Space qualification of MMIC Schottky diodes chips for SWI instrument of JUICE mission

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***Abstract*—The Sub-millimeter Wave Instrument (SWI) is a heterodyne spectrometer onboard JUpiter ICy moons Explorer (JUICE) mission working in two spectral ranges around 1200GHz and 600GHz with a spectral resolving power of about 10^7. The frequencies conversions in the receivers are based on Schottky diodes integrated on MMIC type chips fabricated on GaAs substrates. The contribution from LERMA[1] to the instrument includes the chips dedicated to the 300GHz doublers of both channels and the 600GHz doubler and 1200GHz subharmonic mixer of the 1200GHz channel. These chips were manufactured in the clean room of C2N-CNRS[2] in the frame of a long-term partnership between LERMA[1] and C2N. These chips have been qualified for integration into SWI for the JUICE mission. The presentation will give an overview of the chip qualification process and results.**

Keywords—Schottky diode, GaAs, heterodyne detection, submillimeter wave, THz, space qualification, SWI, JUICE, Jupiter.

I. Introduction

Interplanetary space missions such as JUpiter ICy moons Explorer (JUICE) implies particularly severe constraints on devices reliability over a time range that includes approximately 8 years cruising to Jupiter and operations in varied environments. In addition to the requirement for high scientific return, high technological demands are required on the instruments. The Sub-millimeter Wave Instrument includes a state-of-the-art heterodyne receiver technology based on Schottky diodes MMIC chips operating at frequencies as high as 1200GHz. These devices are research laboratory products: they are produced on a small scale, unlike industrial components which benefit from mass production capabilities.

The approach chosen for qualifying these parts was based on ESCC and MIL standards, with several adaptations to fit into the scientific program needs and constraints (funds, technical, process). It covered two main objectives, to ensure that : i) the active components perform according to their requirement specifications and in the JUICE mission environment, ii) the assemblies (components bonding, substrate mounting …) withstand the JUICE environment specifications (thermal, vibrations, mechanical shocks, …). We will present the approach methodology and main results obtained during the qualification program.

II. Methodology

The contribution from LERMA to the SWI includes the 300GHz doubler of the 600GHz channel (D300X1 block), and the 300GHz doubler (D300X2 block), the 600GHz doubler (D600 block) and the subharmonic mixer (SHM1200 block) of the 1200GHz channel. All these parts include MMIC GaAs-based Schottky diode chips. These chips were designed by LERMA-Observatoire de Paris and fabricated in the clean room of C2N-CNRS specially for JUICE-SWI instrument. Each block contains 1 chip, except the D300X2 which contains 2 chips per block. The qualification process described below was applied both to the chips and to the blocks themselves.

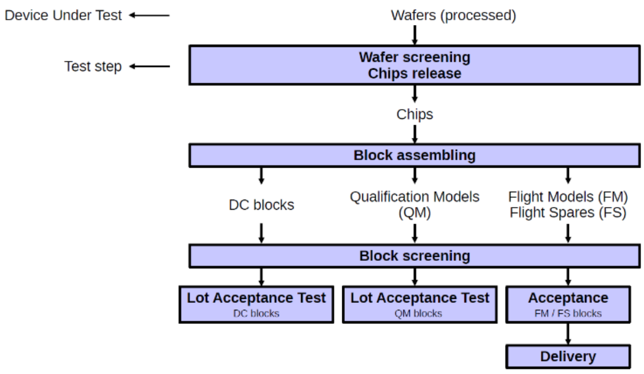

Fig. 1. Overview of qualification methodology.

Fig. 1 summarizes the qualification methodology. The qualification process begins at the end of chips fabrication. Three chip types were fabricated (Fig. 2): 300GHz doubler type (D300 chip), 600GHz doubler type (D600 chip) and 1200GHz subharmonic type (SHM1200 chip). The batches selected for flight provided 140 D300 chips, 140 D600 chips and 119 SHM1200 chips. Systematic measurements of current versus voltage characteristics were performed on all chips by probe testing on wafers before the chips release.

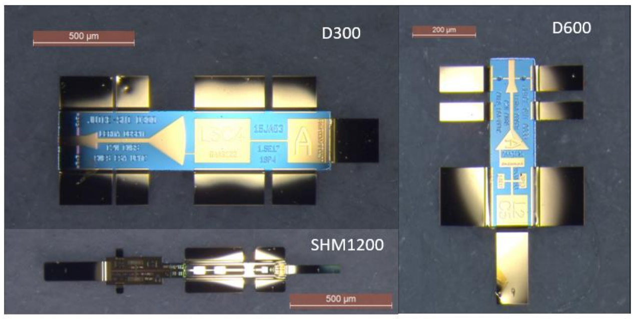

Fig. 2. Photos of D300, D600 and SHM1200 chips after release.

TABLE I. Wafer screening specification for 1 diode

Chip type	Series resistance (Ω)		Ideality factor	
	Min.	Max.	Min.	Max.
D300	5	10	1.12	1.22
D600	15	25	1.15	1.25
SHM1200	35	55	1.35	1.65

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Table I shows the specification applied to the wafer screening. The values are related to one single Schottky diode. Following the wafer screening, the chips were released and integrated in various blocks.

Two block types were used during the qualification process: i) the DC test blocks, which had no RF functionality and ii) the Qualification Model (QM) blocks, which were identical to Flight Model (FM) and Flight Spare (FS) blocks. The diagram on Fig. 1 also includes the process followed by the FM and FS blocks as these ones had communal steps with QM blocks.

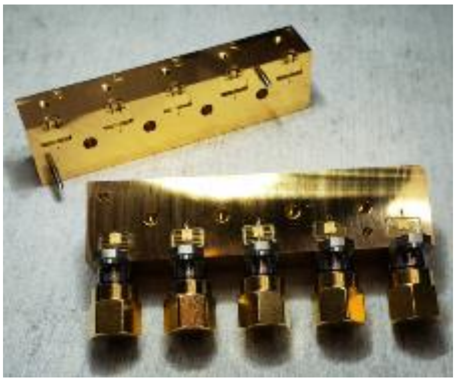

Fig. 3. Photo of a DC test block during the chips integration.

The DC blocks were intended to test a significant number of chips. Each DC block was containing 5 chips of the same type (Fig. 3). Each chip was connected to its individual SMK connector and could be controlled independently in static regime. The qualification program included 3 DC D300 blocks (15 chips), 2 DC D600 blocks (10 chips) and 2 DC SHM1200 blocks (10 chips).

The QM blocks were intended to test the chips under their JUICE operational conditions. Each QM block was first individually submitted to DC and RF measurements in order to check its performance. Then, the D300X2, D600 and SHM1200 blocks were assembled together to form 1200 GHz chains (Fig. 4) and the following tests were performed on assembled chains.

Fig. 4. 300GHz doubler, 600GHz doubler and 1200GHz subharmonic mixer assembled in 1200GHz chain before qualification steps.

All DC, QM and FM/FS blocks were submitted to the block screening tests: thermal cycling (5 cycles), power burn-in and High Temperature Reverse Bias (HTRB) tests. These tests were intended to detect possible early failures on the devices. DC and RF measurements were done before and after each test to check the possible evolution of the ideality, series resistance, doublers output power and receiver sensitivity. These values were compared to the specification.

TABLE II. BLOCK SCREENING CONDITIONS ON QM/FM/FS BLOCKS (BIASING AS SEEN BY EACH SINGLE DIODE)

Test	General conditions	Biasing conditions		
		D300	D600	SHM1200
Thermal cycling	-160°C / +80°C 5 cycles	No bias	No bias	No bias
HTRB	48h 60°C	-5.5V (<3µA)	-4V (<0.5µA)	No bias
Power burn-in	48h 100°C	+2.5mA (<0.8V)	+0.5mA (<0.8V)	+30µA

After the block screening sequence, the DC and QM blocks were submitted to extensive tests (Lot Acceptance Test) intended to model the mission profile at levels higher than the highest planned operational levels. The tests include thermal cycling (50 cycles), humidity, radiation and DC life test for DC blocks and thermal cycling, shocks, vibration, RF life test and destructive physical analysis for QM blocks. The FM/FS blocks were submitted to moderate acceptance tests in view of their integration in the SWI.

III. SCREENING RESULTS

Fig. 5 shows an example of current versus voltage curves measured during the wafer screening. It should be noticed that the presence of 2 diodes in series on the D300 chip results in a curve slope 2 times lower. Fig. 6 shows ideality factor values obtained from the SHM1200 chips. These values were obtained from current setpoints ranging from 1µA to 10µA using the Shockley equation. On the selected batches, the wafer screening specification yield values were 86%, 93% and 71% for D300, D600 and SHM1200 chips respectively.

Table II shows the conditions applied during the block screening on RF blocks. For each test, the biasing conditions are detailed. These conditions refer to the voltage and current as seen by each single diode of the chip. For chip protection, current or voltage limits were fixed, their values are given in brackets.

It should be noticed, that each QM/FM block includes a filtering circuit after the DC ports, allowing to protect the circuits from potential electrostatic discharges. The drawback is that for the mixer diodes, the DC current cannot be directly measured.

The mixer forward current was measured thanks to refined measurement conditions (see Fig. 8). The figure shows the equivalent circuit in static measurement conditions. The nominal values of R_1 and R_2 were around 600 ohms and 400 ohms. The IF port was kept open during the measurement. At low voltage, an accurate value of R_1+R_2 was measured. At high voltage, the diode current was extracted by using this measured value together with the nominal value of R_2 as given by the relation:

$$I_D = \frac{I(R_1 + R_2) - U}{R_2}$$

In the same way, the diodes voltage is obtained by the relation:

$$V_D = V - R_1 \cdot I$$

Thanks to the classical Shockley diode equation, the ideality factor η can be extracted by calculating the slope between V_D (abscissa) and $\log(I_D)$ (ordinate) and by using the relation:

$$\eta = \frac{q}{slope \cdot k \cdot T}$$

With q the elementary electrostatic charge, k the Boltzmann constant and T the temperature of the diodes. The slope was calculated for $V_D > 1.30V$. This method was used to control the ideality factor value on SHM1200 QM/FM/FS blocks before and after the tests and also to control the 30µA current during power burn-in test.

Fig. 7 shows the ideality factor variation during the block screening sequence on QM/FM/FS blocks. All values, including series resistance, receiver sensitivity or RF output power (D300X1), were within specification.

IV. Conclusion

The qualification tests were performed on LERMA's hardware for the SWI of JUICE ESA mission. The qualification process ended successfully and the hardware was delivered for its integration in the SWI.

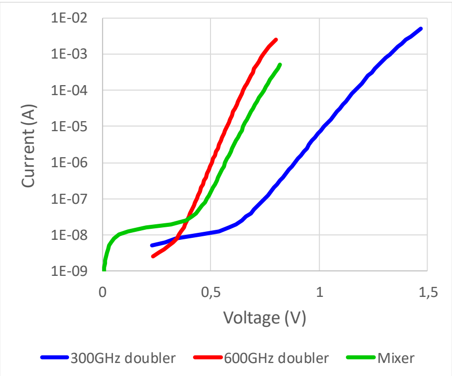

Fig. 5. I(V) curves measurements obtained by probe testing during the wafer screening. The measurement was done on 2 diodes in series on the D300 chip and on 1 diode on D600 and SHM1200 chips.

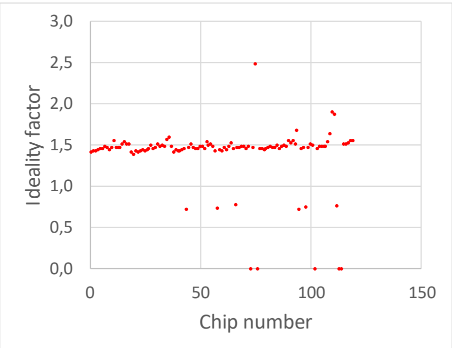

Fig. 6. Ideality factor values obtained on SHM1200 chips from the wafer screening (one point per chip, each chip has two diodes, the value is the mean value of the two diodes).

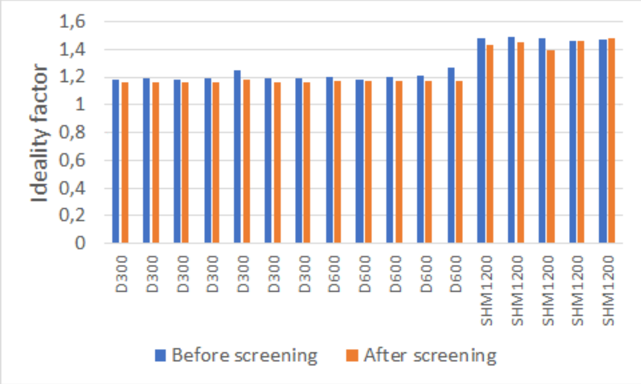

Fig. 7. Ideality factor variation before and after block screening on QM/FM/FS blocks (mean value over the chip).

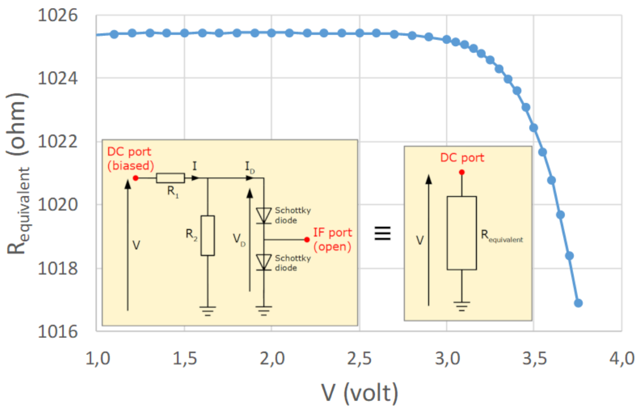

Fig. 8. Equivalent resistance measured from the biasing port on a QM/FM/FS SHM1200 block in static regime. The equivalent simplified circuit is shown as an insert. The IF port should be open (with precaution) so as to include both diodes in the measurement. The current versus voltage diodes characteristic can be deduced (lowest forward current detected around 1µA).

References

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