# Aging Investigation of NbN Hot Electron Bolometer Mixers

Pourya Khosropanah, Vladimir Drakinskiy, Sergey Cherednichenko, Therese Berg

Department of Microtechnology and Nanoscience (MC2)
Microwave Electronics Laboratory
CHALMERS UNIVERSITY OF TECHNOLOGY
412 96 Gothenburg, Sweden
Email: pourya.khosropanah@mc2.chalmers.se

*Abstract*— **This work presents an aging investigation of NbN HEB mixers in usual lab conditions and also in high temperature and high relative humidity environment. A variety of devices have been fabricated using different combinations of resist (SAL), Si, $SiO_2$ and SiN single and multi-layer for bolometer protection. In the accelerated aging tests the degradation is monitored by measuring the DC resistance of the devices during the test. The results show that using multi-layer protection increases the device lifetime significantly.**

## I. INTRODUCTION

NbN HEB mixers are to be used for band 6 low (1.410-1.700 THz) and band 6 high (1.700-1.920 THz) of the HIFI instrument (Heterodyne Instrument for Far-Infrared) [1] on the Herschel Space Observatory [2] due to launch 2007. This will be the first time that HEB mixers are used on a space mission. The double side band receiver noise temperature using these mixers are below 1000 K with 5-6 GHz IF bandwidth and they require less than 500 nW of local oscillator power [3].

Since the assembling of the flight mixer units is now in progress, they will be stored for about two years before the launch. This raises questions concerning the degradation of the mixer chips during this period. This work presents our attempts to estimate the HEB lifetime with different protection layers by comparing the accelerated aging test results in high temperature and high relative humidity with the available data concerning degradation of the devices in usual lab conditions. An independent similar investigation is presented in [4]. Here, a variety of devices have been fabricated using different combinations of Si, $SiO_2$, SiN and resist multi-layers for bolometer protection. Some of these devices are stored in ordinary lab environment and their resistance and the critical current have been measured regularly, in some cases for a period of two years. In the accelerated aging tests the resistance of devices are monitored while exposed to high temperature and high relative humidity. The increase of resistance and decrease of critical current are the measures of device degradation.

## II. DEVICE FABRICATION

The device fabrication is done by several consecutive electron beam lithography steps followed by metallization and lift off, where small contact pads, antenna and the large contact pads are patterned. 5 nm Ti followed by 80 nm of Au is deposited for small contact pads. The antenna and large pads are made from 5 nm of Ti and 200 nm Au. Then a protection layer is defined over the bolometer bridge by one more lithography step. This is to protect the NbN film in the bolometer bridge during the ion milling. In the last step the NbN is etched away using Ar ion milling from the whole wafer except from the bolometer bridge and under the antenna and pads. Figure 1 shows the SEM picture of a bolometer integrated with double slot antenna for 1.6 THz. A variety of devices have been fabricated using different combinations of Si, $SiO_2$, SiN and resist (SAL) multi-layer for bolometer protection. The shapes and the thicknesses of these layers are illustrated in figures 2 and 3. The resist (SAL) is a negative resist and the protection layer is defined by the e-beam writing. The Si and SiN layers are made by magnetron sputtering and the $SiO_2$ layer is deposited using e-beam evaporation. In both cases the bolometer protections are formed using lift off technique. The first protection layers is in rectangular shape and covers the bolometer bridge together with parts of the small contact pads. The second and the third protection layers are in circles which cover the whole center part of the device.

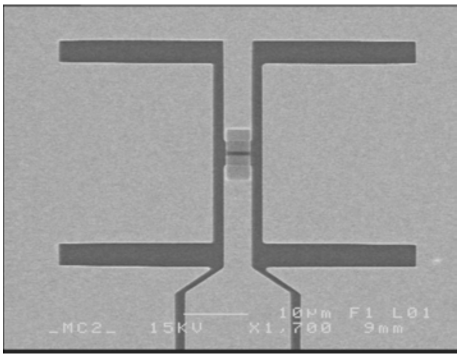

Fig. 1. HEB integrated with double slot antenna for 1.6 THz

## III. DEVICE DEGRADATION IN LAB CONDITION

The HEB devices degrade by time. The degradation appears as increase of resistance and decrease of critical current.

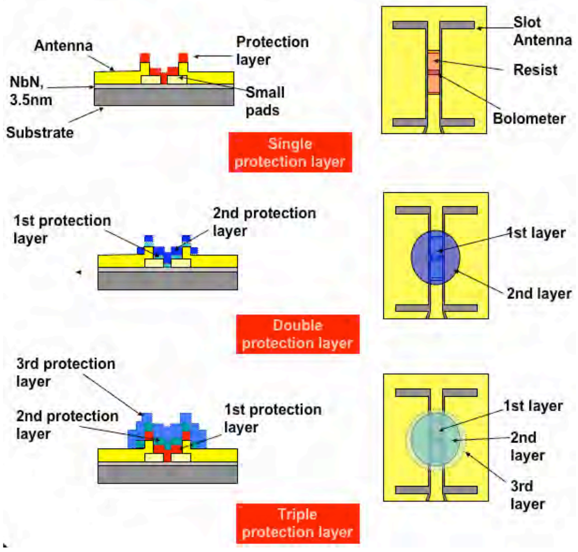

Fig. 2. Protection layers over the bolometer bridge

A number of devices have been stored under ordinary lab conditions in air (around 20°C and 30% RH). The resistance and critical current of these devices have been measured periodically which is summarized in table I.

Although these data show the tendency for the Si+Si double layer protection to be more resistant against aging, the result is not yet conclusive and the accelerated aging tests seems necessary.

## IV. RECEIVER NOISE TEMPERATURE AND MIXER DEGRADATION

In order to see the degradation effect on the mixer performance, receiver noise temperature have been measured two times using the same mixer chip. The mixer was fabricated in February 2004 and kept in desiccator until April 2004 when it was mounted in the HIFI mixer unit and measured for the first time. Then it was stored on the shelf at about 20°C and 30% RH until August 2004, when the second test was performed. During this time the device resistance increased by 5% and the measured critical current decreased by 10%. Figure 4 shows the double side band receiver noise temperature in these two occasions together with the HIFI specification limit. As we see, the mixer performance was not much affected by this level of degradation and the receiver noise temperature is within acceptable limit. The device used in this test has a resist (SAL) protection layer for the bolometer.

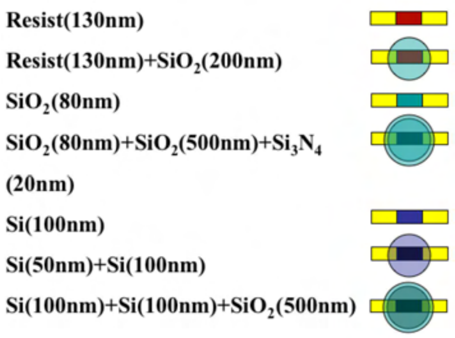

Fig. 3. Variety of HEB protection layers and their thicknesses

TABLE I
HEB DEGRADATION IN ROOM TEMPERATURE AND 30% RH

| Protection | Time (Month) | $dR/R$ (%) | $dI/I$ (%) |
|---|---|---|---|
| SAL | 12 | 20 | 30-50 |
| SAL | 16 | 30 | 50 |
| SAL | 24 | 50 | 60-70 |
| SAL+SiO$_2$ | 7 | 3-13 | 5-12 |
| SiO$_2$ | 7 | 15 | 8 |
| Si+Si | 6 | 2-5 | 6-9 |

## V. VACUUM BAKING TEST

141 hours of vacuum baking was done with 3 devices with resist (SAL) protection. The pressure of $10^{-4}$ mbar was achieved with 2 hours of pre-pumping and temperature was kept constant at 90°C on the hotplate where devices were placed. As it is shown in table II, the resistance and the critical current of these devices did not changed significantly during the test, which means that the heating effect on device degradation in the absence of air is negligible and not affected by temperature.

## VI. ACCELERATED AGING TEST AT 85°C-85% RH

Several devices with a variety of bolometer protection layers were kept in 85°C-85% RH for over 100 hours. The resistance of these devices was monitored during this time. Figure 5 summarizes the result of these tests. The devices with resist (SAL) protection have the shortest lifetime. Although

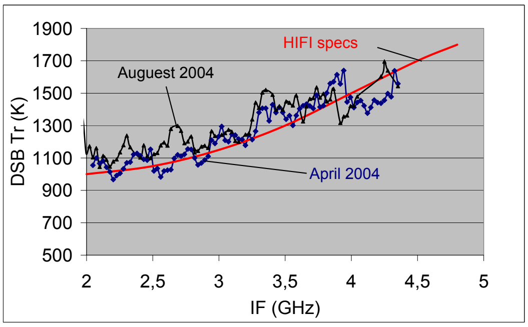

Fig. 4. DSB receiver noise temperature measured twice with about 5 month time difference using the same HEB chip stored in about 20°C and 30% RH during this time.

TABLE II

VACUUM BAKING TEST AT 90°C FOR 141 HOURS

| Device ID | $R$ ($\Omega$) before | $R$ ($\Omega$) after | $I_C$ ($\mu$A) before | $I_C$ ($\mu$A) after |
|---|---|---|---|---|
| A | 87 | 85 | 134 | 132 |
| B | 95 | 93 | 140 | 137 |
| C | 93 | 92.5 | 130 | 118 |

there is a diversity in their performance, they all severely degrade within first 10 hours and before all the other type of devices. Adding an extra layer of $SiO_2$ improves the life time significantly. There is a clear difference in lifetime when the SAL protection is replaced by Si or $SiO_2$. However, the major improvement occurs when double layer Si+Si or triple layer $SiO_2$+$SiO_2$+SiN is used which increase the lifetime of HEB by almost an order of magnitude.

A number of devices were periodically exposed to 10 hour of 20°C-20% RH following by 10 hours of 85°C-85% RH for about 120 hours of total time. As is shown in figure 6, the devices with SAL protection were degraded faster than the devices with Si+Si double protection layer. We can also see that the degradation stops (constant resistance) during 20°C-20% RH and starts again when at 85°C-85% RH.

## VII. ACCELERATED AGING TEST AT 65°C-85% RH

In order to see the temperature effect on the degradation of HEB, a number of devices with SAL and Si+Si protection were exposed to 65°C-85% RH for over 100 hours. As is shown in figure 7, the devices with SAL protection were affected much faster that the devices with Si+Si double protection layer. Comparing this result with the outcome of the 85°C-85% RH (figure 5), one can see that the degradation in 65°C happens considerably slower than in 85°C.

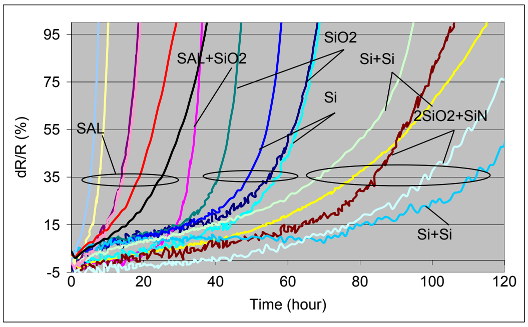

Fig. 5. Accelerated aging test at 85°C-85% RH

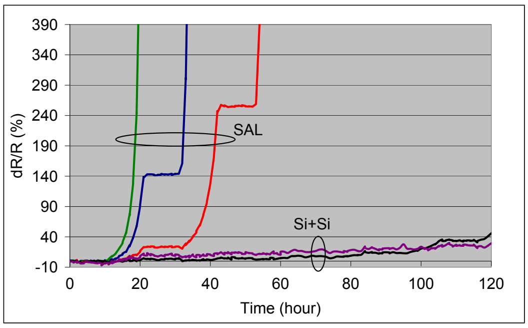

Fig. 6. Periodical aging test: 10 hour of 20°C-20% RH following by 10 hours of 85°C-85% RH repeated for about 120 hours.

## VIII. ACCELERATED AGING TEST AT 50°C-85% RH

Only devices with resist (SAL) protection were used in a 50°C-85% RH aging test. The reason was that they were expected to have shorter lifetime and therefore more practical to test at lower temperature. Using other devices with double or triple layer protection in this test requires very long testing time which is cumbersome. As is shown in figure 8, the devices are degraded in a much slower pace compared with degradation at 65°C and 85°C. The diversity of degradation rate in here is similar to what we see in figure 5 for SAL devices.

## IX. DISCUSSIONS AND CONCLUSION

The 130 nm thick resist (SAL) used traditionally as top layer does not provide good protection against aging. Adding a 200 nm layer of $SiO_2$ on top of the SAL provides a somewhat better protection layer. Replacing the SAL by Si or $SiO_2$ increases the HEB lifetime dramatically. Our measured results show that Si-Si double layer or $SiO_2$-$SiO_2$-SiN triple layer

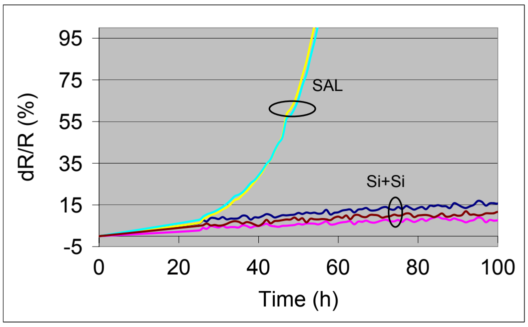

Fig. 7. Accelerated aging test at 65°C-85% RH

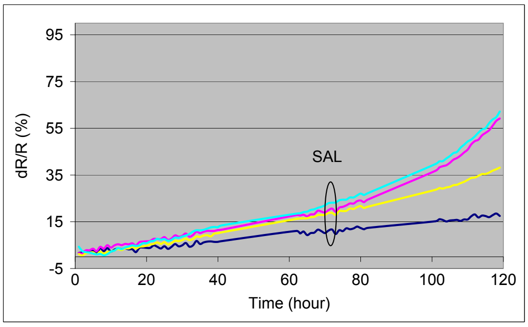

Fig. 8. Accelerated aging test at 50°C-85% RH

provides the best protection layer compared with the others mentioned above.

Baking test (90°C in vacuum) did not show any degradation of devices. This means that the main cause of degradation is the humidity and the process is accelerated at higher temperature.

There is a spread of data for the lifetime of similar devices. As it is shown in figures 9 not all devices with SAL protection behave exactly the same. It is also observed that 1 out of 9 tested devices with Si+Si protection and very similar characteristics surprisingly had a short lifetime (see figure 10). This means that although statistically there is a clear advantage in using multi-protection layers, we cannot assure that every single device of this type will have a long lifetime. Therefore, it is necessary to develop a method to select the flight mixers in a way to be sure about their lifetime.

Comparing the resistance of devices under 85°C-85% RH test with the similar devices degraded in usual lab condition, one can estimate that every hour of accelerated aging test corresponds to about 1 to 1.5 month of shelf time storage. Based on this result for devices with double or triple protection layers, it takes well above 2 years time until the degradation affects the mixer performance. This means that there is no problem with the aging of HEBs during the assembling time of the Herschel Space Observatory.

## ACKNOWLEDGMENT

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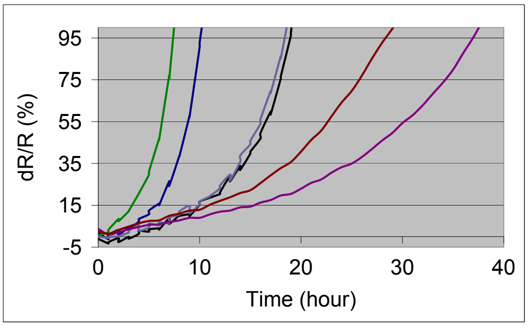

Fig. 9. Spread of data for accelerated aging test at 85°C-85% RH for devices with SAL protection

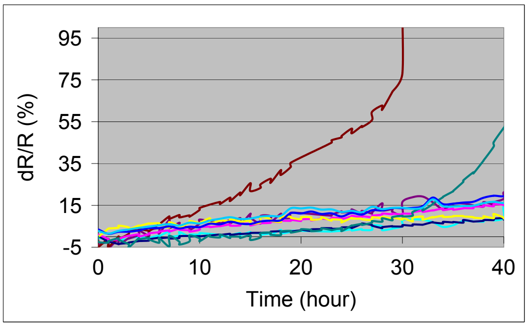

Fig. 10. Accelerated aging test at 85°C-85% RH for devices with Si+Si protection. 1 out of 9 had a short lifetime.

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