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December 18, 2000

Dr. John Webber
National Radio Astronomy Observatory
2015 Ivy Road, Suite 219
Charlottesville, VA 22903-1733

RE: Contract # 55162
"Development of SIS Mixers for MMA Receivers"

Dear Dr. Webber:

Enclosed please find the original and two copies of the final report for the above referenced project.

If you have any questions, please feel free to contact me.

Sincerely,

Ivar Strand, Director
Office of Sponsored Programs

IS:rs
Enc.

xc: Dr. J. Lukens
File 431-6238A

State University of New York at Stony Brook
Department of Physics and Astronomy

Development of SIS Mixers for MMA Receivers

Principal Investigator: Prof. James Lukens

Sponsoring Organization: National Radio Astronomy Observatory

Progress Report

Prepared for: Dr. Anthony Kerr

Report Period: June 2, 2000 - December 1, 2000

Prepared by: Dr. Sergey K. Tolpygo

December 13, 2000

During the sixth and the seventh quarters of the contract, we continued to work on the fabrication and testing of wafers with the 620-750 GHz mixer design. Three fabrication runs were undertaken, yielding wafers NRAO/SUNY2-7, NRAO/SUNY2-8, and NRAO/SUNY2-9. After preliminary dc testing, mixer chips of these wafers were transferred to the NRAO.

The main problem found during dc testing of wafers NRAO/SUNY2-7 and NRAO/SUNY2-8 was a high subgap leakage. I will not repeat here my speculations on what could have caused the problem since these issues were discussed in details in several of our e-mail exchanges. The positive result obtained from these two fabrication runs is that the process modifications and design corrections made in the 620-750 GHz design with respect to the first (200-300 GHz) design do work and improve the process reliability and yield. For example, of about 120 mixers tested on 4 chips of NRAO/SUNY2-7, the yield of mixers showing the appropriate I-V characteristics with the expected LC resonance was about 85%, a considerable improvement with respect to the first design. The spread (1σ) in the normal resistance, R_N, was 10-12%, higher than that we normally have on Si wafers (~ 5%). The average (over all tested chips) resonance frequency in mixers of different designs is shown in the following table.

Table
LC resonance frequency in mixers of different designs

Mixer design type	Resonant frequency (GHz)	Full spread in resonant frequency, 3σ (GHz)
A1	655	16
A2	637	22
A3	596	8
A4	583	5
A5	563	5
B1	624	29
B2	607	5
B3	No data	No data
B4	571	19
B5	No data	No data
C1	592	11
C2	596	11
C3	571	11
C4	559	12
C5	No data	No data

These data are very close to the resonant frequencies obtained in electromagnetic simulations of the mixers. Since the increase of the number in the mixer label (say, A1 to A5) corresponds to the increase of the tuning structure length (from 13 μm in designs A1, to 21 μm in designs A5), one can see that the resonant frequency decreases accordingly. Also, the resonant frequency decreases with increasing overlap of a coupling capacitor (from 4.5 μm in designs A to 5.5 μm in designs C). The spread in resonant frequencies (< 5%) is consistent with half of the spread in the junction R_N. This indicates that the main cause of the spread is variation in the junction area. Higher frequency designs show a larger spread, also as one would expect from a microstrip resonator loaded at both edges by two junction capacitors.

In the fabrication run NRAOSUNY2-9 we tried to minimize the factors suspected to have caused the high subgap leakage. Specifically,

1) a better-polished quartz wafer from a different vendor was used;
2) the trilayer deposition parameters were adjusted to minimize stresses in the trilayer;
3) the beam current during the electron beam lithography was kept below 30 pA to minimize possible local trilayer heating;
4) additional precautions were taken to minimize the trilayer heating during planarization quartz deposition.

As a result, we find a considerable improvement in the trilayer quality, although we do not know which of these changes played the most crucial role. The critical current density on NRAOSUNY2-9 wafer was found to be 11.4 kA/cm^2, very close to the design value of 12 kA/cm^2. From the scaling of junction normal conductance with the junction area, the specific resistance was found to be 14.3 Ω μm, again very close to the value used in the design, 15 Ω μm. The I_cR_N product was found to be 1.5-1.6 mV. This differs somewhat from 1.8 mV used in the NRAO designs. DC testing of about 120 randomly selected mixers showed the average ratio of subgap resistance to the normal resistance $R_{sg}/R_N \sim 5$, while $R_{sg}/R_N = 7$ in the best mixers. The lower subgap leakage did not allow us to see the LC resonance in the mixer structure as clearly as it was possible with the previous wafers. Therefore, no resonance frequency data are available at this time. Seven mixers chips of this wafer were sent to the NRAO for the microwave testing. We have started the work on further reducing the subgap leakage and increasing the fabrication yield and mixer uniformity.

The work on redesigning the photomask set with the 200-300 GHz design has been largely completed, and the data will be submitted for the mask fabrication within a week. In this second iteration of the 200-300 GHz design we are trying to correct for most of the processing problems encountered during the fabrication of wafers NRAO/SUNY1-1 through NRAO/SUNY1-6. This will require one additional photomask plus correcting one from the existing set. We expect to start working on the actual wafer processing in January of 2001.