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EFFECT OF ELECTRON IRRADIATION ON ELECTRON-BEAM EVAPORATED GaAs FILMS

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Transmission electron microscopy and diffraction investigations showed that gallium arsenide films, deposited on amorphous substrates by electron-beam evaporation, are polycrystalline consisting of extremely fine grains. During TEM examination the GaAs films decompose into Ga and As, as revealed from the analysis of electron diffraction patterns. The decomposition is attributed to the combined effect of the ionization and thermal effect of the electron beam.

1. Introduction

The occurrence of macroscopic surface defects in GaAs films can affect the performance and the preparation of electronic devices. The FET degradation caused by oval defects has been recently demonstrated[1)].

Growth defects, namely oval defects and whiskers, in GaAs layers grown by molecular beam epitaxy were observed using selective etching, transmission electron microscopy and electron microprobe analysis[2)]. Such defects were related to morphological defects[3)].

Electron-beam irradiation of thinned crystalline foils of GaAs at temperatures 623 − 673 K was followed by a study of the surface with a high-resolution electron microscope[4)]. Defect complexes were observed at the stage preceeding their collapse to form dislocation loops. The detailed morphology of defects occurring in GaAs layers revealed that surface defects, commonly identified as oval defects, are of two varieties; particulate − originated defects and liquid-gallium originated defects[5]. The former type is sensitive to the cleanliness of the surface, while the latter type was shown to be determined by the growth conditions.

A systematic study showed that whiskers and oval defects have the common origin from liquid gallium droplets and are essentially formed by the similar mechanism[6]. The vapour-liquid – solid mechanism was proposed to be responsible for the growth of whiskers and the formation of the core of oval defects.

The present paper describes an investigation of the effect of electron-irradiation with 60 keV electrons on thin films of GaAs deposited on glass slides by electron-beam evaporation technique.

2. Experimental technique

Thin films of GaAs were prepared by the electron beam evaporation technique using the electron gun controlled unit (ML-P18) attached to a vacuum system (BAL 370, Balzers). The films were deposited on optically flat glass slides at room temperature in a vacuum of about 10^{-4} Pa. The film thickness was monitored by means of a quartz-crystal thickness monitor and calibrated interferometrically.

The films were detached from the glass substrate by immersing the glass edge in redistilled water gently at an angle of 45° until the film detached and floated on the surface of the water where it was then fished on copper grids ready for transmission electron microscopy (TEM) reexamination. An electron microscope (Type EM 10, Zeiss) operating at 60 keV and of resolution 0.6 nm was used.

3. Results and discussion

Figure 1 shows the X-ray powder diffraction traces of as-deposited GaAs film on quartz substrate compared to that of the original bulk material. The absence of any peaks on the X-ray pattern of the as-deposited film indicated that these films were either extremely fine grained or completely amorphous. Thermal voltage results showed that all films were n-type with a very high resistivity.

Spectrophotometer measurements showing the near infrared transmission and reflectance curves of as-deposited GaAs film on quartz substrate at room temperature are shown in Fig. 2. The transmission cutoff occurs at 880 nm (1.409 eV) in good agreement with reported direct energy gap[7–11].

Transmission electron diffraction patterns recorded for as-deposited GaAs films at 60 kV showed ring patterns (Fig. 3) indicating polycrystalline structure. The analysis of the corresponding electron diffraction pattern is given in Table 1 compared to the X-ray standard (JCPDS 32-389, 1984) and good agreement is found showing that the as-deposited GaAs film corresponds to the cubic system, space group F43m with a unit cell parameter $a_0 = 0.56538$ nm. Hence, one can conclude that as-deposited GaAs films, prepared by electron-beam evaporation technique on amorphous substrate at room temperature, are polycrystalline of extremely fine

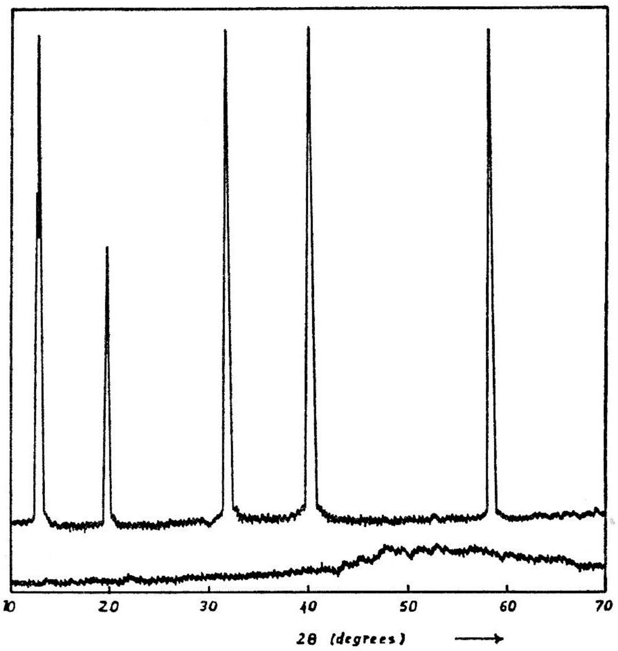

Fig. 1. X-ray diffraction pattern of GaAs *film compared to the powder pattern.*

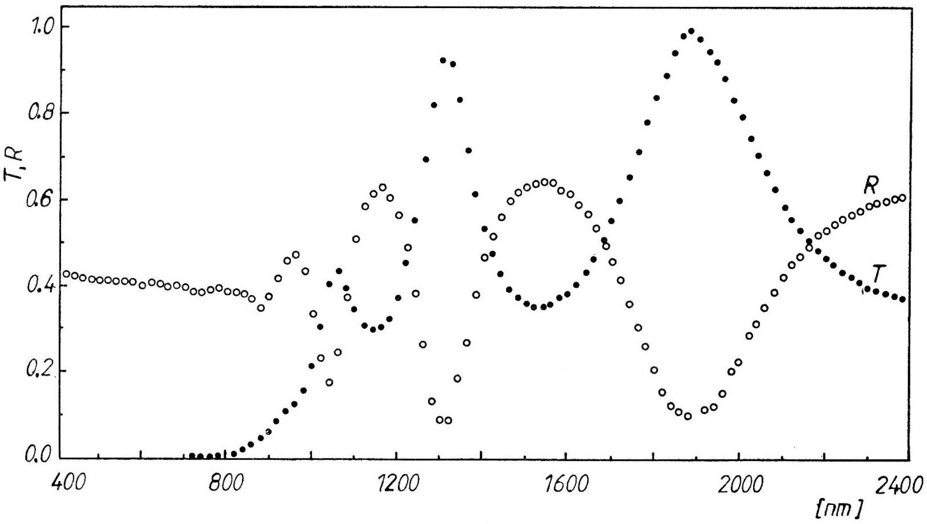

Fig. 2. Near-infrared transmittance and reflectance of as-deposited GaAs *film* (60 nm *thick).*

TABLE 1.

	ASTM data	
d_{obs}	d (nm)	hkl
0.3281	0.3263	111
0.2827	0.2825	200
0.1984	0.19982	220
0.1718	0.17046	311
0.1633	0.16319	222
0.1409	0.14136	400
0.1288	0.12972	331
0.1262	0.12643	420
0.1153	0.11540	422
0.1086	0.10881	333, 511
0.0999	0.09994	440
0.0949	0.09555	531

Analysis of electron diffraction pattern of as-deposited GaAs film.

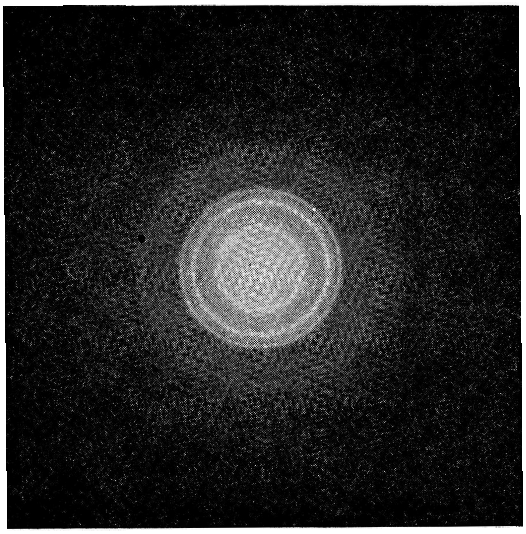

Fig. 3. Electron diffraction pattern of as-deposited GaAs *film.*

grains. During examination of the specimen in the transmission electron microscope, it has been observed that GaAs film, initially dim to the electron beam, became transparent after being subjected to the electron beam for a suitable time. Such observations urged us to investigate the effect of electron beam irradiation on GaAs films inside the electron microscope. The observations indicate that a certain type of decomposition might occur. This was followed systematically by transmission electron micrographs and electron diffraction patterns. Typical transmission micrographs (Fig. 4a–c) showed that the electron beam effect started at the central

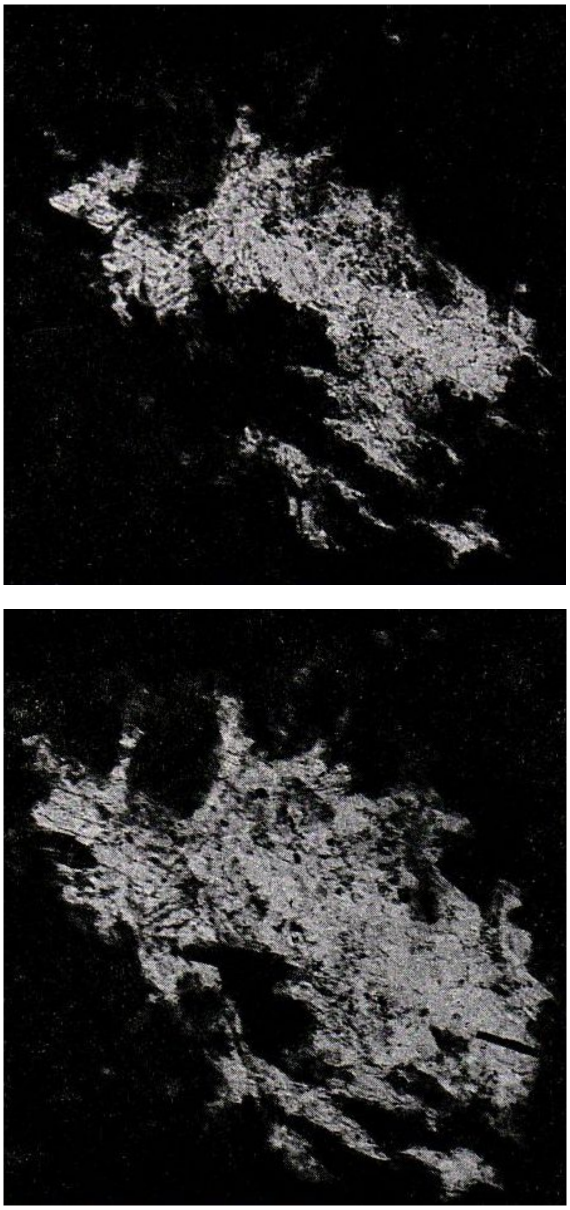

Fig. 4a,b. A series of TEM micrographs showing the effect of electron beam. (Magnification = 80000×).

irradiated region of the specimen which became transparent to the electron beam. The transparent region extended out to the marginal region. Electron diffraction

Fig. 4c. A series of TEM micrographs showing the effect of electron beam. (Magnification = 80000×).

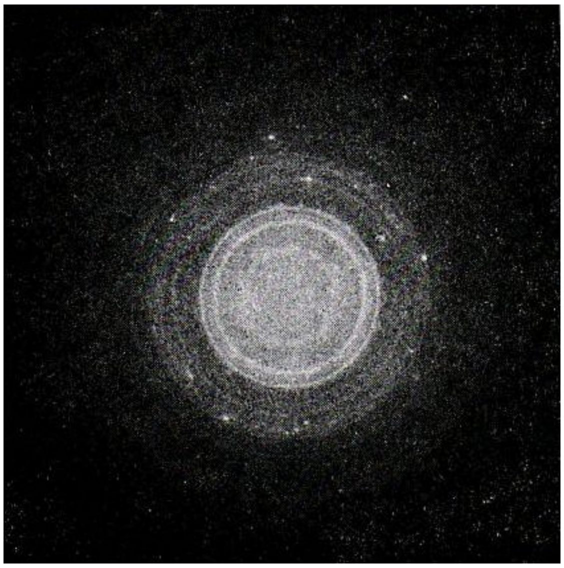

Fig. 5. Electron diffraction pattern of film shown in Fig. 4b.

patterns of such decomposition regions (Fig. 5) indicated that the film is GaAs with fine crystallites giving the characteristic spot pattern superimposed on the ring pattern. The low-index diffraction spots correspond to the (020), (020), (200) and (200) reflecting planes of GaAs. Such crystallites are observable in Fig. 4b.

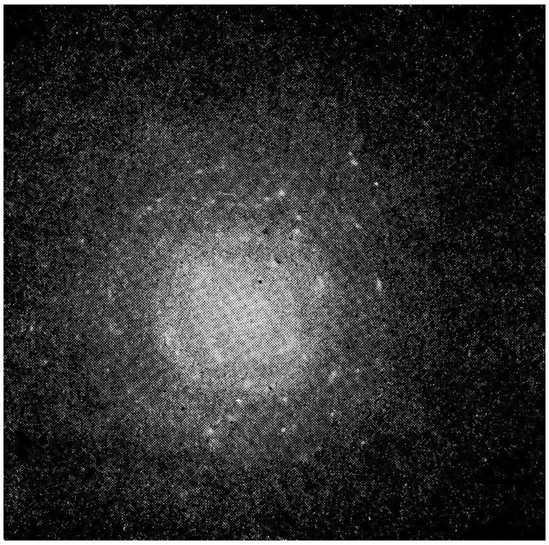

Fig. 6. Electron diffraction pattern of film shown in Fig. 4c.

After a long period of electron irradiation, the electron micrographs showed cubic and hexagonal crystallites throughout the central region with moderate effect on the marginal areas (Fig. 4c). The corresponding electron diffraction pattern (Fig. 6) consists of rings and spots. The analysis of this pattern (Table 2) indicated the presence of small GaAs crystallites of cubic form besides hexagonal crystallites of arsenic, distributed in a polycrystalline GaAs matrix. The faint diffraction rings indicate the decomposition of GaAs. This is confirmed by the appearance of the

TABLE 2.

	ASTM data		
d_{obs}	d (nm)	hkl	Phase
0.3281	0.3263	111	GaAs
0.2771		102	Arsenic
0.1984	0.19982	200	GaAs
0.1879		110	Arsenic
0.1718	0.17046	311	GaAs
0.1633	0.16319	222	GaAs

Analysis of electron diffraction pattern of Fig. 4c.

hexagonal arsenic crystallites as indicated by the electron micrograph and diffraction. One can conclude that under electron irradiation GaAs decomposes to arsenic and gallium, according to the reaction

$$\mathrm{GaAs} \stackrel{electrons}{\longrightarrow} \mathrm{As} + \mathrm{Ga}.$$

The electron beam has two effects; a thermal effect and an ionization effect. It is not possible that the electron beam raises the temperature of the irradiated sample to the melting point of GaAs (1511 K). Hence, the thermal effect cannot solely lead to the decomposition of GaAs. One, then, thinks of the ionization effect of the bombarding electrons. GaAs is covalent to a large extent where the degree of ionization of the chemical bond is 0.32[12].

Electron irradiation, in an initial step, leads to the formation of arsenic Frenkel pairs $\mathrm{V_{As}} - \mathrm{As}_i$[13]. Due to the high irradiation flux, electron-hole pairs recombine via the As_i level and renders As_i mobile which interact with some impurities (B, Si, C) on Ga and As sites via the "Watkins mechanism" forming AsGa antisites and interstitial impurities. The arsenic interstitial is always positively charged. It is most probable that the decomposition of GaAs is the combined effect of the ionization and thermal effect of the electron beam inside the electron microscope.

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EFEKT BOMBARDIRANJA ELEKTRONIMA TANKIH SLOJEVA GaAs PRIPRAVLJENIH METODOM ISPARAVANJA ELEKTRONSKIM SNOPOM

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Difrakcijom i transmisionom elektronskom mikroskopijom pokazano je da se tanki slojevi GaAs napareni na amorfnu podlogu sastoje od veoma finih zrnaca. Tijekom elektronske mikroskopije slojevi se dekomponiraju u Ga i As, što se vidi iz difrakcione slike. Dekompozicija je posljedica ionizacije i zagrijavanja elektronskim snopom.