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/tw

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Thelma Woods
Customer Service Representative

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14. ABSTRACT

In this progress report, we summarize the results to date of experiments to prove the existence of a two dimensional hole gas. If, possible, this hole gas will result in enhanced performance Heterojunction bipolar transistors for military and commercial applications. Also summarized is the background work required to achieve the two dimensional hole gas including several never before reported results on the behavior of p-type dopants in III-Nitrides.

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Progress Report for Piezoelectric Enhanced HBT

January 2000

April S. Brown and Alan Doolittle

During this year, progress has been made toward understanding and implementing a piezoelectric induced hole gas. This report summarizes efforts in two areas; efforts and difficulties set out to achieve a 2D gas, and p-type doping optimization. Finally, future directions will be discussed.

Efforts Set Out To Achieve a 2D Hole Gas

Motivation: Because the control of polarity is a prerequisite for achieving any benefit from piezoelectric effects, and because we can achieve high quality, abrupt interfaces by growing on the cation face of LGO, we designed a sequence of growths to test for a 2D hole gas.

We based our experiments on the work of Shur and Gaska et al. The structure used to "demonstrate hole accumulation" is shown in figure 1. Several problems exist with this structure. First, it consists of several layers that could contribute to conduction. These layers include an AlGaN superlattice, p-type AlGaN buried layer, and p-type GaN top layer. Given the inherent difficulties of extracting layer conduction information from Hall measurements on such a structure, we chose to approach the problem with simpler structures. *Note Shur et al did not extract individual layer contributions from their measurement, and thus, it is not clear as to where the hole conduction originates.* An additional difficulty with this original structure is that the GaN appears to be thicker than the critical thickness, inducing lattice relaxation and removing a major part of the driving force for hole accumulation.

A summary of the 2D hole gas structures attempted to date is given in figure 2. A summary of the possible configurations producing 2D carrier accumulation in summarized in figure 3. Note that only the two bolded structures result in hole accumulation. To date, we have focused on the GaN capped structure. In all experiments, p-type conduction was verified via thermal probe measurements and resistivity was determined from a Vanderpaw configuration. For both sapphire and lithium gallate, the first growth verified proper p-type conduction. Note, for lithium gallate, 0.9 ohm-cm p-type material was possible. For sapphire, thick AlGaN layers were grown, with 30 nm GaN cap layers. All possible combinations of doping, only the GaN, only the AlGaN, and both GaN and AlGaN were attempted. In all cases, the thermal probe indicated p-type material, but the resistivity was higher than in the control case of the undoped GaN alone. For the LGO substrates, the case of both layers doped (most favorable to the formation of a hole accumulation layer) was examined. Again, as was the case of the sapphire substrates, the resistivity was higher than the control sample.

Future work will focus growing room temperature lattice matched AlGaN layers with GaN caps of varying thickness on LGO. This approach will be augmented by examining the full range of thick GaN with AlGaN caps on the anion face of LGO. The use of lattice matched AlGaN will rule out the role of coefficient of thermal expansion induced additive compressive strains in the AlGaN buffer that would act to reduce the

total induced charge. The use of various thickness GaN will rule out the possibility of surface charge induced depletion effects. By examining the anion face structures, the full range of possible combinations of hole accumulation structures will have been produced.

P-type doping Summary

Motivation: To induce a hole gas, holes must first be present in the material . Second, an electric field (polarization induced) must be present to accumulate these holes. Thus, optimization of the conditions necessary to achieve p-type material while still maintaining atomically flat interfaces is important. The parameter space for magnesium doping is extremely broad. Literature values of magnesium beam equivalent pressure, cell temperatures and substrate temperatures range from <1e-10 to 1e-7 Torr, ~120 to 350 degrees C, and 525 to 800 degrees C respectively. Additionally, though most older reports indicate that the material needs to be grown nitrogen rich (this promotes proper incorporation of Mg on the Ga site), no reports currently indicate how far away from the 50% Ga / 50% nitrogen point one should grow. More recent reports indicate growing Ga rich is useful. Some insight has been provided by Guha et al as to the tendency of magnesium to saturate at high concentrations. Based on observed RHEED patterns, we believe this saturation may result from the tendency of Mg to act as a surfactant, promoting a transition from 3D to 2D growth. Thus, a flat surface affords less surface sites where Mg can form multiple bonds. This saturation point is critical in that material grown under Mg saturation conditions tends to be highly compensated and very high resistivity. To date, we have had difficulty producing consistently high concentration p-type material by following various literature recipes. Thus, we have undertaken an effort to map out these saturation points as a function of growth conditions including substrate temperatures, III/V ratios and substrate type. The method chosen was to fix a particular substrate temperature and III/V ratio and grow samples with alternating layers of undoped and doped layers. The doping concentration was varied from 1.6e-11 to 1.6e-8 torr beam equivalent pressure (BEP) in seven steps in a 1-5-10 progression. The SIMs magnesium concentrations are calibrated to samples measured at Evans East. Figures 4 and 5 show SIMs profiles taken at Georgia Tech for a sample grown under low substrate temperatures, 550 and 615 degrees C thermocouple temperatures on lithium gallate. The most striking feature is the very high, 3.5e20 cm^{-3} concentration possible at low substrate temperature. If all this Mg were in substitutional sites with thermal activation energy of 0.16 eV, this would result in a hole concentration of 1.7e18 cm^{-3}. Comparing these estimates with the resistivity of the material examined here, either the hole concentration must be significantly higher or the mobility must be on the order of 7-10 cm^2/Vs.

Several interesting features are currently being examined. Refer to figures 5 and 6 for the following discussion:

A.). The low concentration Mg peaks show very flat profiles, with little if any diffusion spreading. The slope of these peaks is likely due SIMs related effects, not the actual spread in Mg concentration.

B.) The enormously large incorporation, 3.5e20 cm^{-3} . is the largest we are aware of for MBE grown samples. Note also the loss of flatness, indicating transient incorporation (or enhanced diffusion) as will be elaborated on in part D below.

C.) After the Mg shutter is closed, a small spike in the Mg concentration occurs. We believe this is due to the desorption of Mg from the wafer and adsorption of Mg on the cold shutter. Once the shutter closes the heat from the effusion cell evaporates the Mg onto the growing film.

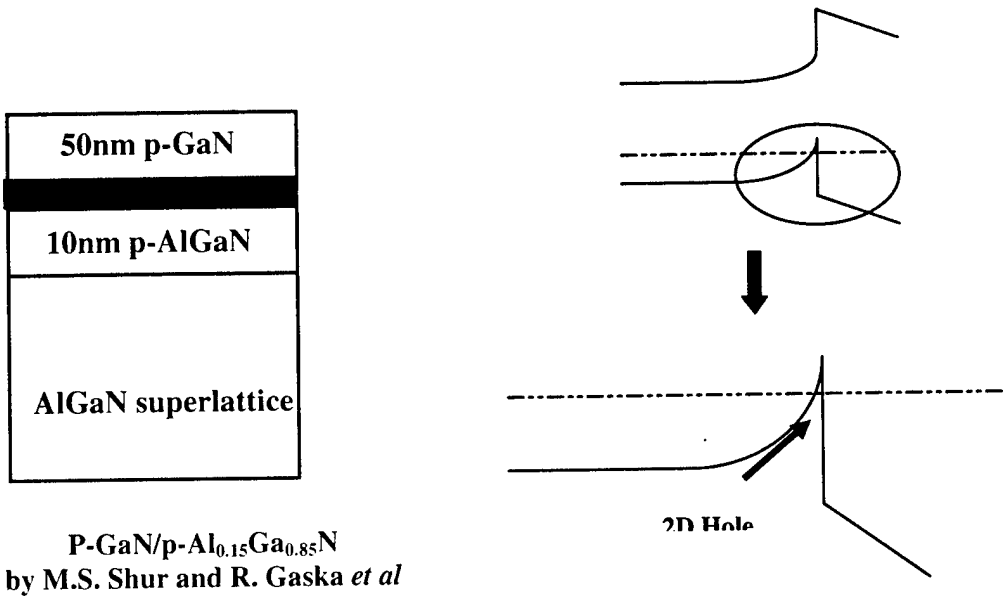
D.) The incorporation at high Mg fluxes appears to be transient determined. By this it is meant that initially the incorporation is high, but as the surface population accumulates, the incorporation reduces. We are currently trying to quantify the time constants for this transient incorporation as a function of Mg flux.

E.) Under very high Mg fluxes, the profile again becomes flat and abrupt. However, this is the first report of a reduced incorporation at low growth temperatures.

F.) At more typical growth temperatures, the Mg concentrations are not only lower at high fluxes, the profiles are more diffused and reduced saturation is much less pronounced. Note however, at low flux, the incorporation is higher.

Figure 7 plots the incorporation as a function of incident beam equivalent pressure. The novel reduced incorporation reported here for the first time is clearly evident as is it's temperature dependence.

These results indicate that at least 3 regimes of Mg incorporation exists, low flux, saturated, and transition regime. Future work will elaborate on these findings and relate them to physical quantities.



P-GaN/p-$Al_{0.15}Ga_{0.85}N$
by M.S. Shur and R. Gaska *et al*

Figure 1

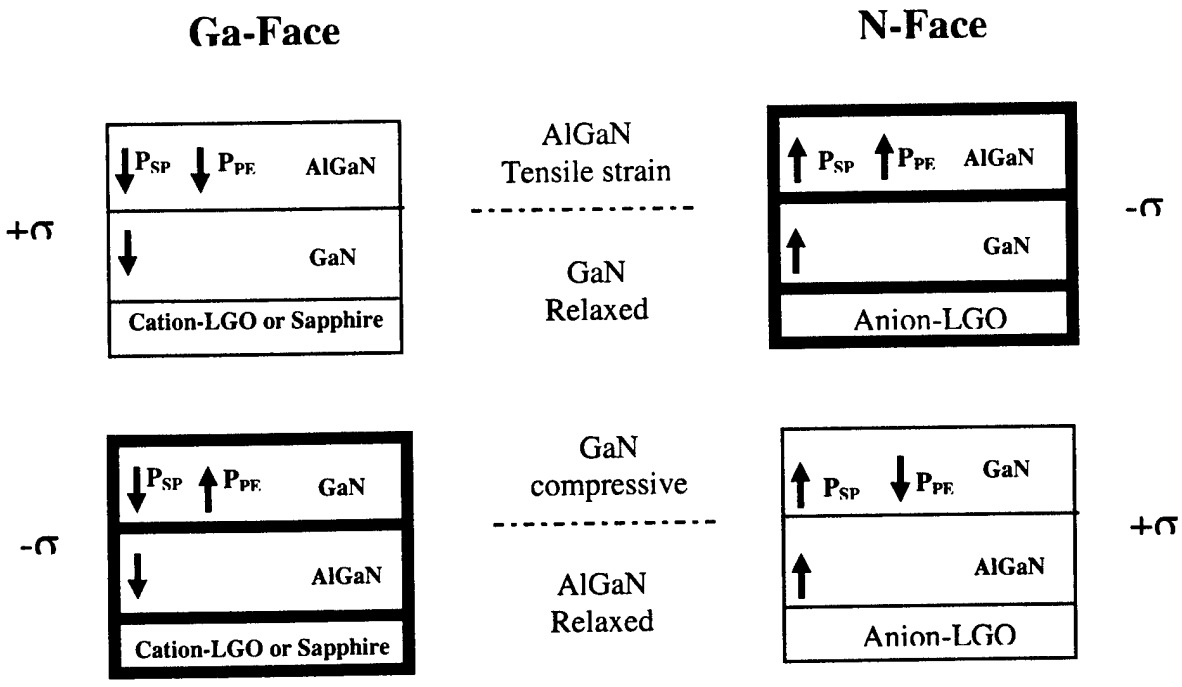
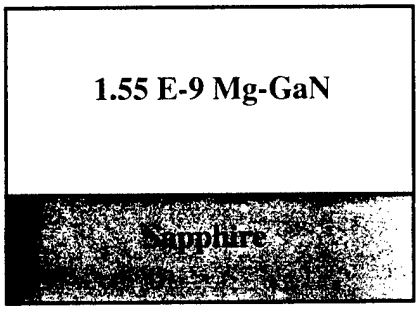


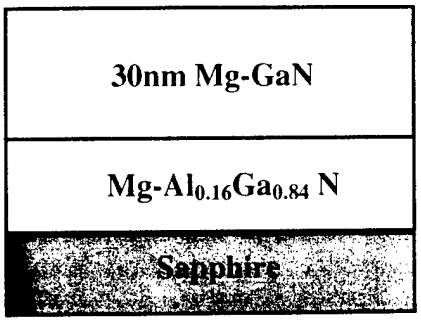
Figure 3

N534



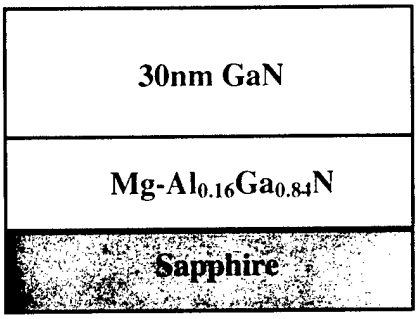
Thermal Probe : P
Resistivity : 50 Ω cm

N535



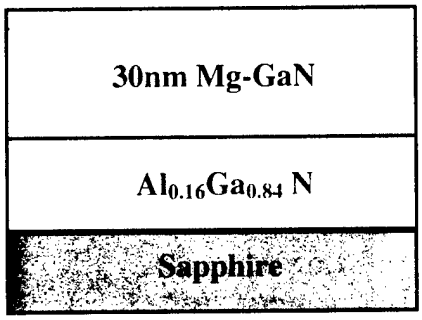
Thermal Probe : P
Resistivity : 500 Ω cm

N536



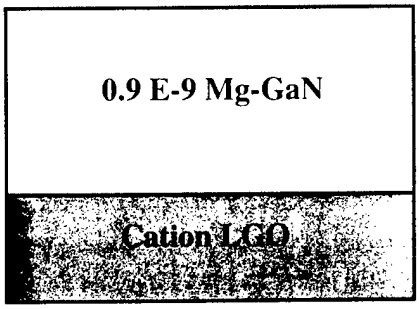
Thermal Probe : P
Resistivity : Cannot measure

N537



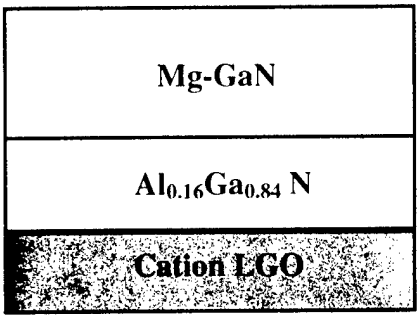
Thermal Probe : P
Resistivity : 5000 Ω cm

N534



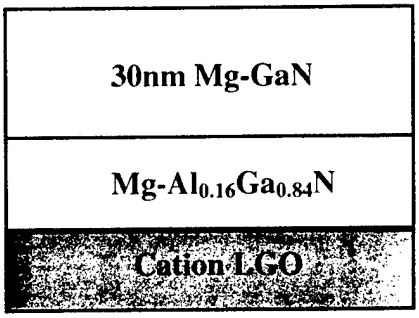
Thermal Probe : P
Resistivity : 1.2 Ω cm

N535



Thermal Probe : P
Resistivity : Cannot measure

N536



Thermal Probe : P
Resistivity : 30 Ω cm

Figure 2

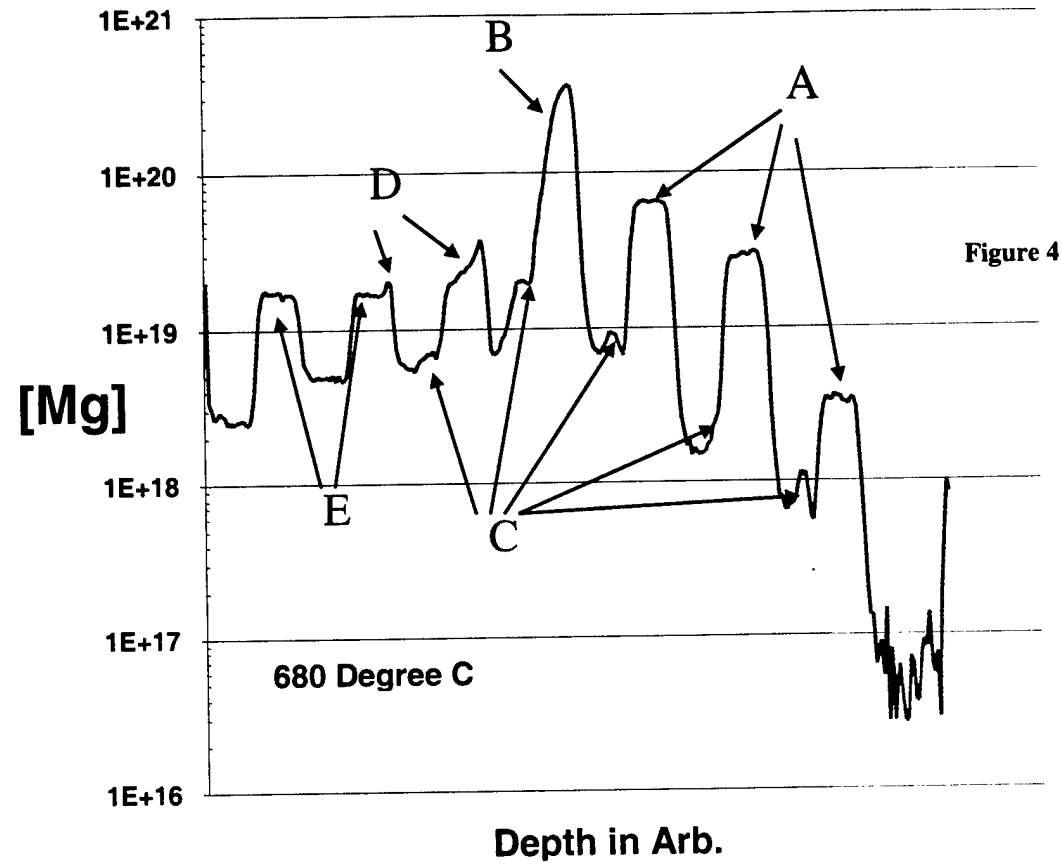


Figure 4

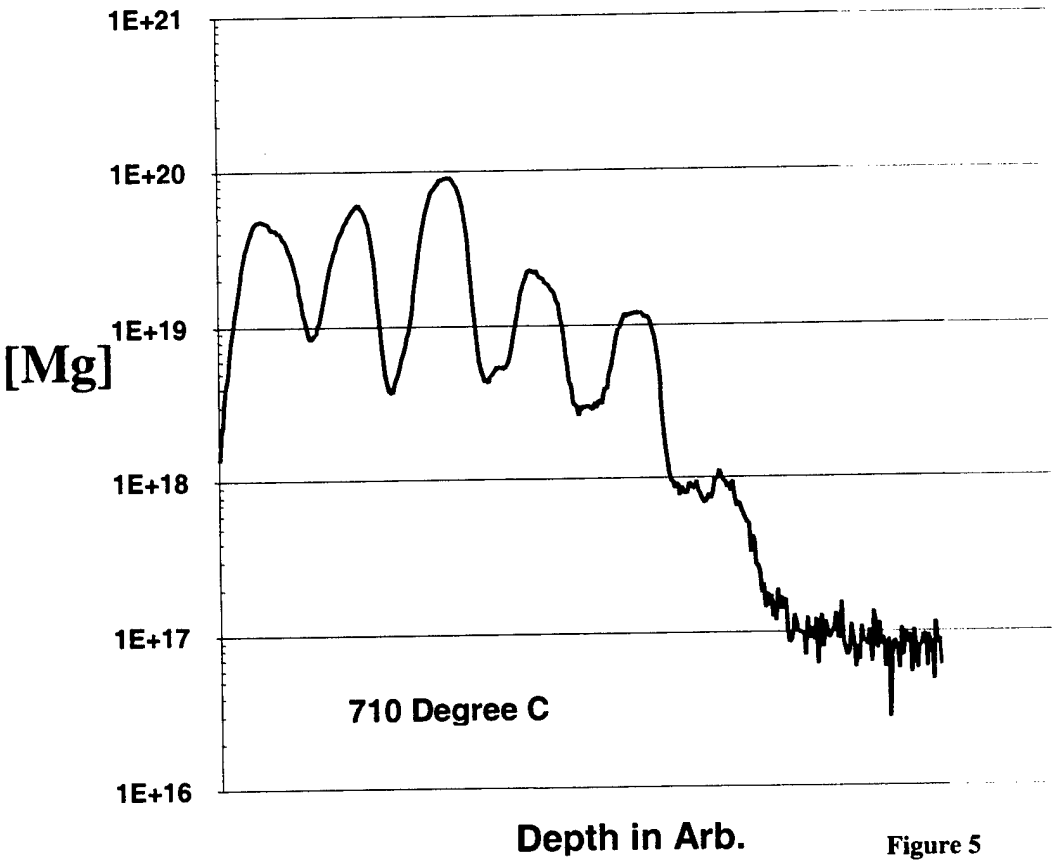


Figure 5

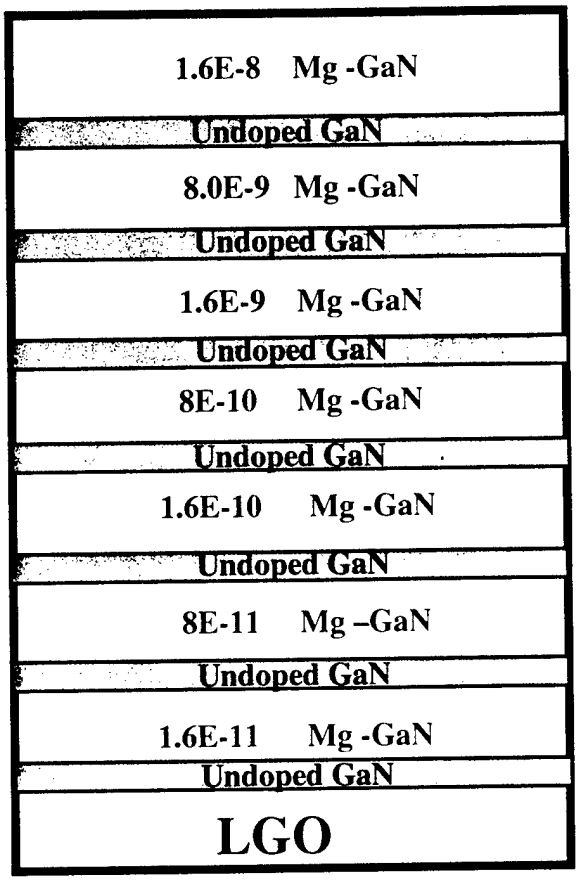

1.6E-8 Mg -GaN
Undoped GaN
8.0E-9 Mg -GaN
Undoped GaN
1.6E-9 Mg -GaN
Undoped GaN
8E-10 Mg -GaN
Undoped GaN
1.6E-10 Mg -GaN
Undoped GaN
8E-11 Mg –GaN
Undoped GaN
1.6E-11 Mg -GaN
Undoped GaN
LGO

Figure 6

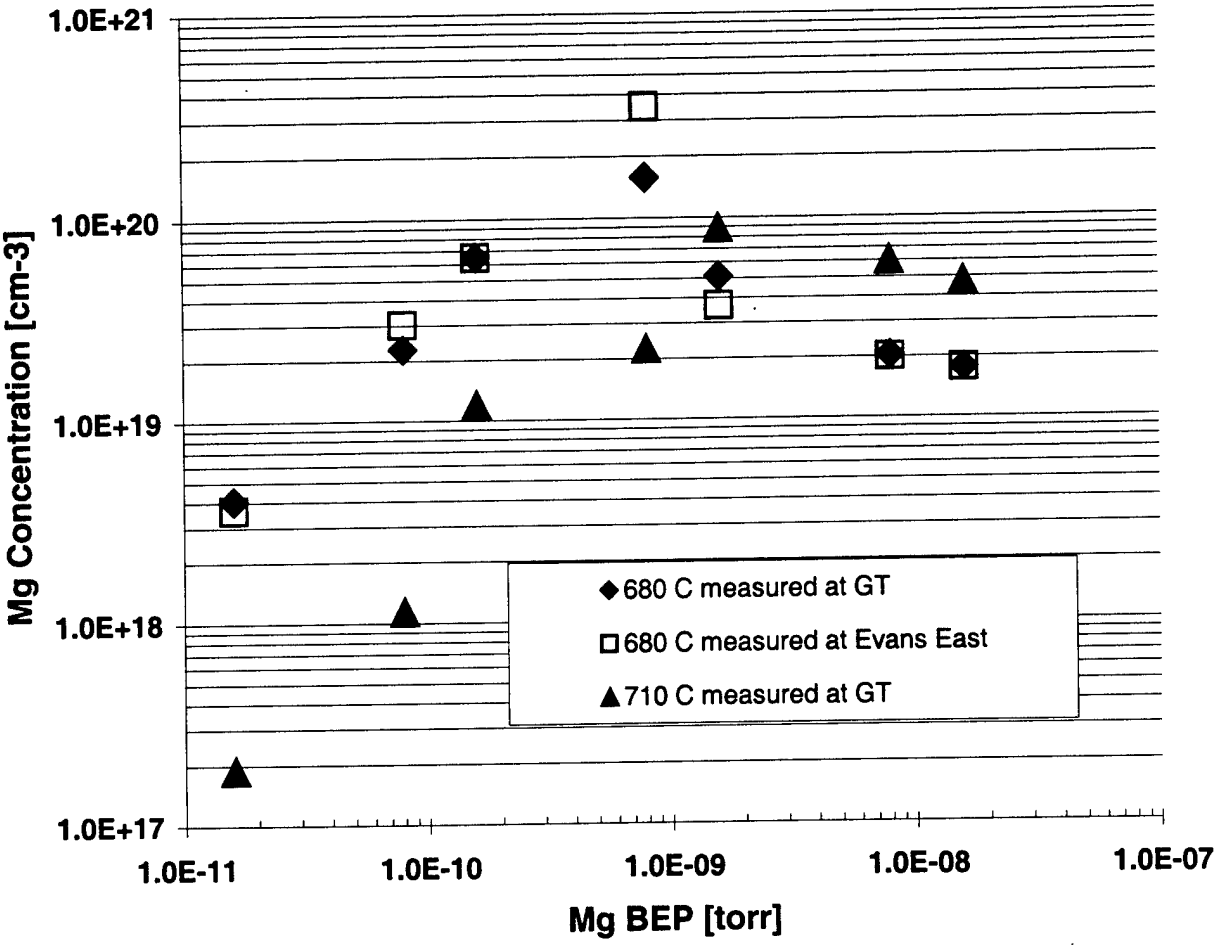

1.0E+21
1.0E+20
1.0E+19
1.0E+18
1.0E+17
Mg Concentration [cm-3]
680 C measured at GT
680 C measured at Evans East
710 C measured at GT
1.0E-11
1.0E-10
1.0E-09
1.0E-08
1.0E-07
Mg BEP [torr]

Figure 7