# Realization of a 150GHz to 450GHz Tripler Circuit Based on a Thin Dielectric HMDS-N-Membrane

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*Abstract* — **The realization of a 150GHz to 450GHz tripler circuit based on a thin dielectric HMDS-N membrane is described. The design requires an integration of a GaAs-based heterostructure barrier varactor on a passive feeding structure based on a thin dielectric membrane, which is realized by thermocompression bonding. First measurements show sufficient output power and efficiencies.**

## I. INTRODUCTION

Integrated circuits for millimeter and submillimeter-waves based on thin dielectric membranes excel in low losses, minimum dispersion and a practicable integration of active and passive elements. These circuits are fabricated by use of micro machining techniques. The applied batch processes on low-resistance silicon substrates combine the advantages of high reproducibility and low costs.

The dielectric membranes are made of plasma-polymerized hexamethyldisilazane (HMDS-N) with the addition of oxygen. The fabricated membranes have a thickness of 5µm and show an elastic behavior.

A transition from coplanar waveguide based on a thin HMDS-N-membrane to rectangular waveguide was developed and characterized as a low loss arrangement. Using this transition the attenuation of coplanar waveguides based on these membranes was determined at 0.25dB/mm for D-band frequencies (110GHz – 170GHz). [1]

In this paper the fabrication and characterization of a 150GHz to 450GHz tripler based on a 5µm thin HMDS-N-membrane are described. To realize this tripler an integration of a heterostructure barrier varactor (HBV) on a passive circuit deposited on a thin HMDS-N-membrane was developed. The performance of the HBV is described in [2]. The measurement results show a maximum efficiency of 1.4% at an output frequency of 451.8GHz by feeding with 150GHz. The maximum output power is 1.4mW.

## II. CIRCUIT-DESIGN

Fig. 1 shows the schematic structure of the tripler circuit based on a thin dielectric membrane. The left side presents the supply of 150GHz. The transition from rectangular waveguide to microstrip line can be observed, which is realized by a nearly triangular patch placed in the E-plane of the rectangular waveguide. The microstrip line is subsequently tapered to a coplanar waveguide by decreasing the slot between signal line and ground. The same structure for the output frequencies of about 450GHz can be observed at the right side. Both structures are connected by a GaAs-based HBV which is placed in the middle. To match the impedances, stub lines are placed near to the HBV on both sides of the circuit. To make sure that the ground potentials on both sides of one stub are identical, metallic bridges are required.

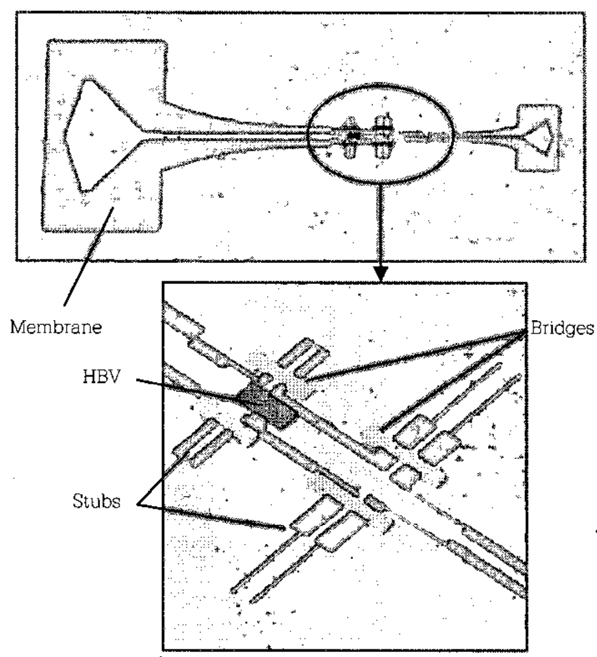


Fig. 1 Schematic structure of a Tripler Circuit based on a thin dielectric membrane.

## III. PROPERTIES OF HMDS-N- MEMBRANES

HMDS-N is a silicon-organic monomer. The chemical structure is: $(CH_3)_3$-Si-NH-Si-$(CH_3)_3$. The membrane layer is deposited from HMDS-N by plasma



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polymerization with the addition of oxygen. The reactor design is presented in [3].

The material composition and the intrinsic stresses depend on the deposition conditions. The hardness is adjustable from polymer-like soft to glass-like hard films of high density. The films deposited at high plasma power exhibit compressive stresses, so that the released membranes get rippled. Films deposited at low plasma power showing tensile stresses, cause the membranes to be stretched.

In order to realize tripler circuits or other components based on thin HMDS-N membranes the membranes have to be flat and temperature-insensitive up to the temperatures generated in the following processes. Therefore the HMDS-N films are deposited under low intrinsic compressive stresses. Afterwards the substrate is annealed at 230°C. During annealing water, hydrogen, methane and nitrogen are removed from the HMDS-N film – the membranes get smooth. Fig. 2 shows a FTIR-spectrum of an HMDS-N film before and after annealing.

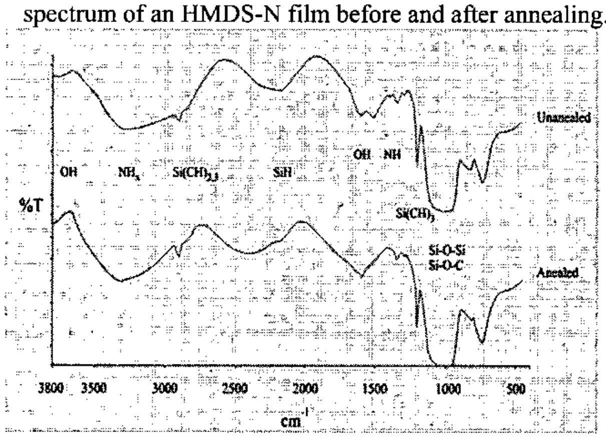


Fig. 2 FTIR transmission spectrum of a plasma-polymerized HMDS-N-film before and after annealing

## IV. Fabrication

The sequence of fabrication processes to realize triplers based on thin HMDS-N membranes is shown Fig. 3.

A low-resistance silicon substrate is coated with a 200nm thin $Si_3N_4$-film by low-pressure-chemical-vapour deposition. Subsequently the 5µm thin, elastic and stress free HMDS-N membrane layer is deposited by plasma-polymerization and annealed at 230°C for about 6 hours. A 100nm thin titanium/gold-layer is sputtered on top of the HMDS-N layer. This layer is used to feed the following gold electroplating to grow the 1.5µm thick tripler structures, which are masked by photolithography. After electroplating the photoresist and the fed titanium / gold-layer are removed by acetone and wet chemical etching respectively. Afterwards the backside $Si_3N_4$ is opened by a plasma etching process using $SF_6$. The structured $Si_3N_4$ is used as a mask for the later silicon etching. Before this etching process, the bridges need to be fabricated.

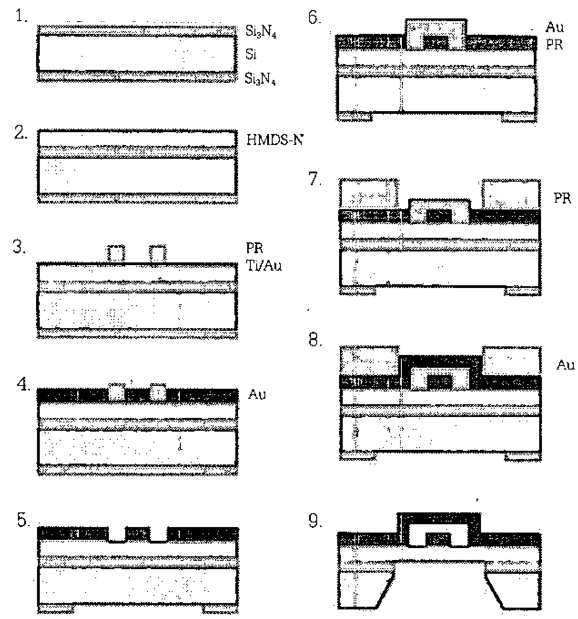


Fig. 3 Flow chart of tripler fabrication processes

The bridges are realized by a double-resist technology using electroplating. Therefore, the bottom sides of the bridges are formed by photolithography. Next, a thin titanium / gold-layer is sputtered on these structures at low powers to reduce the generated heat. A second lithography is made to structure the mask for the following electroplating of the bridges. After electroplating, both photoresist layers and the feeding titanium/gold layer are removed by acetone, wet chemical etching and nitric acid. The drying occurs very carefully by dipping the substrate in isopropanol and placing it in a 90°C oven. Now the underlying silicon is removed in a 40%KOH-solution with a temperature of 80°C. During this process the tripler-side of the substrate is protected against the KOH-solution by an etch-holder. The solution is used as long as the holder is leak proofed. Afterwards the remaining silicon is removed by use of a SF6-plasma-etching process. Finally a HBV is placed in the middle of the passive structure by thermocompression bonding with temperatures around 200°C.

Fig. 4 shows a photograph of the passive tripler structure based on a 5µm thin HMDS-N-membrane. The coplanar waveguides, stubs and bridges at both sides of the tripler - 150GHz and 450GHz can be observed.

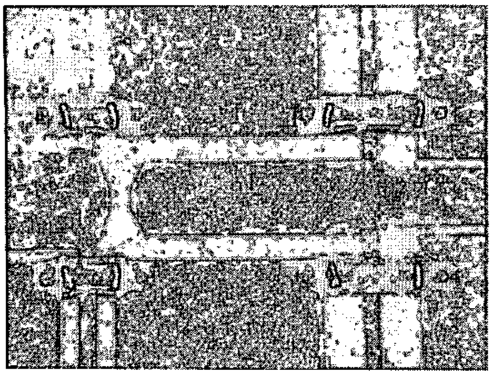

Fig. 4 Photograph of a fabricated tripler feeding structure based on a 5μm thin dielectric HMDS-N membrane

## V. CHARACTERIZATION

The triplers are characterized in a test fixture, where the stimulating frequency of 150GHz is supplied by a curved waveguide. The generated output signals around 450GHz are guided along a second rectangular waveguide placed on the other side of the test fixture. The signals are measured by a frequency analysator.

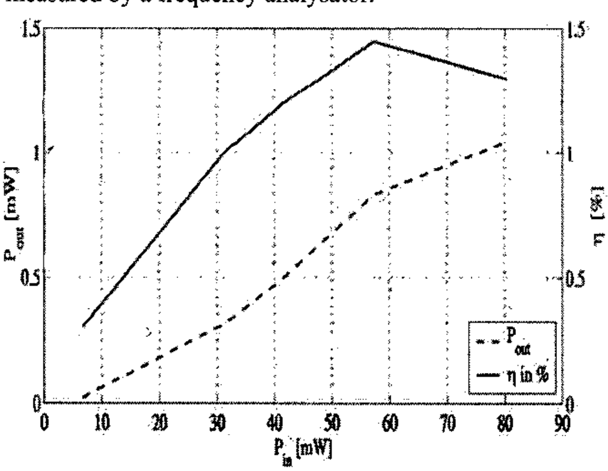


Fig. 5 Measured output power at 451.8GHz versus input power at 150GHz

The dependence of the output power at 451.8GHz on the input power at 150GHz is shown in Fig. 5. A maximum efficiency of 1.45% can be observed at an input power of 58mW. The maximum output power was measured at 1.05mW. Considering the losses due to the test fixture of approximately 5dB the measurements show very satisfactory characteristics.

## V. CONCLUSION

A 150GHz to 450GHz tripler is fabricated using micromachining techniques. To realize the tripler a HBV is integrated on a passive feeding structure based on a 5μm thin HMDS-N membrane by thermocompression bonding. The measurements show a maximum efficiency of 1.45% at an output frequency of 451.8GHz with an input power of 58mW at a frequency of 150GHz. These triplers are used for the realization of a power combining tripler line consisting of 5 identical tripler structures [4].

## ACKNOWLEDGEMENT

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