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Deposition of Buffer Layers for MOCVD of $Y_1Ba_2Cu_3O_{7-x}$ on GaAs

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Abstract

For the deposition of $Y_1Ba_2Cu_3O_{7-x}$ on GaAs, a material well suited for microwave applications, it is inevitable to use a passivating buffer layer. In this paper we report on a study of the suitability of MOCVD-grown MgO and Y_2O_3 buffer layers as protecting films for the GaAs. It can be shown that it is possible to deposit MgO and Y_2O_3 buffer layers at relatively low substrate temperature. The possible detoriation of the GaAs is examined by low temperature photoluminescence. But nevertheless our attempts to grow $Y_1Ba_2Cu_3O_{7-x}$ on these buffer layers reveal that it is inevitable to lower the deposition temperature for the HTc compound on buffer layers.

1. Introduction

The deposition of $Y_1Ba_2Cu_3O_{7-x}$ on semiconducting substrates is favorable for some applications. Especially for microwave applications GaAs is an attractive material, because it allows the combination of active semiconductor devices with passive structures realized with the HTc superconducting compound. But the incompatibility of GaAs with the growth conditions (high temperatures in oxidizing atmosphere) required for high quality $Y_1Ba_2Cu_3O_{7-x}$ hinders a direct combination of these materials. The GaAs decomposes at these conditions into gallium clusters and evaporating arsenic if it is not stabilized by additional arsenic or protected by a buffer layer. Therefore we investigated the suitability of MgO and Y_2O_3 as passivating buffer layers for GaAs. We selected MgO and Y_2O_3 as materials for the buffer layer for different reasons. MgO is a well proven substrate material for epitaxial $Y_1Ba_2Cu_3O_{7-x}$ and Feng et al. [1] demonstrated that it is possible to attain critical current densities up to $2*10^5$ A/cm^2 at 77 K even on polycrystalline MgO. Another important advantage of MgO is the fact that it grows crystalline on GaAs at low temperatures [2]. The use of Y_2O_3 as buffer layer seems advantageous since Y is a constituent of the HTc compound and therefore a contamination of the superconducting film by the buffer layer is not expected. For example Oishi et al. [3] obtained high quality $Y_1Ba_2Cu_3O_{7-x}$ on single crystalline Y_2O_3 substrates.

2. Growth equipment

The present study was performed in a commercial Aixtron LP-MOCVD system, comparable to equipment used in III-V epitaxy, with a horizontal cold wall reactor. The metalorganic precursors which are stored outside the reactor in individual bubblers are transported via a carrier gas into the reaction zone. The apparatus offers the

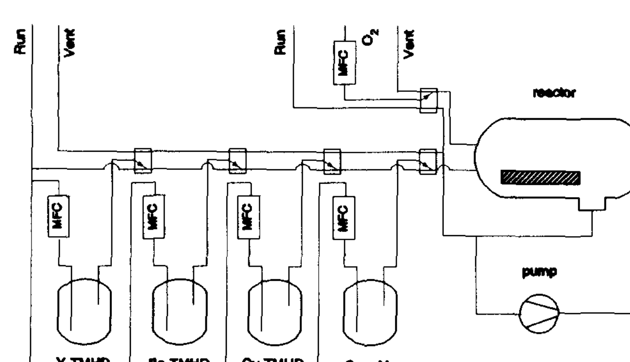

Fig. 1: schematic diagram of the MOCVD equipment

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possibility to introduce four metalorganic sources independently into the reaction chamber which makes the system very flexible. For the growth of $Y_1Ba_2Cu_3O_{7-x}$ the ß-diketonate complexes of Y, Ba, Cu in combination with oxygen are used. The dimensions of the radiation heated susceptor allows us to grow on different substrates simultaneously or to coat wafers with 2 inch diameter. A schematic drawing of our growth equipment is shown in Fig. 1.

3. Experimental results and discussion

After the deposition which was normaly carried out at a substrate temperature of 1023 K and a total pressure of 10 hPa the $Y_1Ba_2Cu_3O_{7-x}$ films were slowly cooled down under one atmosphere of oxygen. This process yields high quality YBCO (T_c = 88 K, J_c (77 K) in excess of 10^6 A/cm² and transition widths of less than 1 K) on standard perovskite substrates.

For the deposition of buffer layers on GaAs it is a basic demand for these materials that they can be grown without detoriation of the underlying GaAs. Therefore the decomposition behavior of the precursor is an important criterion for its suitability. In this study bis-cyclopentadienyl-magnesium (Cp_2-Mg) and the commonly used tetramethylheptanedionate-yttrium (TMHD-Y) were examined as Mg and Y sources under this aspect.

As it can be taken from the Arrhenius-plot of the growth rate versus the reciprocal growth temperature MgO

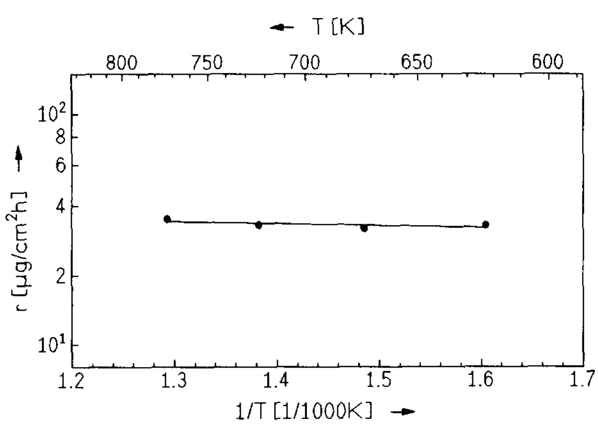

Fig.2: MgO growth rate versus reciprocal growth temperature for Cp_2-Mg in combination with oxygen

(Fig.2) exhibits the desired diffusion controlled growth regime in an extended temperature region from 623 K - 773 K if Cp_2-Mg is used as precursor. In contrast to this the growth of Y_2O_3 is kinetically controlled below 723 K

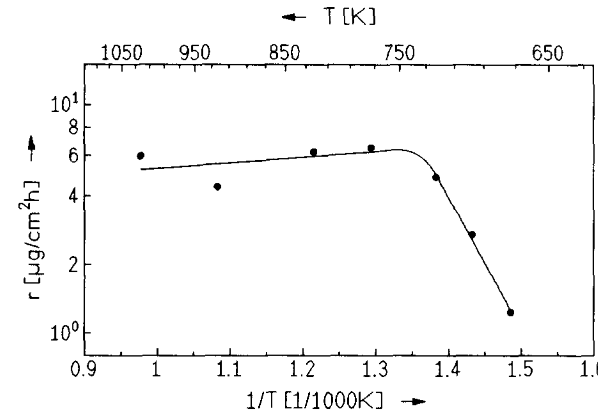

Fig.3: Y_2O_3 growth rate versus reciprocal growth temperature for Y-TMHD in combination with oxygen

(Fig. 3). But as we will demonstrate later even this temperature is acceptable. So we can ascertain that the decomposition behavior of these precursors doesn't impede their use as buffer layers on GaAs.

The SEM micrograph (Fig. 4) exhibits the typical surface morphology of a thin MgO-films (100 nm). Very thick

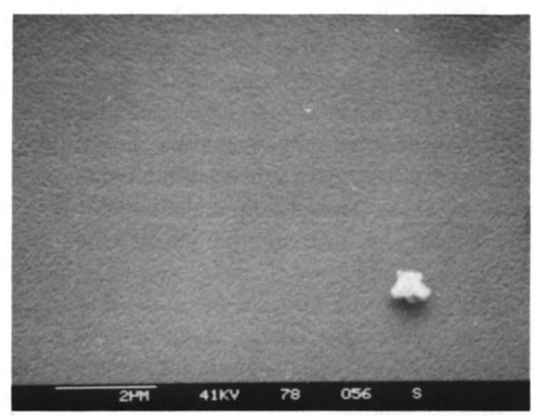

Fig.4: SEM-micrograph of a 100 nm thick MgO layer

films in the range of 1 μm tend to get cracks. Fig. 5 is a SEM-micrograph of a thin Y_2O_3 film. In both cases smooth films can be obtained.

In order to examine whether the deposition of the buffer layers is detrimental to the GaAs-substrate we applied the very sensitive tool of low temperature (10 K) photoluminescence spectroscopy. The investigations were performed on low n-type doped GaAs epitaxial layers. The spectrum of such an untreated sample taken as reference is displayed in Fig. 6(I). While the structure at

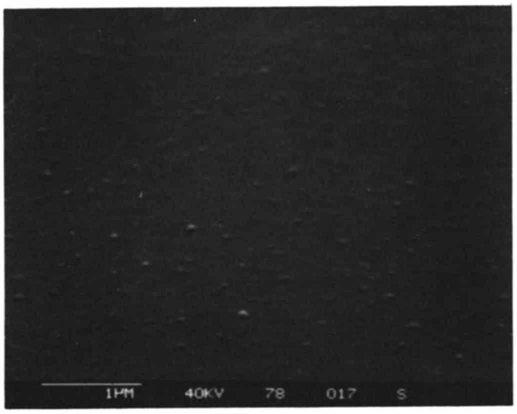

Fig.5: SEM micrograph of a 40 nm thick Y_2O_3 film deposited at 773 K

820 nm is ascribed to excitonic transitions the peak at

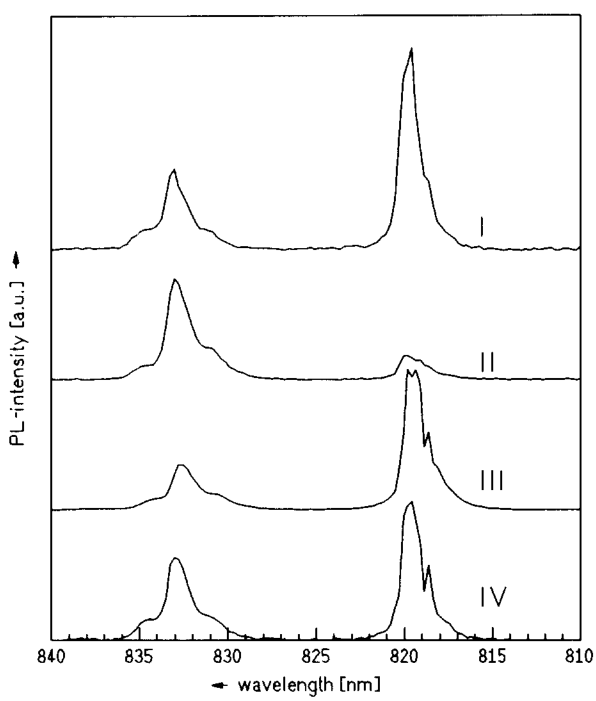

Fig.6: 10 K PL spectra:

I) reference spectrum of the n-doped sample before growth
II) sample coated with 120 nm MgO
III) sample after the removal of the MgO
IV) sample after the removal of the Y_2O_3

834 nm is caused by band to donor transitions. The incorporation of significant amounts of Mg during the growth of the buffer layer at a temperature of 723 K into the GaAs lattice where it acts as an acceptor can be excluded since no additional peaks (expected at 830 nm) become visible in the spectrum of the sample (Fig. 6(II)) which was coated with 180 nm MgO at a temperature of 723 K. But the attenuation of the excitonic peaks may not only be caused by absorption in the GaAs but also by a damage of the GaAs-MgO interface. To prove this assumption we etched the MgO with diluted 20% HF. The corresponding spectrum (Fig. 6(III)) of the sample is very similar to the reference spectrum indicating that no significant damage of the GaAs by the MgO deposition has occurred. This is also true for the deposition of Y_2O_3 (Fig. 6(IV)).

An additional application for thin dielectric films is their use as insulating interlayers between different superconducting planes. The electrical characterisation of the MOCVD deposited films was carried out on the

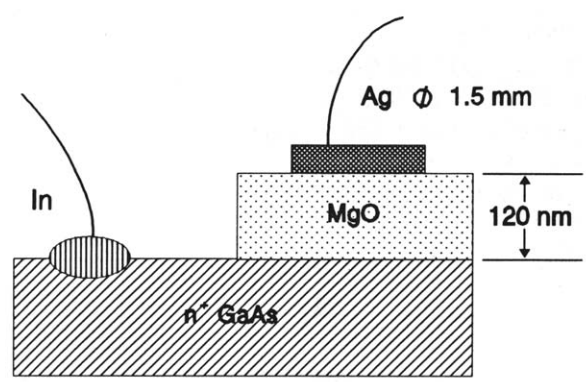

Fig.7: test structure for the evaluation of the insulating properties of MgO

structure displayed in Fig. 7. Gold was evaporated through a shadow mask to form a contact pad of 1.5 mm diameter on the 120 nm thick MgO film. The n^+ doped GaAs was contacted by alloying indium to it. The corresponding current-field characteristic measured at roomtemperature is depicted in Fig. 8. As can be seen from the diagram the MgO has a high specific resistance of $\varrho(1\ V) > 10^{12}$ Ohm cm. The dielectric strength, not shown in this diagram exceeds the value of 1 MV/cm. It can be expected that these properties get even better at 77K. This is sufficient for most applications.
The original intention for these films was to use them as passivating layers for GaAs. Therefore we tried to grow $Y_1Ba_2Cu_3O_{7-x}$ on these buffer layers on GaAs with our normal growth parameters. This attempt failed, the films were not dense enough to prevent the GaAs from detoriation. The $Y_1Ba_2Cu_3O_{7-x}$ films on GaAs exhibited

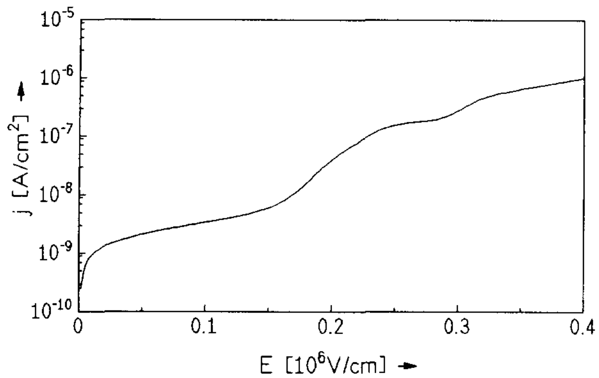

Fig.8: current-field characteristic of the test structure depicted in Fig.7

high resistivity at room temperature and a detoriated surface morphology. The evaporating arsenic was transported via gas phase diffusion in the reactor and supressed superconductivity even on standard dielectric substrates coated in the same growth run. This arsenic contamination on these substrates was detected by EDX (energy dispersive analysis by x-rays). Our experiments reveal that it is inevitable to lower the growth temperature for $Y_1Ba_2Cu_3O_{7-x}$ and to coat the GaAs from the backside in order to deposit successfully superconducting layers on GaAs. Investigations to lower the substrate temperature are in progress now.

4. Conclusion

We have shown that MOCVD is an appropiate method for depositing smooth MgO and Y_2O_3 buffer layers on GaAs. The precursors under investigation, Y-TMHD and Cp_2-Mg exhibited a decomposition behavior that allows to grow at temperatures where no significant degradation of the GaAs occurres. This aspect was proved by low temperature photoluminescence spectroscopy. Further on we demonstrated that MOCVD deposited MgO is suitable for applications as insulating interlayer. However the original intention to use these films as passivating buffer layer couldn't be fully satisfied at our standard growth temperature of 1023 K.

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