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Metal hydride microwave components - a new class of microwave components

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Summary

Racomna Research AB has invented a new class of microwave components, in which the metal-insulator transition in metal hydrides is exploited. The new class of components lies between the traditional active and passive ones; metal hydride components are switched or varied by a control voltage, but the voltage is not necessary for operation and when the voltage is switched off the component stays in the same state. The control voltage is typically a few volts.

Metal hydrides change their properties reversibly between a conducting metallic state and an insulating dielectric state with the exchange of hydrogen. The new class of components are made by planar layers of ion conducting materials, one of which being a metal hydride layer. Hydrogen ions can be driven into or out of the metal hydride layer by an external voltage. The metal hydride can, thus, be switched and the properties of the components changed. Metal hydrides can be used to form switchable or variable components, such as variable attenuators, stubs with variable length, variable or tuneable capacitors, variable inductances, variable couplers and filters, and switchable antennas.

By changing the pattern of the conducting layer of a microwave circuit, the entire circuit can change from one design to another. Entire new designs are possible. Circuits with multiple functions are possible. The first microwave application of switchable metal hydrides to be found in commercial products will probably be trimming of microwave integrated circuits. Trimming is still often made manually. Using metal hydride components trimming can be automated and made “on chip”. Compensating for temperature changes or ageing is another possible future application.

INTRODUCTION

Scientists at Racomna Research AB have recently shown that a metal hydride can act as microwave switch [1]. Thus, metal hydrides form the base of a new class of microwave components, which lies in between the traditional active and passive components. Passive components (resistors, capacitances, inductances etc.) have fix properties and no control voltage. Active components (diodes and transistors) need an external voltage for operation. Metal hydride components have properties that are switched or varied by a control voltage. However, the voltage is not necessary for operation and when the voltage is switched off the component remains in the state it had when the voltage was switched off.

Metal hydrides have been found to exhibit switchable optical properties when hydrogen is exchanged [2]. The first material that was found was yttrium hydride, which switches between metallic yttrium dihydride (YH_2) and dielectric yttrium trihydride (YH_3). The switching between the metallic and the dielectric states is reversible. Switchable optical properties have been demonstrated for several other materials, such as lanthanum hydride, gadolinium hydride, and magnesium-nickel hydride.

Optical devices have been made with switchable metal hydrides as the active material [3]. These devices have been switchable mirrors. When the metal hydride is in its metallic state the mirror is highly reflecting; when the metal hydride is in its dielectric state the mirror has low reflectance and appears dark. The structure of the devices is similar to that of other electrochromic devices. The devices consist of several layers of ion conduction materials. Hydrogen ions are driven into or out of the metal hydride by an applied positive or negative voltage.

In this report we discuss microwave devices based on switchable metal hydrides, which is a new class of microwave components or devices. This patent pending technology was invented by and is being developed by Racomna Research AB, which is a research company, jointly owned by Racomna AB and Uppsala universitets Utveckling AB (Uppsala University Holding Company).

MICROWAVE PROPERTIES OF METAL HYDRIDES

Scientists at Racomna have – for the first time – demonstrated switchable microwave properties of metal hydrides. A thin layer of yttrium hydride was used in the initial experiments. The yttrium hydride was part of a microstrip transmission line formed by gold on a quarts substrate. In Figure 1 the microwave switching properties at 5 GHz of the yttrium hydride layer are illustrated.

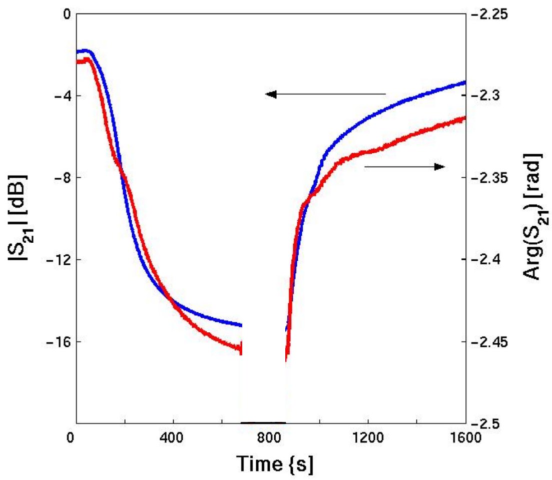

Figure 1. The first measurement of switching microwave properties of yttrium hydride. The magnitude and argument of the microwave transmittance, S_{21}, at 5 GHz is shown during hydration (0 – 700s) and dehydration (850 – 1600s).

The change from the metallic state (high transmittance) to insulating state (low transmittance) is reversible. The reversible switching can be exploited in microwave circuits. In Figure 2 the transmission of the sample is shown vs. frequency. Also shown in the figure is the microwave transmission for a microwave transmission line with gold instead of yttrium hydride and for one with the yttrium hydride replaced by air. These two curves are the ideal states of the microwave transmission line.

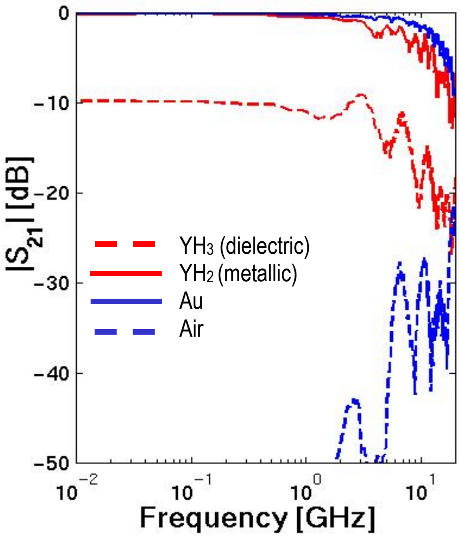

Figure 2. Frequency dependence of the yttrium hydride in its metallic and insulating states. Comparsion with data for "ideal samples" are also shown, i.e. for samples where the yttrium hydride was replaced with a good metal (gold) and a good isolator (air).

It is worth mentioning in connection to Figure 2 that mobile telecommunication systems operate at ~0.5 (NMT), ~0.9 (GSM), or ~2 GHz (GSM,3G), whereas W-LAN operate around ~2.4 and ~5.4 GHz. Most satellite communication systems operate at various frequencies between 4 and 30 GHz. Navigation radars operate at ~10 GHz. In GPS a frequency of 1.2 and 1.5 GHz is used. Metal hydrides can, thus, be used in most mof today's microwave applications.

APPLICATIONS AND DEVICES

The properties of a microwave circuit or component are often determined by the geometry of the conducting layer on an insulating substrate. This is the case in particular in microstrip technology. Areas of metal hydrides that can be switched between a conducting and an insulating state can be used to change the geometry of the conducting layer in a controlled way. In microwave integrated circuits various components can be obtained by the pattern of the metallic layer. Capacitors, conductance, couplers and filters are obtained in this matter. The switching properties of metal hydrides can be exploited in microwave circuits by changing the geometry of the conducting layer. The properties of the components that are formed by the different geometries can, thus, be varied. Metal hydrides can be used to form switchable or variable components, such as variable attenuators, stubs with variable length, variable or tuneable capacitors, variable inductances, variable couplers and filters, and switchable antennas.

Since metal hydrides can be used to change the geometry of the conducting layer of a microwave circuit the applications are numerous. Entire new designs are possible. By changing the pattern of the conducting layer of a microwave circuit, the entire circuit can change from one design to another. Circuits with multiple functions are possible.

An example of a variable component is shown in Figure 3. It is a "stub", which is a common part of microwave circuits and that are used e.g. for impedance matching. The length of the stub determines the impedance of the specific part of the circuit. If the length of the stub is changed, the impedance will change.

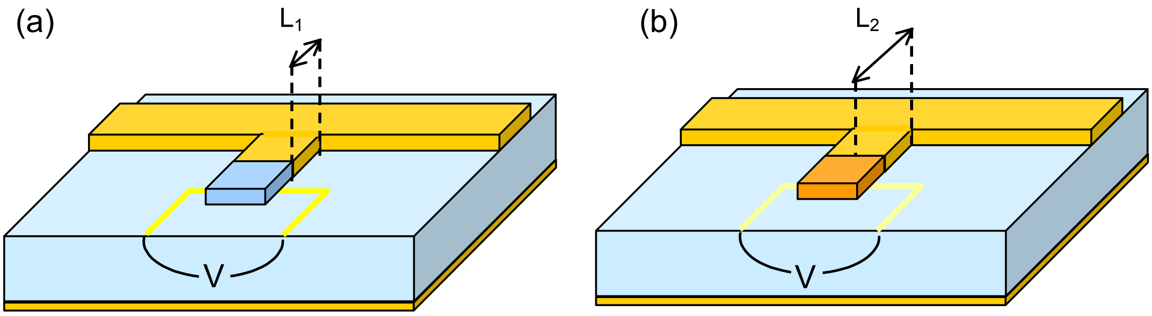

Figure 3. The length of a stub can be changed if metal hydrides are used. The dielectric substrate is blue and the microstrip transmission line is orange. At the end of the stub there is a voltage controlled switchable device, the active material of which is a metal hydride. The control voltage, V, is applied via thin conducting line (yellow in the figure). In (a) the metal hydride is in its dielectric state and the microwaves see a stub of length L_1. In (b) the metal hydride is in its metallic state and the microwaves see a stub of length L_2.

The first microwave application of switchable metal hydrides to be found in commercial products will probably be trimming of microwave integrated circuits. Trimming of microwave circuits is today typically made after fabrication. The purpose is to come as close to the desired properties of the circuit or device as possible. Trimming compensates for 1) variations in components induced by the process 2) errors or limitations in the design tools, and 3) variations in material properties (e.g. substrate thickness, dielectric constant, and conductivity). Trimming is made typically by screw adjustment or by adding or removing metal. Trimming is still to a large extent made manually. Manual trimming increases the yield but the cost for each circuit increases since the trimming can be time consuming and require both expensive equipment and skilled personnel.

Metal hydride microwave components offer the possibility to change the geometry of the metallic layer in microwave integrated circuits by an external voltage. The trimming can, thus, be automated and time and money can be saved. Furthermore, metal hydride microwave components can be integrated in MMIC, thus enabling trimming of these. Metal hydrides could be used to make circuits with built-in compensation for temperature drift and ageing. This feature could be exploited e.g. in space applications.

DISCUSSION

In order to realise microwave components based on metal hydrides, technology is borrowed from the already existing electrochromic components [3,4]. The microwave components contain – except for the active metal hydride layer – layers of materials that are ion conduction but electrically insulating. The processes that are use in the manufacturing are standard ones like sputter deposition, evaporation, electrodeposition and photolithography.

The technical advantages with the metal hydride microwave components that we presently can see are:

- New trimming techniques that easily can be automated are enabled. Trimming “on chip” is possible.
- Planar structures are made, which is an advantage since they are easily compatible with standard design tools and production processes.
- Most typical microwave components, that presently are passive, can be made switchable or tuneable.

- Most of the materials and deposition processes that are required for producing a device are relatively well known from the development and production of electrochromic optical components.
- The voltage required for controlling a device is low, typically ± 1 V or ± 3 V.
- Entire new designs are possible. By changing the pattern of the conducting layer of a microwave circuit, the entire circuit can change from one design to another. Circuits with multiple functions are possible.

Metal hydride components give the RF/microwave engineer a new tool. Metal hydrides will be used together with today's and tomorrow's active and passive components, and probably together with emerging technologies like RF-MEMS.

At Racomna we are presently working with the development of the first all solid state microwave device using switchable metal hydrides. Before this type of device or circuit can be commercially available further research and development is required. The design of various microwave devices and circuits with metal hydrides should be investigated in order to optimise the performance. Microwave properties of the various known switchable metal hydrides should be determined in order to facilitate the design of future devices and circuits. Other ion conducting materials used in the devices should be further characterised as well. The deposition processes should be further adapted to the requirements of the processes used in industrial production of microwave circuits.

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