon (Ar) gas with a flow rate of 100 sccm (standard cubic centimetres per minute) for an hour was done. Then tube has been heated up to 950°C with a ramp of 8°C min^{-1}, and was kept at this temperature for 40 min with constant Ar flow of 250 sccm. Then furnace was cooled to room temperature under normal cooling (Fig. 1).

The surface morphology of as-synthesised CdTe nanowires has been studied using field emission scanning electron microscope (FESEM) (Model Hitachi S-4800). Phase of as-synthesised material was recognised by X-ray diffraction (XRD) (D8 Advance, Bruker instrument) and elemental composition of the CdTe nanowires was analysed by energy-dispersive analysis of X-ray (EDAX). Then optical property was studied by photoluminescence (PL) spectroscopy (Model Shimadzu RF-5301 PC). The field emission current density–applied field (*J–E*) and current–time (*I–t*) measurements were carried out by field emission microscope in a 'close proximity' (planar diode) configuration. The CdTe nanowires served as a cathode and a semi-transparent cathodoluminescent

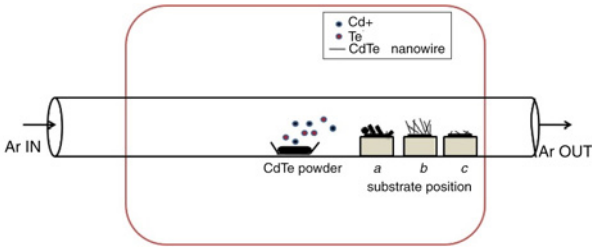

Fig. 1 *Schematic of synthesis approach to prepare CdTe nanowires*

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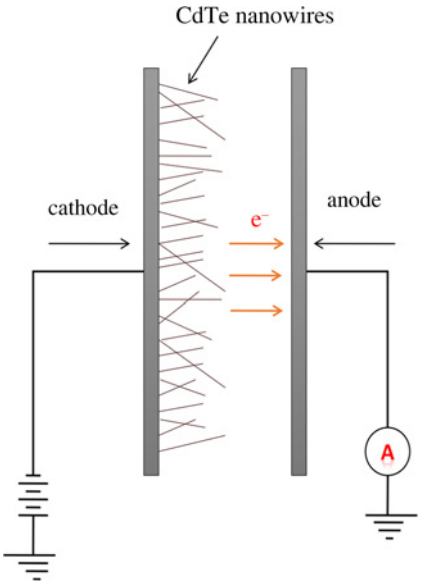

Fig. 2 *Schematic of the field emission diode assembly*

phosphor screen as an anode. Fig. 2 is a schematic of diode assembly for field emission study in case of CdTe nanowires. The area of specimen was 0.25 cm^2. Using vacuum compatible conducting silver paste, the cathode was pasted onto a copper rod and fixed at a distance of ~1 mm in front of the anode screen. The cathode did not show any appreciable degassing and vacuum was obtained with usual speed. After baking the system at 150°C for 12 h, pressure of $\sim 1 \times 10^{-8}$ mbar was obtained. Keithley Electrometer (6514) and a Spellman high-voltage DC power supply (0–40 kV, USA) was used to take the *J*–*E* and *I*–*t* measurements at this base pressure.

3. Results and discussion: The as-synthesised material was first examined by FESEM observation. Figs. 3*a*, *c* and *e* are low magnification and Figs. 3*b*, *d* and *f* are high magnification FESEM images of as-synthesised material at distances of 22, 23 and 24 cm on Si substrate from source, respectively. At a distance of 22 cm, the crystal like structure was grown of micrometre range and at a distance 24 cm very few CdTe nanowires were grown on Si substrate. However, at the distance 23 cm (Figs. 3*c* and *d*) highly dense CdTe nanowires were grown on a substrate with an average diameter of ~50 nm and length of a few microns. This sample was used to examine further characteristics.

For the growth of the nanowires, the most suitable parameters are observed such as temperature of 950°C, constant Ar flow of 250 sccm, time duration of 40 min and distance of the Si substrate at 23 cm. At the distance of 23 cm, possibly the flux of Cd and Te vapour species may be high enough which leads into the maximum and fast growth of CdTe nanowires in the horizontal tube furnace.

A typical XRD spectrum of given CdTe nanowires is shown in Fig. 4 exhibiting a set of well-defined diffraction peaks implying the crystalline nature of the CdTe nanowires. The diffracted peaks found at 23.7°, 46.5°, 56.7°, 62.3°, 71.3° and 76.3° are indexed to the cubic crystalline structure of CdTe with lattice parameter $a = b = c = 6.48$ Å (JCPDS Card No. #651085). Also, the diffraction peaks at 38.2° and 63.6° corresponding to Si. There are no any peaks related to other materials were found which shows the high purity of the CdTe nanowires.

The stoichiometry of the CdTe as-synthesised nanowires was analysed by EDAX, and the typical pattern is shown in Fig. 5. Elemental analysis shows that the atomic ratio (Cd:Te) is nearly 1:1, which is consistent with CdTe.

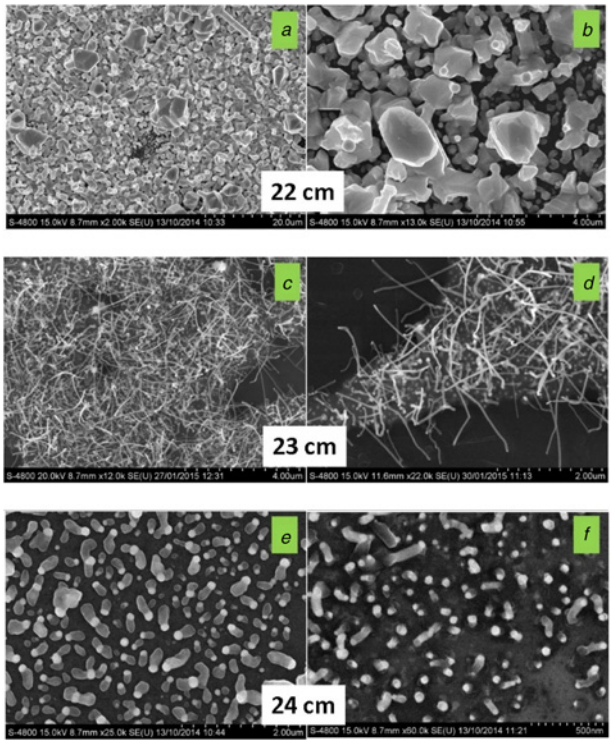

Fig. 3 *FESEM images of CdTe nanowires grown at 950°C with constant Ar flow 250 sccm at distance of*
a, *b* 22 cm
c, *d* 23 cm
e, *f* 24 cm

The PL of material is intricate because it is sensitive to the growth conditions, crystal size and shape [12]. Fig. 6 gives the PL spectrum of as-synthesised CdTe nanowires at room temperature. It shows strong emission peak at 630 nm which is consistent with previous literatures [13–15].

The field emission study of as-synthesised CdTe nanowires was studied. The *J*–*E* plot of CdTe nanowires is shown in Fig. 7*a*. It shows that turn-on field defined as the field required to draw an emission current density of 0.1 μA/cm^2 that has been found to be 2.2 V/μm. The maximum current density for CdTe nanowires has been achieved to be 210 μA/cm^2 on the application of high applied electric field 7.8 V/μm. The Fowler–Nordheim (*F*–*N*) plot, i.e. ln (J/E^2) against ($1/E$), derived from the observed *J*–*E* characteristic is shown in Fig. 7*b* showing the overall linear

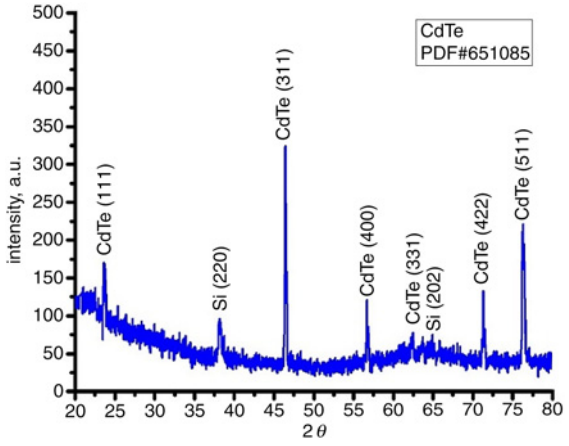

Fig. 4 *XRD pattern of the CdTe nanowires grown on a Si substrate*

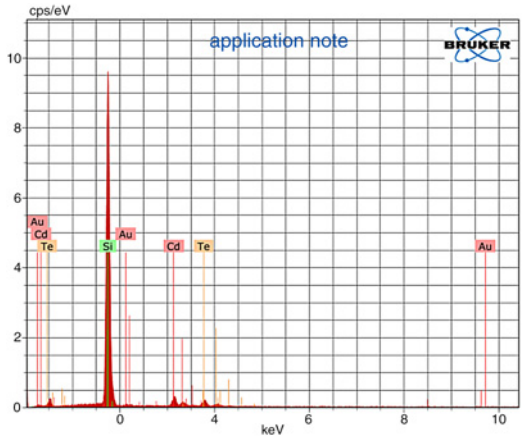

Fig. 5 *EDAX spectrum of the CdTe nanowires*

behaviour [9]. The *I–t* plot at the preset of 1 μA emission current for the duration of 3 h is shown in Fig. 8. Field emission image shown as inset of Fig. 8 depicts large number of tiny spots indicating the participation of large emitter in the field emission. Overall, stable emission current is found for the duration of the measurement. The emission current shows the small amount of instabilities/fluctuation in the form of 'spikes'. During the emission process, there might be some gas molecules present inside the field emission chamber, due to adsorption, desorption of these gas molecules and ion bombardment phenomenon results to instabilities in emission current [16]. The average emission current of the CdTe nanowires emitter remains constant over the entire duration which shows no signs of degradation.

The field enhancement factor (β) estimated from observed *F–N* plot mathematically expressed as follows [17]

$$\beta = -\frac{(6.8 \times 10^3)\emptyset^{(3/2)}}{\text{slope}}$$

where $\emptyset$ is the work function of the material.

By considering the work function for CdTe as 5.7 eV [18], field enhancement factor has been found to be 4125. The high value of β supports the observed low turn-on field value for CdTe nanowires [19].

The field emission properties of CdTe nanostructures are unexplored hence comparison for low turn-on field between II–VI group semiconducting nanowires and present study has been done as shown in Table 1 [20–24]. It indicates that turn-on field for CdTe nanowires in the present work is lower than II–VI group semiconducting nanowires.

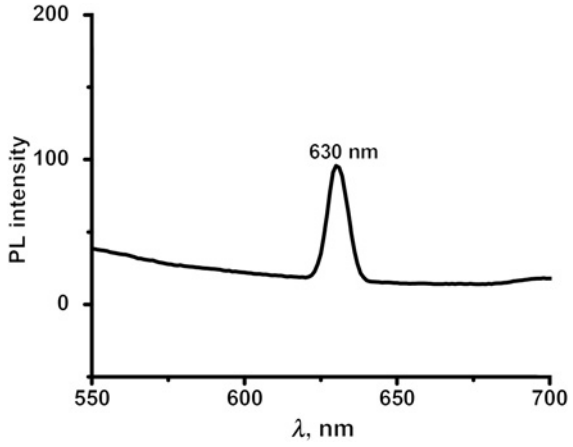

Fig. 6 *PL spectra of CdTe nanowires*

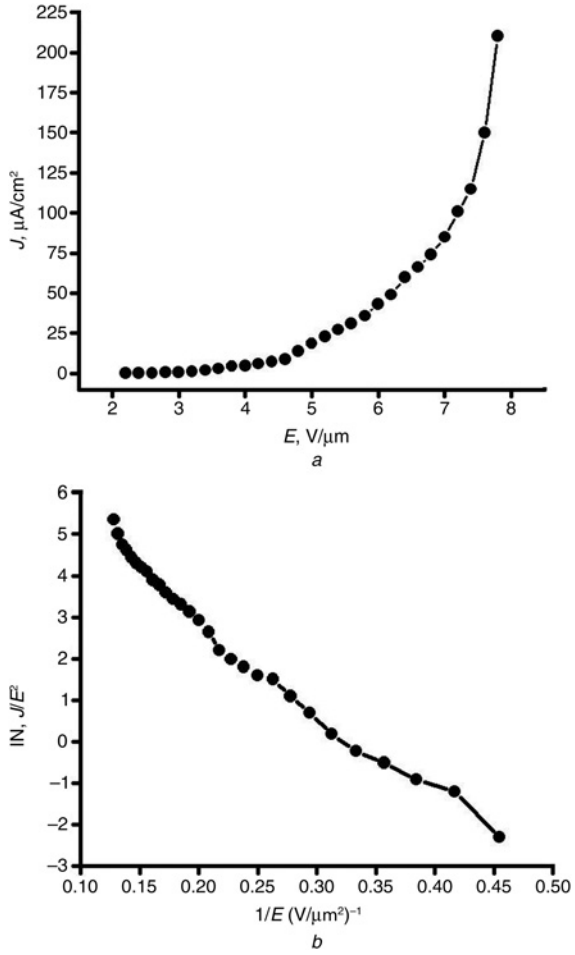

Fig. 7 *Field emission results of CdTe nanowires*
a J–E plot of CdTe nanowires
b F–N plot derived from *J–E* plot

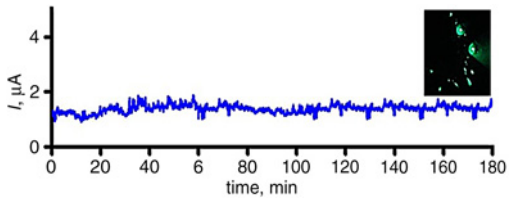

Fig. 8 *I–t plot of the CdTe nanowires with field emission image as inset*

Table 1 Turn-on field of different metal–oxide nanostructure

Sl. no.	Material	Turn-on field (for 0.1 μA/cm^2)	References
1	zinc oxide (ZnO) nanowires	6.0 V/μm	[20]
2	ZnO nanowires	6.8 V/μm (for 10 μA/cm^2)	[21]
3	ZnO nanorods	3.6 V/μm (for 10 μA/cm^2)	
4	zinc sulphide nanowires	5.41 V/μm	[22]
5	zinc selenide nanowires	4.05 V/μm	[23]
6	cadmium selenide nanowires	4.3 V/μm (for 10 μA/cm^2)	[24]
7	CdTe nanowires	2.2 V/μm	present study

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4. Conclusion: CdTe nanowires has been synthesised by the simple thermal evaporation technique through VLS mechanism. FESEM image of synthesised material shows the formation of highly dense CdTe nanowires. The given nanowires emitter shows the promising field emission behaviour in terms of low turn-on field, stable field emission current. The observed low turn-on field may be due to the high value of β as well as nanometric features of the CdTe nanowires. Better field emission behaviour in terms of low turn-on field and better emission stability makes the present emitter more suitable for micro/nano-electronics device applications.

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