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On-Wafer Calibration of Vector Network Analyzer – Fabrication of LRM Calibration Standard

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ABSTRACT

Vector network analyzer or VNA has become ascendant of most measuring networks above 1 GHz. These networks consist of various manufacturing defects (due to resistance, capacitance and inductance) including VNA errors. To measure these errors, VNA was calibrated using a calibration kit. The usage of this calibration kit squanders a lot of time and money; moreover, the results are not accurate. To avoid this, the concept of on-wafer calibration is introduced, wherein calibration patterns are developed on a wafer and hence connected to specially designed RF probes to calibrate VNA.

***Keywords**: Calibration, on-wafer, vector network analyzer, photomask, autocad, fabrication*

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INTRODUCTION

The idea of *on-wafer calibration* **[**1**]** came into limelight in 1983 in view of the demerits of calibration techniques, which were practiced using a calibration kit. Calibration here means the process whereby the magnitude of the output of a measuring instrument is related to the magnitude of the input force driving the instrument. The on-wafer calibration is carried out on a vector network analyzer (VNA) [2], an instrument that can measure networks, which lie in the frequency range of 10 Hz to 4 GHz.

VNA error models are based upon the use of S-parameter **[**3**]** (scattering parameter) representations of network properties. The VNA measures uncorrected S-parameters of the device to be tested if not calibrated. The measuring devices comprise of microwave circuits, SAW (surface acoustic wave) devices and transmission lines.

The networks used usually have various manufacturing defects (due to resistance, capacitance and inductance) including VNA errors such as noise or dynamic range, cable repeatability, or instrument drift. To measure these errors, VNA is calibrated using a calibration kit. The ideal calibration kit comprises various calibration standards such as Line, Match, Load and Thru. These are basic calibration standards but actual calibration is done using LRM calibration technique, which is explained in detail in the subsequent sections.

For on-wafer calibration, calibration patterns are developed on a wafer and connected to specially designed RF probes for calibration. VNA on-wafer calibration is done before the packing and manufacturing of high-frequency devices, to store all possible errors inside the

VNA before actually measuring the high frequency devices.

MATERIALS AND METHODS

RF Probes

Probes [4**]** are used to connect calibration kit to VNA and have the following features:

Configuration

For tip placement there are three types – GSG, GS, or SG (where S is the signal tip and G is a ground tip). The tips can be either of BeCu (Beryllium Copper) or Tungsten.

Pitch

It is ground (G) to signal (S) tip spacing in microns from 50 to 1250 microns. For standard GSG probes, the two spacings are equal. For the on-wafer calibration kit, the design is for SG configuration probe and the pitch is 300 micron.

Calibration Types

- Orthogonal calibration
- Linear calibration

Calculations

The data in the calculations are provided by DRDO.

Line – There are two parallel strips with definite reactance.

Length = 800 µ

Breath = 100 µ

Reciprocal thru – length = 800 µm

Breadth = 800 µm

Pitch of the probes (center-to-center distance of the pads) is 300 µ.

Distances between the pads are 200 µ.

Calculation for Match

For designing match for 50 Ohm of resistance, we would need to calculate the width (*W*), length (*L*) and thickness (*T*) for different materials. In accordance with the constraints in the fabrication techniques, two of the three parameters were kept constant and the third was calculated. The basic formula for resistance is:

$$R = (\rho \times L) / A$$

Here, $A = W \times T$

This gives,

$$R = (\rho \times L) / (W \times T)$$

where,

R is the resistance between the two contacts

ρ is the resistivity of the material used

L is the length

W is the width

T is the thickness of the layer

The calculation for match is done for three different materials, i.e., gold, aluminum and chromium.

Aluminum

$\rho = 2.82 \times 10^{-8}\ \Omega - m$ [5]

$W = 2$ µ

$T = 0.3$ µ

L = ?

$$L = (W \times T \times R) / \rho$$

Here,

$R = 50\ \Omega$

$L = (2 \times 10^{-6} \times 0.3 \times 10^{-6} \times 50) / (2.82 \times 10^{-8})$

L = 1064 µ

□□*Chromium*

$\rho = 12.7 \times 10^{-8}\ \Omega - m$ [6]

W = ?

T = 0.03 µ

L = 200 µ

$\boldsymbol{W = (\rho \times L) / (T \times R)}$

Here,

R = 50 Ω

$W = (12.7 \times 10^{-8} \times 200 \times 10^{-6}) / (.03 \times 10^{-6} \times 50)$

W = 16.932 µs

Similarly, for gold pads deposited on chromium, following calculation is done (Table I):

□□*Gold*

Length = 200 µ

Thickness = 90 nm

Breath = 5.644 µ

Table I. Length, Width and Thickness of Three Different Materials.

S. No.	Choice of Material	Length (µm)	Width (µm)	Thickness (µm)
1.	Aluminum	1064	2	0.3
2.	Gold	200	5.644	90 nm
3.	Chromium	200	16.932	0.03

Choice of Material

The calibration patterns are made on a wafer. Depending on the conductivity and reactivity of the material, the most commonly used materials are aluminum, chromium and gold.

PHOTOMASK FABRICATION EQUIPMENTS

Following are the equipments used for fabrication of photomasks:

1. Laser pattern generator (DWL-200)
2. Developer wet station
3. Chrome etching wet station
4. Inspection microscope

FABRICATION

Mask Preparation of LRM Calibration Standard

The manually prepared designs of LRM calibration standards are translated on a chrome blank.

Photomask Fabrication Process

The design prepared in AUTOCAD [7] was saved in DWG format. The design is given in Figure 1, for both linear calibration and orthogonal calibration. The first set is for linear calibration and the second set is for orthogonal calibration. To represent orthogonal calibration, OT is used as an abbreviation. Here, L is for line, R is for reflect and M is for match. This drawing is saved as a DWG file.

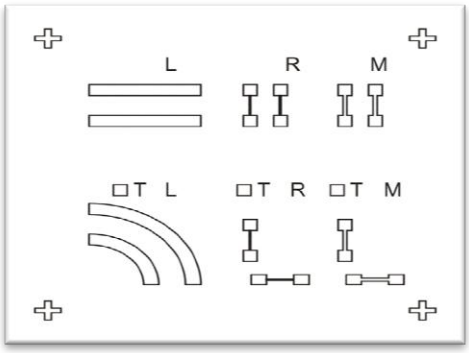

Fig. 1 CAD Layout of LRM Calibration Standard for Both Orthogonal and Linear Calibration

- The DWG format is converted into DXF format, which is then forwarded to OS9 controller that controls the laser pattern generator.
- Next step is to write the patterns on a blank mask.

Photoblank

It basically consists of three parts:

1. Photo mask substrate materials

   To prepare the LRM patterns**,** soda lime glass of dimension 3" × 3" was used. Soda lime glass is easy to work with as it etches quickly, bonds at relatively low temperatures, and is inexpensive; however, the etching quality is suspect and auto fluorescence of the glass can be problematic. Therefore, this type of glass is typically used in preliminary studies.

2. Photo resist

   The substrate was precoated with thick positive photo resist (AZ 1518) layer.

3. Chrome/Chrome oxide layer

   The substrate has an 80 nm thick layer of Chrome and a 20 nm thick layer of chrome oxide. Chrome oxide layer acts as an anti-reflection coating. It is coated on the photo resist. After preparing the photomask blank, the major work starts. The mask is to be written using a laser pattern generator. Before writing, another important step is to transfer the design patterns in the laser pattern generator controller which is OS9.

Prepararing the Mask

- Exposure – The patterns are exposed to a laser (413 nm) for about one hour. Three masks for three different materials, i.e., Al, Au and Cr were to be made that took around three hours.
- Developing – After exposing, the patterns were developed on the photoresist. Developing was done using a chemical namely MF319, which is alkaline in nature.

Following are the pictures (Figures 2 and 3) captured by an inspection microscope. The pictures show the photo mask after developing.

Linear Calibration

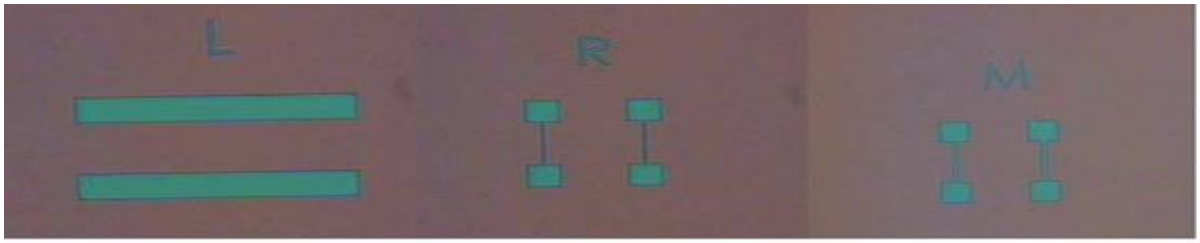

Fig. 2 Developing of the Photomask Using Linear Calibration**.**

Orthogonal Calibrat

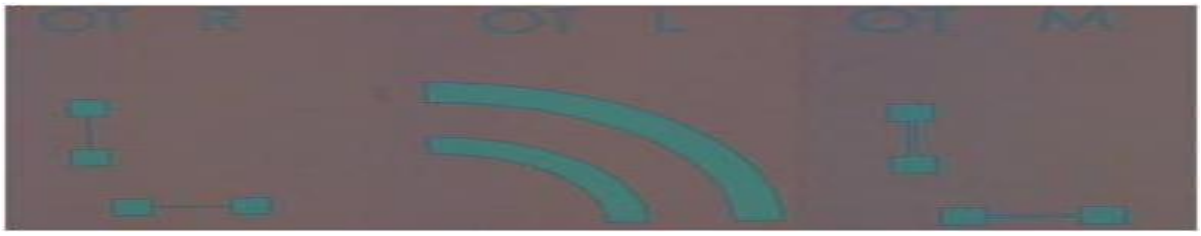

Fig. 3 Developing of the Photomask Using Orthogonal Calibration**.**

- Etching–etching was done to remove both the chrome and chromium oxide layers. The etching was carried out in an etching solution, chrome etch18 micro strip 2001, which is generally acidic in nature. For feature size up to 1 μm, wet etch process will be sufficient to meet the goals except for the masks, where the application requires a very sharp line definition such as SAW devices. The wet process is carried out in a chrome etching station.

The below given pictures (Figures 4 and 5) show the photomask after etching. The photographs were taken in transmission mode by an inspection microscope

Linear Calibration

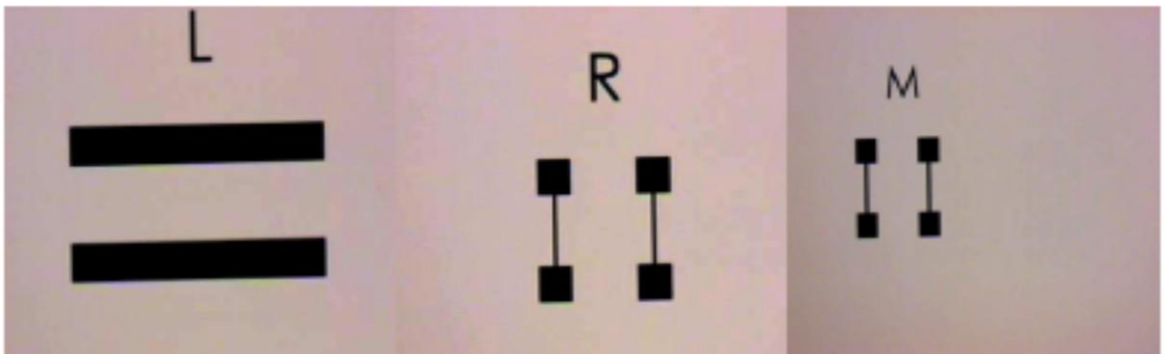

Fig. 4 Etching of the Photomask Using Linear Calibration

Orthogonal Calibration

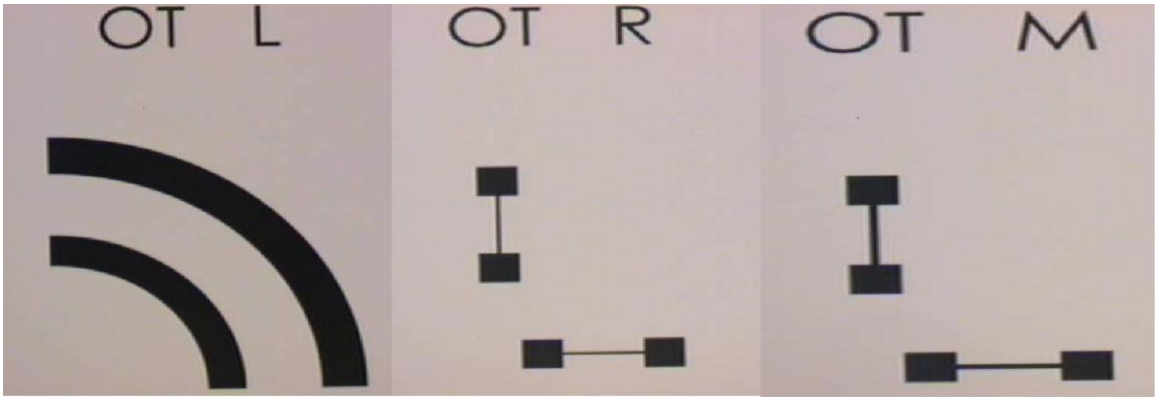

Fig. 5 Etching of the Photomask Using Orthogonal Calibration

- Stripping – It is the method of removing photo resist from the patterns after stripping; the plate is once again washed or cleaned using DI water and dries using nitrogen gas.
- Inspection – Ensure no unetched chrome or pinholes are present. This process is usually followed after developing, etching and stripping.

Process Parameters for Mask Fabrication

Various process parameters used for writing of patterns on mask plate and subsequent processing of the written masks were:

S. No.	Parameter Name	Optimized Value
1.	Exposure Energy	70–110 mW
2.	Development Time	60 s
3.	Cleaning Time	5 min
4.	Etching Time	60 s
5.	Cleaning Time	5 min
6.	Stripping Time	30 min
7.	Cleaning Time	5 min
8.	Final Cleaning	10 min

RESULTS AND DISCUSSION

After preparing the photo mask for LRM calibration standard, the patterns were to be transferred to the substrates. Keeping in mind the time constraints, chrome was chosen as the substrate for the pattern generation. Therefore, only one pattern of chrome was created using

the written mask. To achieve this, the anti-reflection coating (chromium oxide on top of the chromium layer) of the fabricated mask had to be removed for isolation of the created structures of the fabricated mask. The removal of chromium oxide layer was carried out in a reactive ion etching system, using the gas plasma. The process parameters of the recipe used for oxide removal were:

1. Oxygen (O_2) gas – 10 sccm
2. Carbon tetrachloride (CCl_4) gas – 4 sccm
3. Pressure − 0.08 Torr
4. Time − 60 s, +30 s (2 steps)

Further, these process parameters can be followed for aluminum and gold.

CONCLUSIONS

The LRM structures were successfully designed for aluminum, chromium and gold. The design for chromium was used to fabricate the final structures, the fabrication of gold and aluminum is done in a similar way. Complete design was transferred to a mask plate using a writing tool and various processes/process equipment. The structures of LRM were finally isolated on the same mask plate. The developed patterns at various stages of processing and final isolation of structures confirmed successful fabrication of the structures. These structures can be used for the calibration of vector network analyzer.

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