L4: Laboratory of micromachined structures, microwave circuits and devices

The laboratory is one of the promoters of the RF – MEMS topics in Europe, The laboratory is participating in the FP6 network of excellence "AMICOM" (2004 -2007). The laboratory was recognized at national level as RF-MEMS Center of Excellence, financed by the National Programme MATNANTECH (2002-2005).

The laboratory has successful applied to a FP7 project in the REGPOT 1 /2007 call. The project "European Centre of Excellence in Microwave, Millimetre Wave and Optical Devices, based on Micro-Electro-Mechanical Systems for Advanced Communication Systems and Sensors" will start in 2008 and it will be coordinated by Dr A Müller.

• **Mission:** scientific research and technological development of micromachined microwave and millimetre wave devices and circuits, contributions to the developing strategy of the domain. The new RF MEMS technologies including the "membrane supported circuits" represents a solution to manufacture high performance microwave and millimeter wave devices and circuits devoted to the emerging communication systems.

• **Main area expertise:** ♦ Development of a new generation of circuits devoted to the millimeter wave communications based on the semiconductor (Si, GaAs, GaN) micromachining and nanoprocessing materials; ♦ Design and manufacturing of passive circuits elements, monolithically and hybrid integrated receiver front-ends based on silicon and GaAs micromachining;

♦ Acoustic devices (FBARs and SAWs) based on micromachining and nanoprocessing of wide band gap semiconductors (AlN, GaN); ♦ Micowave devices based on carbon nanotubes; ♦ Microwave devices using CRLH materials (metamaterials); ♦ MEMS and NEMS technologies developement.

• **International network:** Partner in the international network FP6 Network of Excellence "Advanced MEMS for RF and Millimeter Wave Communications" coor. LAAS-CNRS Toulouse/ Univ. Perugia (2004 – 2007)

• **International cooperations:** The laboratory has bilateral governmental cooperation with ITC-irst Trento, Univ Tor Vergata, Rome and CNR Rome.

• **National projects:** In the PN II programme, the laboratory has 4 new started projects (3 Partnership and 1 Capacities) as coordinator and one as partner, three CEEX projects (INFOSOC and RENAR) as coordinator, two CEEX projects as partners and four projects in the MINASIST+ programme. The laboratory had finished also 6 projects in the MATNANTECH Programme (PNI) one in the MINASIST programme.

• **Research team:** has multidisciplinary expertise in physics and electronics of microsystems and is composed of 7 senior researchers (5 of them with PhD in physics, electronics, microwave and chemistry), 1 early stage researcher (PhD in electronics), and 2 PhD students in physics.

• **Specific facilities:** Computers and software for microwave electromagnetic simulations (IE3D and Fidelity from ZELAND software packages); Vector network analyzer Hewlett Packard 0.1-18 GHz; Süss Microtech EP 4 prober; "On wafer" measurement system in the 0.1 -65 GHz range: microwave network analyzer Anristu in the range 0.04-65 GHz, and Karl SUSS Microtec Probe Station, obtained through a successful CEEX project (Module 4)

• **Awards:** **Finalist of the Descartes Prize 2002** of the EC for the coordination of the MEMSWAVE Project, **Romanian Academy Prize "Tudor Tanasescu"** for "Micromachined circuits for microwave and millimeter wave applications MEMSWAVE" (2001); second prize for the MATNANTECH project, SIRMEMS (CONRO 2003).

Team from left to right:
Alina Cismaru;
Alexandru Muller;
Gheorghe Sajin;
Mircea Dragoman;
Dan Neculoiu;
Cristina Buiculescu;
Ioana Petrini;
Dan Vasilache;

Laboratory Head — Dr. Alexandru Muller (alexandru.muller@imt.ro)

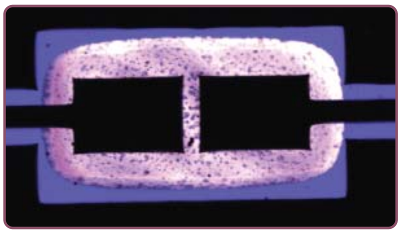
He obtained M.Sc.in physics (1972) and PhD in physics at Bucharest University in 1990;

Competences: Silicon, GaAs and GaN micromachining and nanomachining: manufacturing of RF MEMS components and circuits, technological process in GaAs MMICs, design, modeling and manufacuring of microwave passive membrane supported circuits (1997-European priority), micromachined inductors, filters and antennae, monolithically as well as hybrid integrated receiver front end modules.

Dr. Müller is the coordinator of the European project FP7 REGPOT (2008 – 2010) "European Centre of Excellence in Microwave, Millimetre Wave and Optical Devices, based on Micro-Electro-Mechanical Systems for Advanced Communication Systems and Sensors" - Project No 202897. He has coordinated the ***European Project FP 4 MEMSWAVE (1998-2001)***, and ***was the leader of the Romanian team in the FP6 NoE AMICOM and member of the Board of Directors of this project***. He is member of Micromechanics Europe Workshop and MEMSWAVE workshop steering committees. He is member of IEEE and EuMA. Dr Muller is member of PhD Jury in Politechnica Univ. Bucharest and Univ. Paul Sabatier/LAAS Toulouse. Co-editor of the Micro and Nanoengineering Series (Romanian Academy). He had invited papers at important European conferences. He has more than 150 contributions in books and international journals/conferences.

Dr. Müller is finalist of the Descartes Prize competition 2002 of the European Community with the MEMSWAVE Project, Romanian Academy Prize "Tudor Tanasescu"; second prize for the MATNANTECH project, SIRMEMS (CONRO 2003).

MEMBRANE SUPPORTED AlN FBAR STRUCTURES OBTAINED BY MICROMACHINING OF HIGH RESISTIVITY SILICON



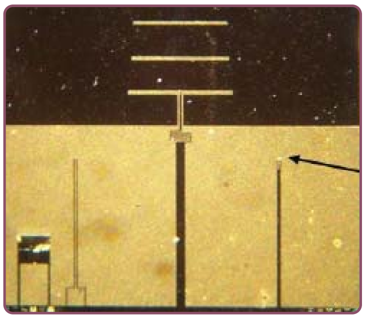
Top optical photo of the manufactured FBAR structure (w = 300μm, membrane dimensions: 1000x400μm).

AlN membrane supported F-BAR structures were manufactured and characterized. The 2μm thin AlN layer was grown using sputtering techniques, on a high resistivity (111) oriented silicon substrate. Conventional contact lithography, e-gun Ti/Au evaporation and lift-off techniques were used to define top-side metallization of the the FBAR structures. Bulk micromachinig techniques were used for the release of the AlN membrane. The bottom side metallization of the micromachined structure was obtained by means of sputtered gold. S-parameter measurements have shown a resonance around 1.6 GHz. Microwave measurements have proved the viability of these types of FBAR structures as the relevant material parameters like effective coupling coefficient are comparable to those obtained by other material deposition methods

Achievements: An AlN based resonator on high resistivity (111) silicon substrate for operation around 1.5 GHz has been fabricated using micromachining techniques and magnetron sputtering for AlN layer deposition. Resonator structures of this type can be used as building blocks for the fabrication of high Q and wide bandwidth filters, for use in reconfigurable front-ends of various mobile and wireless applications.

CEEX INFOSOC Project "Integrated RF-MEMS circuits based on silicon, gallium arsenide and wide band gap semiconductors for advanced communication systems – ACOMEMS" (2006-2008) Co-ordinator, IMT-Bucharest, Project Manager: Dr. A Müller (alexandru.muller@imt.ro)
Partners: National Institute for Material Physics, "Politehnica " Univ. Bucharest, "Valahia" Univ. Targoviste, "Ovidius" Univ. Constanta, Institute of the Macromolecular Chemistry "Petru Poni", Iasi.

GaAs MEMBRANE SUPPORTED MILLIMETER WAVE RECEIVER MODULE FOR 60 GHz



Optical photo of the 60 GHz receiver structure micromachined on GaAs

GaAs membrane supported millimeter wave receiver operating in the 60 GHz frequency range was fabricated and characterized. The receiver structure is based on the monolithic integration of a Yagi-Uda antenna with a Schottky diode, both having as support the same 2.2 μm thin semi-insulating GaAs membrane. The fabrication processes is based on GaAs micromachining. The experimental characterization of the Yagi-Uda antenna receiver was performed using a measuring set-up designed and realized in the laboratory.

Achievements: Design, modeling and manufacturing of 60 GHz GaAs micromachined receiver structures. The design procedure, the technological processing and characterization techniques open a window of opportunity for the development of innovative architectures for circuits and systems operating at higher frequency, up to the sub-millimetre wave frequency range

CEEX INFOSOC Project "Integrated RF-MEMS circuits based on silicon, gallium arsenide and wide band gap semiconductors for advanced communication systems – ACOMEMS" (2005-2008) Co-ordinator, IMT-Bucharest, Project Manager: Dr. A Müller (alexandru.muller@imt.ro)
Partners: National Institute for Material Physics, "Politehnica " Univ. Bucharest, "Valahia" Univ. Targoviste, "Ovidius" Univ. Constanta, Institute of the Macromolecular Chemistry "Petru Poni", Iasi.

STUDIES OF THE BIOLOGICAL EFFECTS OF ELECTROMAGNETIC FIELDS

Human beings are bioelectrical systems. Our hearts and brains are regulated by internal bioelectrical signals. Environmental exposures to artificial electro-magnetic fields (EMFs) can interact with fundamental biological processes in the human body. In some cases, this can cause discomfort and disease. Since World War II, the background level of EMF from electrical sources has risen exponentially, most recently by the soaring popularity of wireless technologies such as cell phones (two billion and counting in 2006), cordless phones, WI-FI and WI-MAX networks.

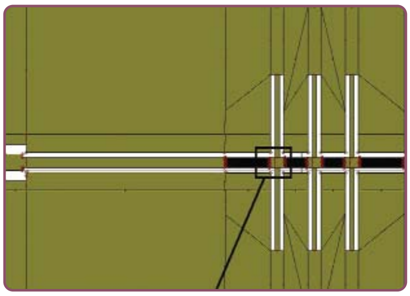
Several decades of international scientific research confirm that EMFs are biologically active in animals and in humans, which could have major public health consequences.

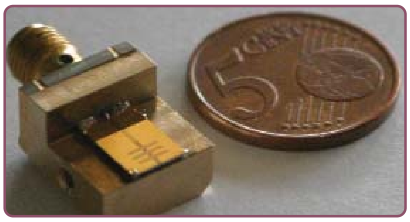
Achievements: Emphasizing biological effects following the specimen exposure in controlled media (in laboratory); Determining of specific absorption ratio (SAR) in biological media following irradiation in controlled condition with electromagnetic waves specific GSM system

CEEX CERES Project „Researches on bio-electro-magnetic interactions and biological effects of human exposure to radiofrequency and microwaves electromagnetic fields - BIO-EM-R"
Co-ordinator: Land Forces Academy „Nicolae Balcescu" Sibiu.
IMT Bucharest: partner in reserch team, **Project manager for IMT Bucharest: Dr. George Sajin**

METAMATERIAL MEDIA AND DEVICES IN MICROWAVE FREQUENCY DOMAIN

Due to their unusual but interesting characteristics which are not encountered in nature, the microwave circuits based on metamaterial (MM) properties became a very interesting topic in the actual research field. The present tendency in the European research in this domain is (a) to study new geometrical configurations with special propagation characteristics (b) to "invent" new devices and applications of these media and (c) to "populate" the frequency domain below infrared domain with new EMBG structures and devices, using, mainly, the newest technological approaches. One possibility to obtain transmission media having these characteristics is to develop circuits which under certain conditions may model the homogeneous MMs. For two dimensional circuits, artificial MMs have been proposed by using different lattice structures or periodic repetition of unit cells using circuit components.


CRLH antenna layout


CRLH antenna in a test fixture


Measuring test set for S11 scaterring parameter

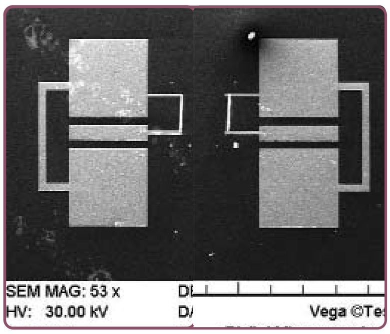
Another class of MMs is the artificial LH (Left-Hand) transmission line. This may be implemented by using chip capacitors and parallel connected inductors. On this way, devices such as branch coupler and antenna have been reported, the main advantage of this type of circuits comparing to the classical ones being the dual frequency response to any frequency ratio.

Achievments: Manufacturing of EMBG structures by microprocessing of metallic substrate (Designing and obtaining of the technological masks; Microprocessing of EMBG structures; Functional chracterization of EMBG structures) and designing of microwave devices on EMBG media (Establishment of microwave EMBG device structures; Assesement of the difficulties and establishment of methods to avoid it; Designing of chosen structures)

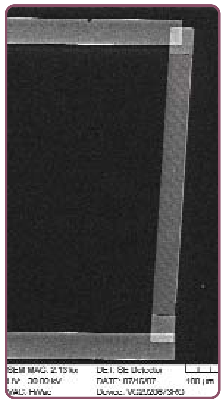
CEEX INFOSOC Project "Microwave structures and devices on microprocessed media with frequency selectivity"-ELMAG_SF (2005-2008), Co-ordinator, IMT-Bucharest. Project Manager: Dr. George Sajin-(gheorghe.sajin@imt.ro);
Partners: INCDIE ICPE CA Bucharest; „Politehnica" University Bucharest, INCD-FM Bucharest.

WIDE BAND GAP SEMICONDUCTOR SAW TYPE DEVICES FOR GHZ APPLICATIONS, MANUFACTURED USING NANO-LITHOGRAPHIC TECHNIQUES

Experiments to develop SAW structures with operating frequencies in the GHz range were performed on AlN and GaN thin films with nano-metric lines for an interdigitated transducer (IDT). After the nanolithography there were obtained some very good quality inerdigitated Ti/Au structures (with 30 digits and 29 interdigits 300nm wide, 220nm high and 200μm long). Lift-off techniques to remove the undesired metal were used. On wafer microwave measurements of the SAW structure have demonstrated its functionality. It was evidenced a pronounced resonance at about 2.8GHz. Future development of WBG semiconductors and nanolithography based techniques will permit the developing of a new generation of SAW devices, operating over 5 GHz, able to be to used in 4G mobile phones and in 5.2 GHz WLAN applications



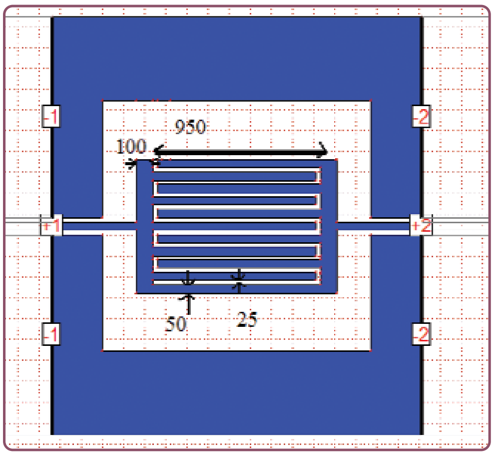
Two experimental SAW structures with the two IDTs placed "face to face"


An IDT with 30 TiAu fingers and 29 interdigits (finger width and interdigit width are about 300 nm)

Achievements: A SAW structure for an operating frequency of about 2.8 GHz was successfully developed on a thin AlN layer sputtered on high resistivity silicon. The structures were obtained with the support of the Nanoscale –Conv Project (Nr 6111/2005-CALIST)

CEEX INFOSOC Project "Integrated RF-MEMS circuits based on silicon, gallium arsenide and wide band gap semiconductors for advanced communication systems – ACOMEMS" (2005-2008) Co-ordinator, IMT-Bucharest, Project Manager: Dr. A Müller (alexandru.muller@imt.ro)
Partners: National Institute for Material Physics, "Politehnica " Univ. Bucharest, "Valahia" Univ. Targoviste, "Ovidius" Univ. Constanta, Institute of the Macromolecular Chemistry "Petru Poni", Iasi.

NEW RECONFIGURABLE MICROMACHINED FILTERS DEDICATED TO RECONFIGURABLE FRONTENDS FOR MOBILE COMMUNICATION SYSTEMS 3G AND „BEYOND" 3G" WHICH ENDURE THE DCS 1800MHz AND WLAN 5.2 GHz STANDARDS



Atipical stop band resonator

The project started at the end of 2007 with study regarding the atipical rezonators to be used in the design of the reconfigurable filters.The filters will be manufactured by MEMS technologies usig an original circuit architecture. Complex L-C structures configurated on bulk silicon and others suspended on dielectric membranes will be used. 1.5 μm thick $SiO_2/Si_3N_4/SiO_2$ membranes will be obtained by micromachining of <100> high resistivity silicon.

Achievments: Modeling and electromagnetic simmulations of atipical resonators.

PN II Partnership Project "Advanced circuits for microwave, millimeter wave and photonics based on MEMS technologies MIMFOMEMS" **(2007-2010)**
Co-ordinator, IMT-Bucharest.
Project Manager: Dr. A Müller (alexandru.muller@imt.ro)
Partners: National R&D Institute for Material Physics, "Politehnica" Univ. Bucharest, Institute of the Macromolecular Chemistry "Petru Poni" Iasi, SITEX 45 Bucharest.

COMPOSED RIGHT/LEFT HANDED (CRLH) MEDIA AND DEVICES FOR MILLIMETER WAVE FREQUENCY DOMAIN

The purpose of this project is elaborating some devices – directional couplers and miniatural antennae – on MTM to facilitate the filling with devices of the millimetric waves (mm-wave) domain. In this approach the unconventional characteristis of the MTM will be used in order to overpass some difficulties that regular materials cannot. This is also the reason why the frequency area between the microwaves domain and the far infrared is partially uncovered by applications. In order to obtain these devices we will use modern techniques offered by the microprocessing of the CLRH structures through laser ablation controlled at a hundredths/tenths nanometers levels.

Achievements: Studies and analyses concerning the geometries of devices structures on metamaterials for frequencies in the millimeter wave domain.
• Studies and analyses on the geometries of CLRH media in the millimeter wave domain
• Studies and analyses concerning the properties of the used materials
• Studies and analyses concerning the technologies of submicronic substrate processing in order to obtain CLRH media in the millimeter wave domain

PN II Partnership Project "Millimeter wave devices on metamaterials microprocessed by laser ablation METALASER" (2007-2010) Co-ordinator, IMT-Bucharest, Project Manager: Dr. Gh. Sajin (gheorghe.sajin@imt.ro)
Partners: National R&D Institute for Laser Physiscs, Plasma ans Radiation, Bucharest, "Politehnica" Univ. Bucharest, INCDIE ICPE CA Bucharest

ADVANCED FEMTOSECOND LASER SYSTEM FOR METAMATERIALS and PHOTONIC CRYSTALS NANOSTRUCTURING

By materials ablation with fast pulsed lasers (femtoseconds), the thermal effect round the ablated area is negligible. By laser beam focusing at diffraction limit, good quality and reproducible microprocessing with sub micron resolution can be obtained on metals, plastics, and dielectrics. Due to the very high laser pulse power density (GW-TW/cm^2), the nonlinear optical effects of multiphotonic absorption are dominating. So, laser radiation can be absorbed even in transparent materials for the fundamental wavelength (775 nm, in our case). Multiphotonic absorption took place in smaller volumes than laser focused spot size, only where the laser intensity overtakes the threshold of the nonlinear optical effect. Negative refractive materials, very intensive studied worldwide in the last years, open the possibility for new basic phenomena and for promising applications as well in electromagnetic waves communications, development of super lenses with sub-wavelength resolution and antireflective materials. Such new artificial materials can be made as metamaterials (MTM) structures or photonic crystals (CF). MTM are artificial periodic structures with cell dimension much smaller than the electromagnetic radiation wavelength. The incident wave "sees" MTM like a homogenous structure; the refraction prevails over diffraction and scattering phenomena. "Classical" techniques used to manufacture such structures are microelectronic processing (vacuum deposition of metallic or dielectric layers, photolithographic processing). The actual worldwide tendency of extending MTMs from GHz to THz and further to optical domain requires innovative technologies able to lead the processing resolution in the nano-metric domain.

Achievements: Drawing up the functional system of the advanced laser system for nanostructured materials.
• Studies and analyses of the photonic processing necessities for CRLH structures at very high frequencies
• Analyse of the rezults and drawing up the research report

PN II Partnership Project - FEMAT (2007-2010). Co-ordinator, National Institute for Laser Physics, Plasma and Radiation, Bucharest, IMT Bucharest: partner in reserch team, Project manager for IMT Bucharest: Dr. George Sajin

L4: Participation to European Projects

Results obtained by the Laboratory team in the FP6 Network of Excellence AMICOM

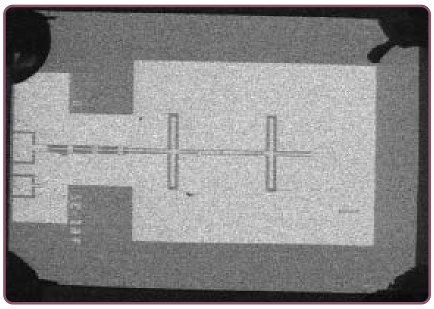
Results obtained by the Laboratory team in the FP6 Network of Excellence “Advanced MEMS for RF and Millimeter Wave Communications” (**AMICOM;** 2004-2007) – ***http:\\www.amicom.info***, coordinator LAAS-CNRS, Toulouse/ Univ Perugia.

IMT contact person for **AMICOM**: Dr. Alexandru Müller, member of Board of Directors (**alexandru.muller@imt.ro**)

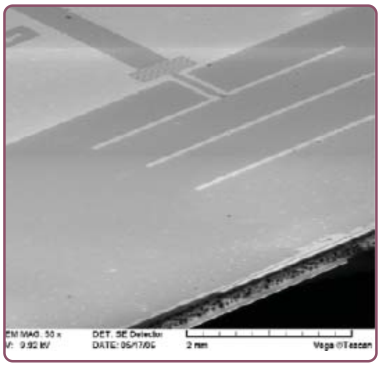
The research work in **AMICOM**, was performed via two “North Star” Projects: “MMID – Millimeter Wave Identification” and “ReRaFE – Reconfigurable Radio Front-End”. The technological research was developed together with partners from FORTH Heraklion, VTT Helsinki, TU Darmstadt, LAAS Toulouse, IMEC Leuven and ITC-irst Trento.

Achievements:

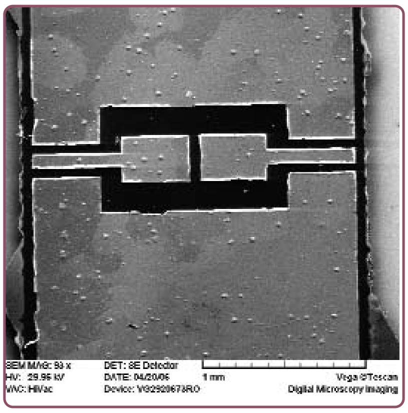
- Design, modelling and manufacturing of a membrane supported Yagi-Uda antenna for 45, 60 and 77 GHz,
- Monolithically integrated receiver front end with a membrane supported Yagi Uda antennae
- Design, modelling and manufacturing of advanced F-BAR test structures;
- Switches for 60 GHz on GaAs substrate;
- Lumped elements filter structure manufactured by bulk and surface of micromachining;
- Architecture for the 60 GHz membrane supported reconfigurable filter;
- Diplexer filters based on FBAR resonators;
- Design of tunable bandpass and bandstop reconfigurable filter for MMID applications;
- Millimeter wave identification (MMID) system, Demonstration of the MMID concept;
- 60 GHz Band-pass and band-stop tunable filters using surface and bulk micromachining.
- 60 GHz radiating elements (Yagi-Uda antenna).
- FBAR resonators.
- Tunable band-pass filters for 1-6 GHz frequency range.
- 60 GHz receiver for the MMID tag.



SEM photo of the 77 GHz micromachined receiver structure with folded slot antenna, to be used as tag **(IMT, VTT, ITC irst)** - European Microwave Week , EuMW-EuMC 2007, Munchen, Germany, 8 – 12 October 2007, pp. 1034-1037



SEM photo of the 60 GHz GaAs membrane supported receiver module **(IMT, FORTH, VTT)**- Proc of the MEMSWAVE Conference, Barcelona, Spain, June, 26-29, 2007, pp15-18



SEM pthoto of the series connection of 2 FBAR structures (IMT, FORTH, TUD) - International Microwave Symposium Digest, IEEE MTT-S 2007, pp.877-880

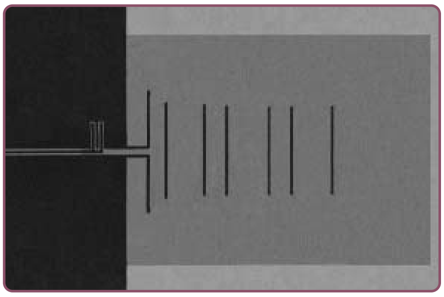


Photo of the 77GHz Yagi-Uda antenna structure

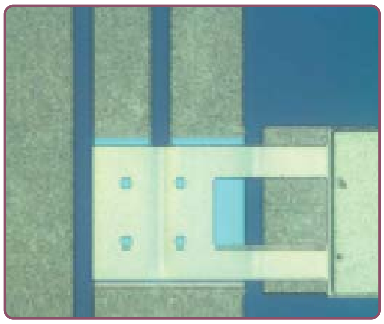
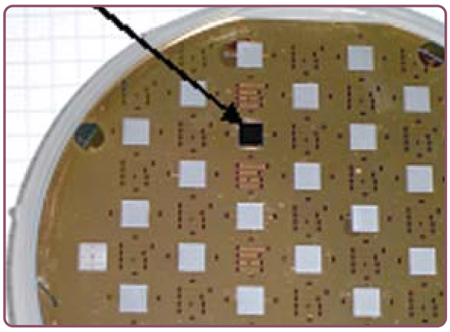


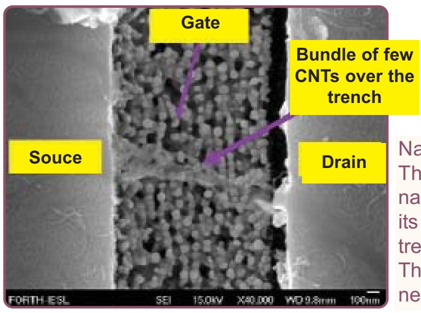
Photo with detail of the cantilever beam from the tunable band-stop filter (IMT, LAAS) - Electronics Letters Vol43 No12, June 2007, p. 676-677



CNT array mounted inside the trench and terminated with two CPW line.

The entire structure formed by millions of nanotubes behaves as a microwave resonator with a quality factor of 800 at 1.4 GHz.

M. Dragoman, D. Neculoiu, A. Cismaru, K. Grenier, S. Pacchini, L. Masenq, and R. Plana, “High quality nanoelectromechanical microwave resonator based on a carbon nanotube array”, Appl. Phys. Lett., vol. 92, pp. 063118/1-3, 2008.



Nano-oscillator technological implementation. The nanoscilator consists of a bundle of nanotubes suspended of a metallized trench at its bottom and two electrodes at each end of the trench micromachined into a GaAs substrate. The device has demonstrated amplification and negative differential resistance.