MONOLITHIC METAL-INSULATOR-SEMICONDUCTOR (MIS) VARACTOR FREQUENCY MULTIPLIERS IN THE MILLIMETER AND SUBMILLIMETER WAVE REGION

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Abstract

Unintentionally doped layers of AlGaInP with energy gaps of approximately 2.0 eV were grown lattice matched to GaAs. Metal-insulator-semiconductor (MIS) capacitors were made with the AlGaInP layer for the insulator on n-type GaAs. The accumulation mode was successfully demonstrated. This MIS varactor structure can be grown using MOCVD technique and planar diode array can be easily achieved.

Introduction

We have investigated the electrical properties of various $(Al_xGa_{1-x})_yIn_{1-y}P$/ GaAs epitaxial structures. In particular, capacitance versus voltage (C-V) and current versus voltage (I-V) were used to ascertain the electrical behavior of the structures and the metal contacts to these structures. This work continues in the direction established by Casey et. al. [1] on the properties of AlGaInP/GaAs MIS structures. As can be seen from the raw and analyzed C-V data shown in Figs. 1 through 3, epilayers of $(Al_xGa_{1-x})_yIn_yP$ with x=0 (i.e. GaInP, which will be referred to as sample #1) grown on N^+ GaAs form virtually perfect Schottky diodes with highly uniform parametric characteristics. The addition of Al to form AlGaInP produces a highly resistive (approximately 10^{12} to 10^{13} Ohm-cm) epitaxial layer. AlGaInP epilayers of identical thickness (1 μm) to that of sample #1 grown on N^+ GaAs displayed a constant capacitance over the bias range of +/- 30 volts, and a resistivity of approximately 10^{13} Ohm-cm, indicative of a dielectric insulator.

C-V and I-V Characteristics

In this work, a multitude of samples were investigated. Schottky contacts to AlGaInP-containing samples W375 and W407 represent the general trend found for conventional metal Schottky contacts to GaAs-based (i.e GaAs and AlGaAs) semiconductors. Sample W375 consisted of a 0.6 μm AlGaInP layer with a multiple GaInP/AlGaInP quantum well on top of a 1 μm GaAs low-doped layer grown on a highly conductive N^+ GaAs substrate. Sample W407 consisted of a 0.1 μm AlGaInP layer, a 84 Å GaInP layer, and a 0.6 μm AlGaInP layer on top of a 1 μm GaAs low-doped layer grown on a highly conductive N^+ substrate. Large area Ohmic contacts were made to the back of the N^+ GaAs substrate by sintering AuGe for 1 minute at approximately 430 ^oC. Schottky contacts to the AlGaInP epilayers were made using the conventional tri-level TiPtAu metalization scheme. Fig. 4 shows the C-V curve of a W375 Schottky contact dot (area 1.05×10^{-3} cm^2). There is considerable hysteresis between the forward and reverse direction C-V curves. This hysteresis was seen in all Schottky contact samples as further evidenced by the C-V curve (Fig. 5) of a W407 Schottky contact dot (area 1.05×10^{-3} cm^2). This is a general feature observed for all the Schottky contacts to AlGaInP which were studied. The large shift in flatband voltage of the C-V curve of sample W407 compared to that of W375 is due, in part, to the thin GaInP layer inserted in the AlGaInP epilayer.

The I-V characteristics of these samples have also been studied. Depending on the exact structure of the AlGaInP/GaInP epitaxial layers, current behavior ranging from Frenkel-Poole emission to a modified Schottky emission/conduction process were experimentally observed for the AlGaInP-containing Schottky contact samples. A 1 μm, unintentionally doped n-type GaAs layer was grown on the substrate and then the undoped AlGaInP layer was grown. The breakdown voltage of this structure is close to 35 V.

High-Frequency Performance

Since a very thin AlGaInP layer can be grown by MOCVD technique. The epilayer of the AlGaInP/GaAs MIS varactor can be made thin enough to reduce the transit time for electrons to travel through this layer, therefore, the cut-off frequency in the submillimeter wavelength can be easily achieved. The high breakdown voltage of the AlGaInP/GaAs MIS varactor structure also provides the capability of high power operation. Using the high resistivity AlGaInP layer for the insulator, different MIS varactor structures are designed as efficient millimeter-wave frequency multipliers. These MIS varactor structures contain either a 100 Å or 200 Å thickness of AlGaInP insulator layer. The predicted cut-off frequencies of these different MIS varactor structures as functions of the epilayer thickness are shown in Fig. 6. The predicted high-frequency performances of two different MIS varactor frequency doublers are shown in Fig. 7. The structures of these two different MIS varactor frequency doublers can also be seen in Fig. 7. More studies are needed to fully develop and utilize the novel AlGaInP/GaAs MIS diode. However, planar diode-grid array of the MIS varactor on the III-V compound semiconductors can be easily achieved. Using the monolithic integrated circuit technique, thousands of MIS varactors will be fabricated on a wafer to make frequency multiplying surface [2].

References

[1] H.C. Casey, Jr., J.S. McCalmont, H. Pandharpurkar, T.Y. Wang, and G.B. Stringfellow, "Current-voltage and Capacitance-voltage Behavior of High Resistivity AlGaInP on GaAs", Applied Physics Letters, Vol. 54, No. 7, p. 650, 1989.

[2] R. J. Hwu, L. P. Sadwick, N. C. Luhmann, Jr., and D. B. Rutledge, "DC and Millimeter Wave Performance of Watt-Level Barrier-Intrinsic-N^+ Diode Grid Frequency

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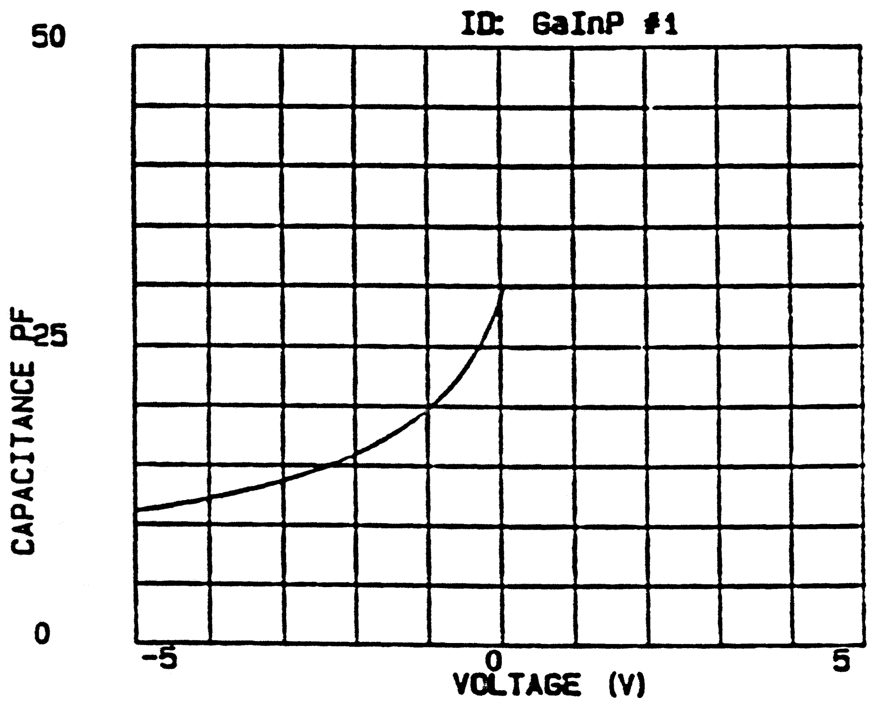

Fig. 1 C-V curve of GaInP sample.

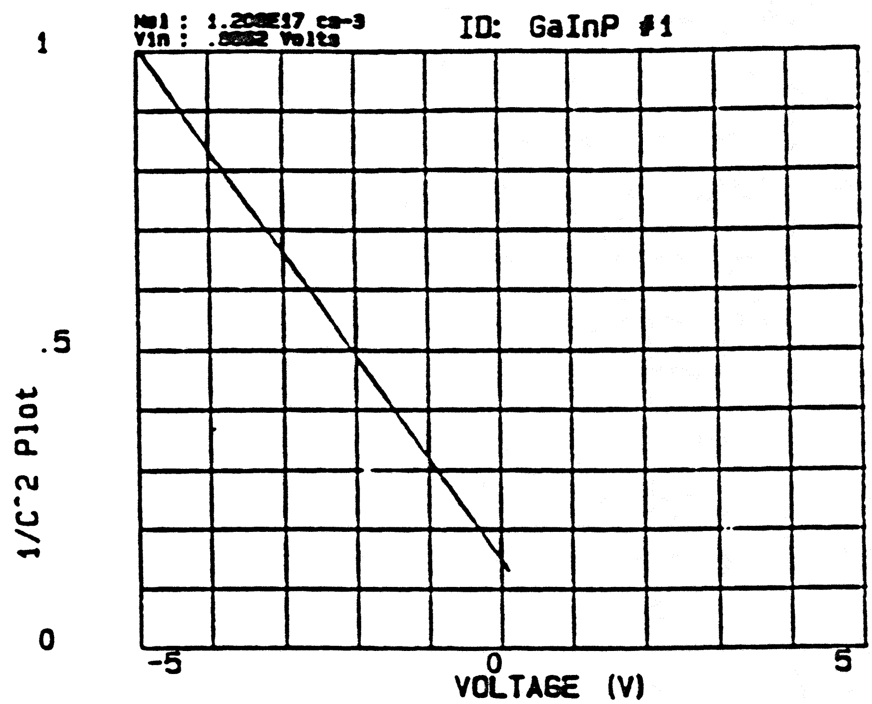

Fig.2 $1/C^2$ versus V curve of GaInP sample.

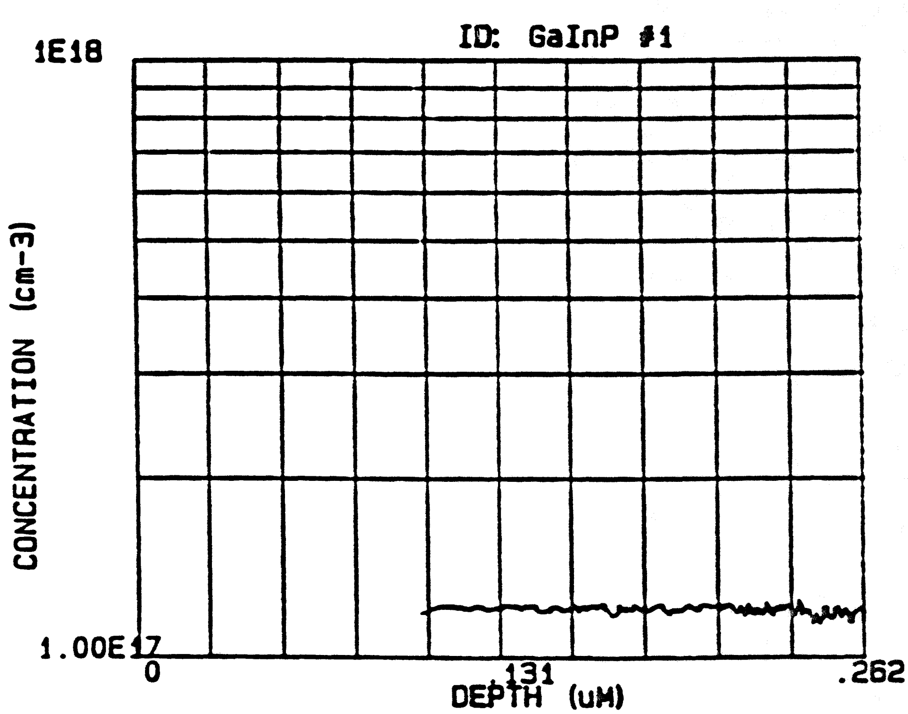

Fig. 3 Doping profile of GaInP sample.

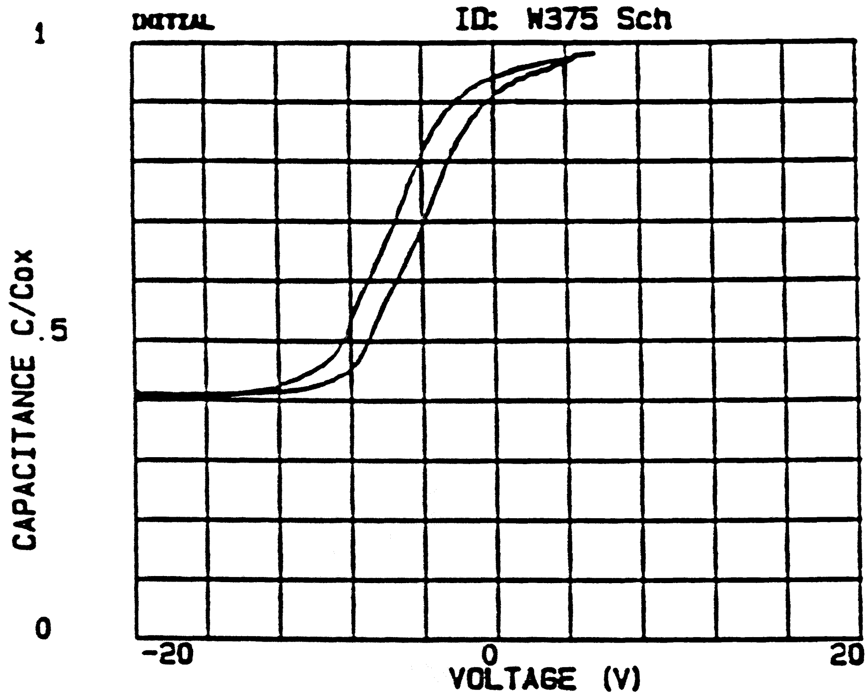

Fig.4 C-V curve of AlGaInP-containing sample W375.

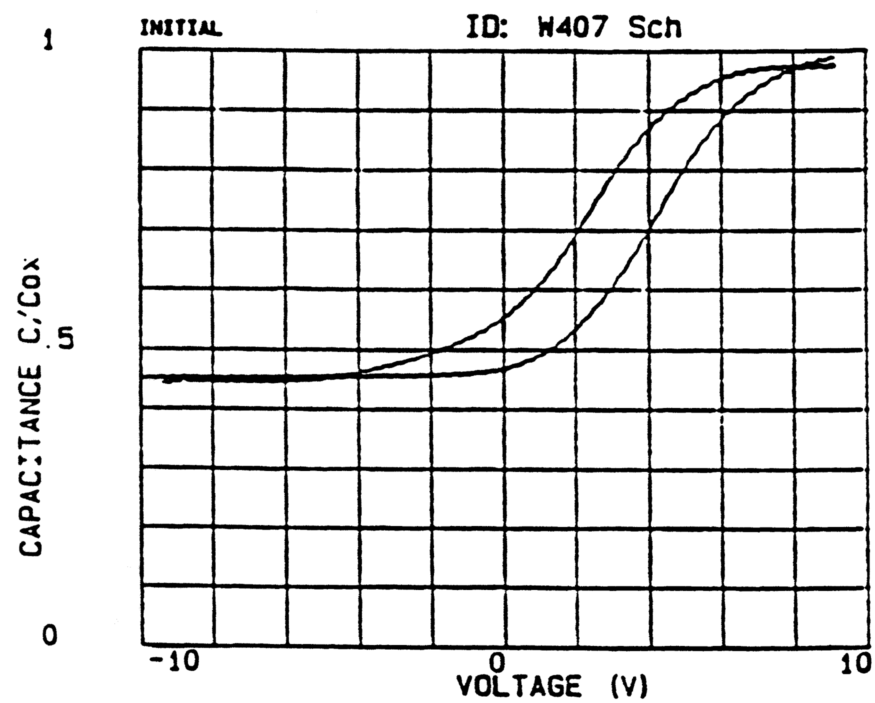

Fig. 5 Representative C-V curve of AlGaInP-containing sample W407.

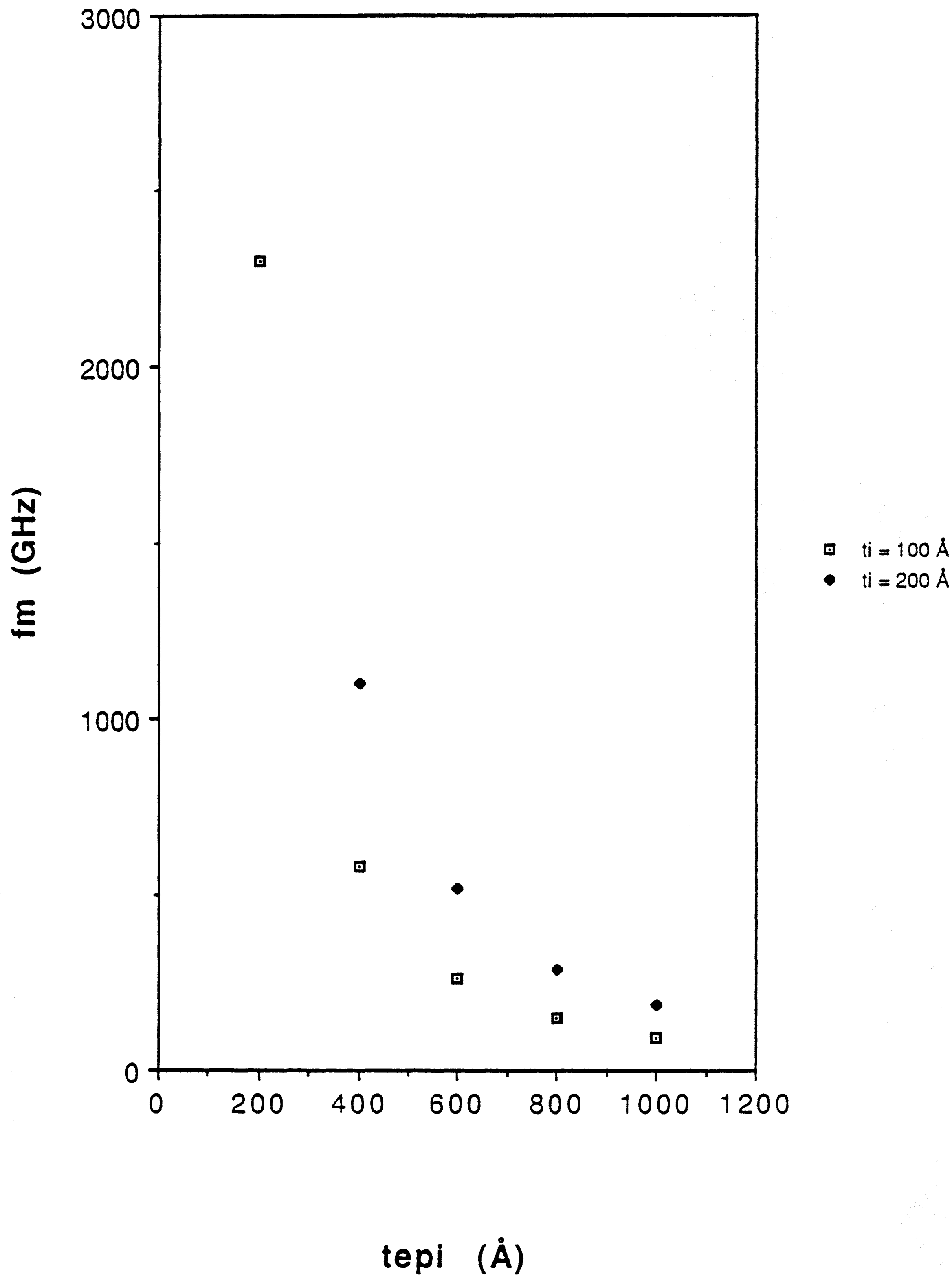

Fig. 6 Calculated cut-off frequency versus epilayer thickness for the MIS varactor structures contain either a 100 Å or a 200 Å thick of AlGaInP insulator layer.

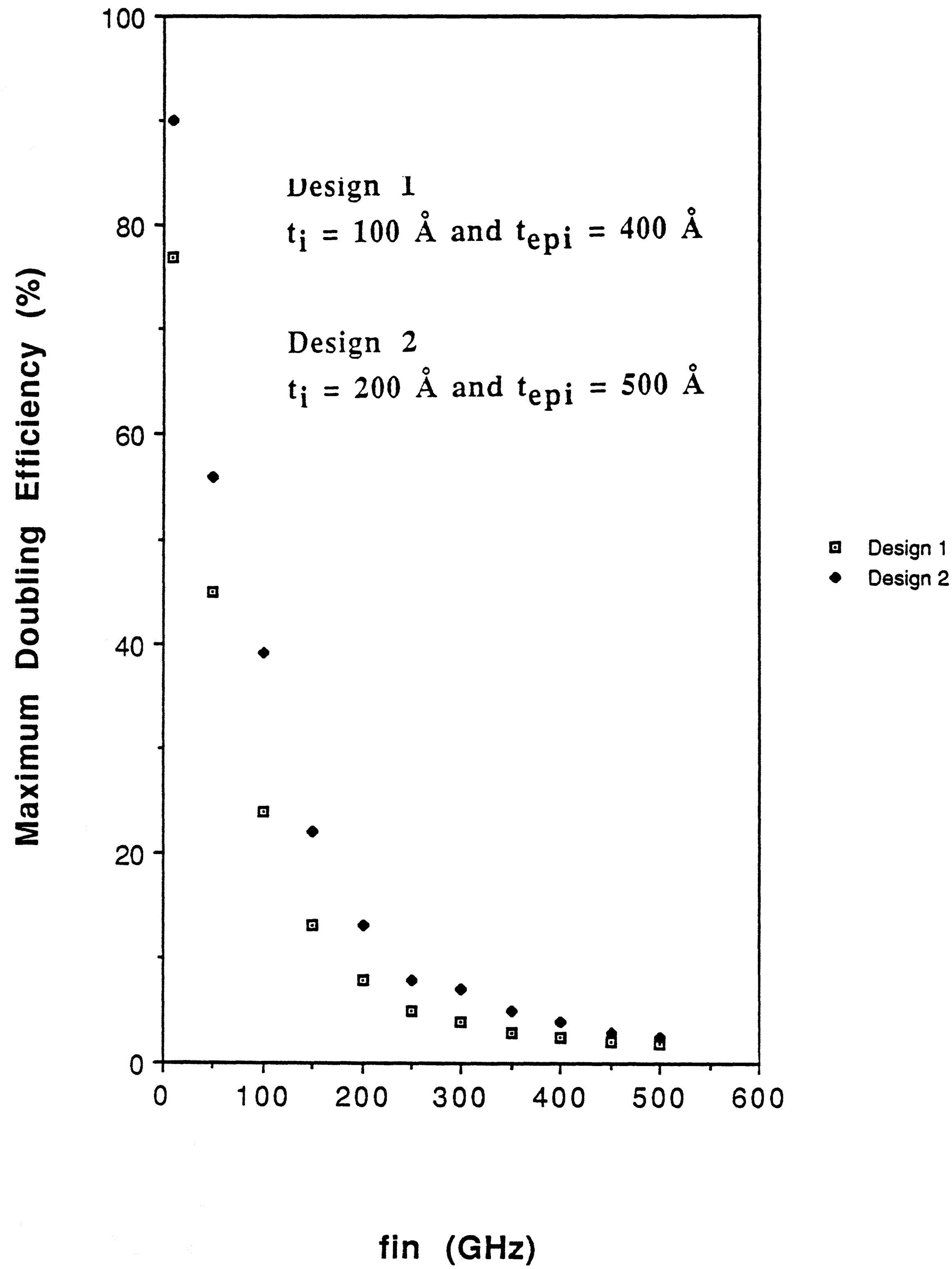

Fig. 7 Predicted maximum doubling efficiency versus input frequency for two different MIS varactor frequency doublers.