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THE USE OF TRIS(TRIMETHYLSILYL)ARSINE TO DEPOSIT GaAs BY OMCVD

by

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THE USE OF TRIS(TRIMETHYLSILYL)ARSINE TO DEPOSIT GaAs BY OMCVD

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ABSTRACT

Chemical vapor deposition experiments using $(\text{Me}_3\text{Si})_3\text{As}$ with either GaCl_3 or Me_3Ga at ambient pressure have produced films of GaAs on Si and semi-conducting GaAs substrates. The films have been characterized by X-ray diffraction and Auger electron spectroscopy, and each have small amounts of C and O impurities. No desired films were deposited from $(\text{C}_6\text{F}_5)_3\text{GaAs}(\text{SiMe}_3)_3$ at 500°C and low pressures.

INTRODUCTION

In 1986, we reported the initial use of silylarsines to prepare gallium-arsenic compounds via metathetical elimination of a silyl halide [1] and, during the ensuing years, we exploited the utility of this type of reaction to prepare a number of novel gallium-arsenic systems [2]. As a part of these studies, it was also demonstrated that dehalosilylation reactions could be used to prepare AlAs, GaAs, and InAs [3]; thus, reactions between $(\text{Me}_3\text{Si})_3\text{As}$ and MX_3 (M = Al, X = Cl; M = Ga, X = Cl or Br; M = In, X = Cl) proceed at relatively low temperatures according to equation 1. Subsequently, Alivisatos *et al.* reported that GaAs nanocrystals are produced in experiments using GaCl_3 , and they also



demonstrated that the same reaction carried out in quinoline afforded somewhat smaller crystallites which are soluble in pyridine as well as quinoline [4]. More recently, we found that reaction of $(\text{Me}_3\text{Si})_3\text{As}$ with GaCl_3 in a 1:2 mole ratio at room temperature affords the relatively stable yellow solid having the empirical formula AsCl_3Ga_2 and, on heating, this new single-source precursor eliminates GaCl_3 to give microcrystalline GaAs [5]. Here we report the use of the gas-phase reactions of $(\text{Me}_3\text{Si})_3\text{As}$ with GaCl_3 and Me_3Ga to produce GaAs films. In addition, we report that CVD experiments using the adduct $(\text{C}_6\text{F}_5)_3\text{GaAs}(\text{SiMe}_3)_3$ did not afford any desired films.



EXPERIMENTAL

Tris(trimethylsilyl)arsine was synthesized according to published procedures [6]. Gallium trichloride, purchased from Alfa, Inc., was sublimed prior to use. Trimethylgallium was purchased from Alfa, Inc. and used without further purification. The adduct $(\text{C}_6\text{F}_5)_3\text{GaAs}(\text{SiMe}_3)_3$ was prepared [7] by combining $(\text{Me}_3\text{Si})_3\text{As}$ (0.438 g, 1.49 mmol) with $(\text{C}_6\text{F}_5)_3\text{Ga}\cdot\text{OEt}_2$ [8] (0.960 g, 1.49 mmol) in 80 mL of benzene in a 250-mL one-necked round-bottomed flask equipped with a Teflon valve. Following removal of the mother liquor from the crystals which formed after 2 days, the latter were dissolved in benzene and the two solutions combined. Removal of the volatiles in vacuo afforded $(\text{C}_6\text{F}_5)_3\text{GaAs}(\text{SiMe}_3)_3$ as a white powder containing a very small amount of yellow impurity (1.19 g, 1.380 mmol, 92.8% yield), mp $209\text{--}213^\circ\text{C}$ (dec., brown gas-evolving liquid),

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sublimes $\sim 155^\circ\text{C}/10^{-5}$ Torr; ^1H NMR (C_6D_6) δ -0.090 (s, Me_3Si), -0.009 (s, Me_3Si), 0.112 (s, Me_3Si), [9].

Chemical vapor deposition experiments using two separate precursors were carried out in a vertical Pyrex reactor at atmospheric pressure with H_2 as a carrier gas. Precursors were stored in Pyrex bubblers connected to a mixing manifold and individual flowmeters by stainless steel flexible tubing. A flow rate of $150\text{ cm}^3/\text{min}$ was used for $(\text{Me}_3\text{Si})_3\text{As}$ and GaCl_3 and $10\text{ cm}^3/\text{min}$ for Me_3Ga . Hydrogen diluent was introduced in the mixing manifold at a rate of 1 liter/min. Heat tape was used to warm the bubblers of $(\text{Me}_3\text{Si})_3\text{As}$ (102° - 103°C) and GaCl_3 (41° - 42°C), their transport lines, and the mixing manifold. Trimethylgallium was kept at -12°C (v.p. ~ 31 Torr [10]) and the transport line at ambient temperature. Silicon and GaAs substrates were cleaned as described previously [11], and the Si was subsequently etched in 48% HF for 5 minutes, followed by rinsing with distilled water and drying under a stream of N_2 . Substrates were placed on an inductively heated graphite susceptor at 400°C for GaCl_3 and 500°C for Me_3Ga .

Deposition experiments with $(\text{C}_6\text{F}_5)\text{GaAs}(\text{SiMe}_3)_3$ were done in a vertical Pyrex reactor under low pressure. The precursor was heated under a dynamic vacuum and sublimed or carried in a stream of Ar across the substrate mounted on a heated block.

X-ray diffraction data were obtained on a Philips 12045 diffractometer using a Cu K α radiation tube. Auger spectra were recorded on a Physical Electronics Ind. Model 10-155 spectrometer with a 3 kV beam energy and a current density of $\sim 4\text{ mA}/\text{cm}^2$.

RESULTS AND DISCUSSION

Deposition of GaAs using $(\text{Me}_3\text{Si})_3\text{As}$ and GaCl_3 in our reactor occurred in the presence of a visible white vapor and appeared to be influenced by substrate temperature and relative amounts of precursors used. A film of GaAs with nonuniform thickness and poor morphology was deposited on etched Si at 400°C during 1 1/2 hr. Thickness measurements by profilometry along one edge of a masked area gave an average value of 8000 \AA . The X-ray diffraction pattern contained peaks with d values of 3.252, 1.984, and 1.702 \AA , which were consistent with various orientations of GaAs [12]. The Auger spectrum of an Ar-sputtered sample contained peaks at 1054 eV and 1210 eV characteristic of the LMM lines of Ga and As respectively. The peak-to-peak ratio of the As to Ga lines was 0.56 in comparison to a measured value of 0.58 for an n-doped sample of GaAs and 0.63 from a published spectrum [13]. The spectrum also contained very weak peaks at 272 eV and 505 eV corresponding to the KLL lines of C and O respectively. No evidence of Si or Cl was found within the detection limits of the spectrometer. Additional deposition experiments at a substrate temperature of 500°C or with GaCl_3 at ambient temperature and 60°C gave no evidence of GaAs. In all instances, a yellow-brown solid formed in the manifold exit tube going into the reactor.

The use of Me_3Ga produced thicker, more uniform films of GaAs, but still with poor morphology. Contrary to the behavior of the $(\text{Me}_3\text{Si})_3\text{As}-\text{GaCl}_3$ system, no white vapor was observed in the reactor during deposition and no residue remained in the mixing manifold. The X-ray diffraction pattern contained peaks with d values of 3.276, 2.002, 1.705, and 1.702 , which were also in good agreement with those for GaAs [12]. The Auger spectrum of an Ar-sputtered sample contained Ga and As peaks at 1047 and 1203 eV respectively with an average As to Ga ratio of 0.37, indicating a Ga-rich film. This is not surprising in view of the considerable difference in volatiles of $(\text{Me}_3\text{Si})_3\text{As}$ and Me_3Ga and the difficulty in regulating low mass flows in our reactor. The Auger spectrum also contained a very weak C and a weak O peak. As in the GaCl_3 system, no evidence for Si was found.

In a related experiment, an attempt was made to deposit GaAs on a Si substrate in vacuo using the adduct $(C_6F_5)_3GaAs(SiMe_3)$. No films were obtained with a substrate temperature of 500°C at pressures of 1×10^{-5} Torr without a carrier gas. Those results are similar to the behavior of $(C_6F_5)_3GaAsEt_3$ as reported by Maury, et al. [14].

In summary, we have demonstrated in principle the growth of GaAs using $(Me_3Si)_3As$ as an alternate source of As with $GaCl_3$ and Me_3Ga . These initial films are of poor quality but nevertheless offer encouragement for further investigation. The adduct $(C_6F_5)_3GaAs(SiMe_3)_3$ does not yield GaAs at 500°C and low pressures.

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