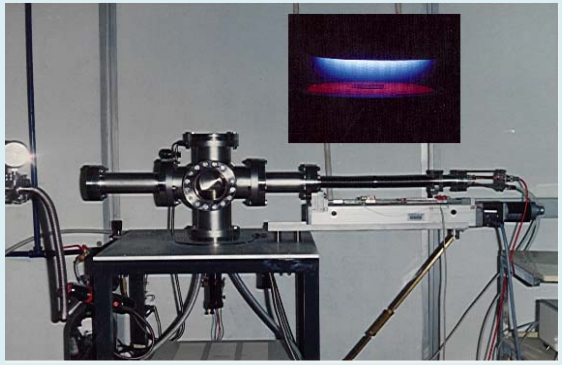
EXCELLENCE CENTER FOR NOVEL MATERIALS - CENM

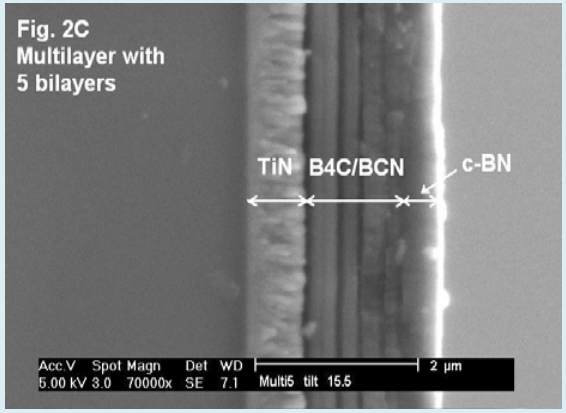
Enhancing academy-industry-state ties

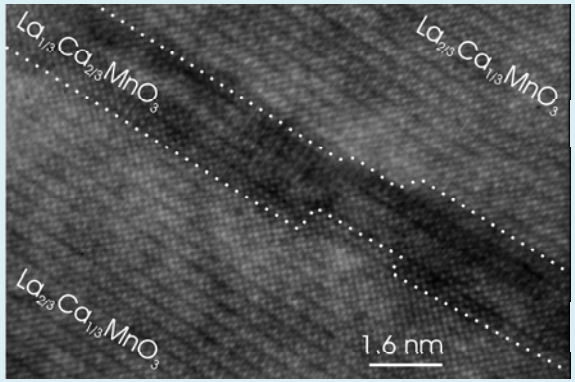


www.cenm.org

CENM

Director
Pedro Prieto





ECNM

Excellence Center for Novel Materials

Welcome

- About us
- Motivation
- Research Lines
- Members
- Application Sectors
- Scientific Groups
- Scientific Articles
- Bibliography Acquired
- Equipment Acquired
- Calls for Projects
- Legal Framework
- Forms
- Organizational Flowchart
- Directory
- Funding
- Technological Foresight and Surveillance
- Reports
- Events
- Services
- Contac us
- Graduates
- Attendance at Events
- News
- Home

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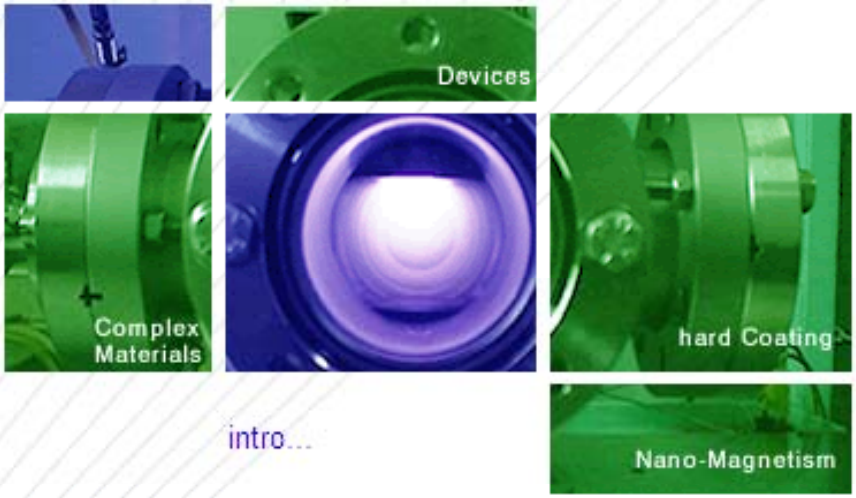
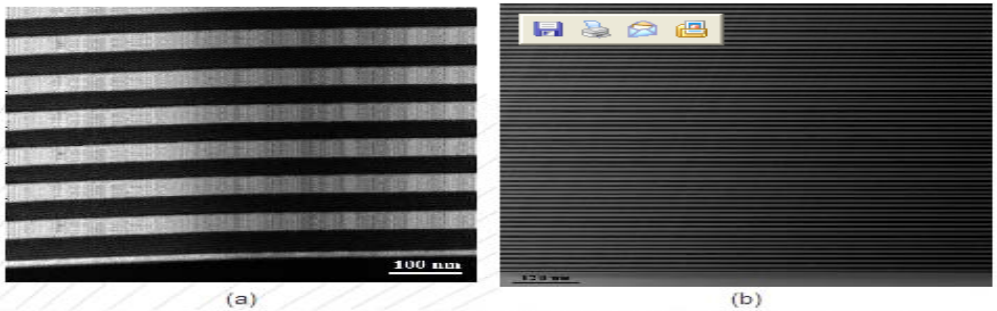
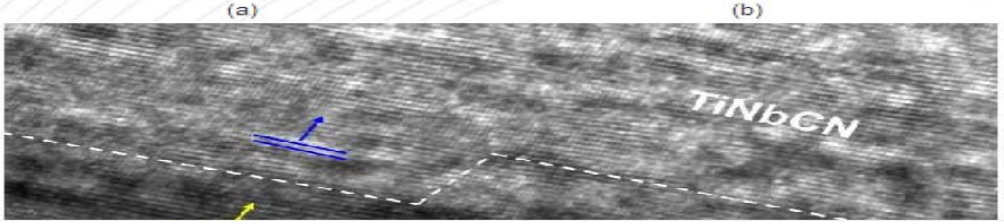


Resultados de la Investigación sobre
Multicapas de TiCN/TiNbCN
Julio Cesar Caicedo, investigador CENM





2009 APS April Meeting
FIP
Physics in Latin America

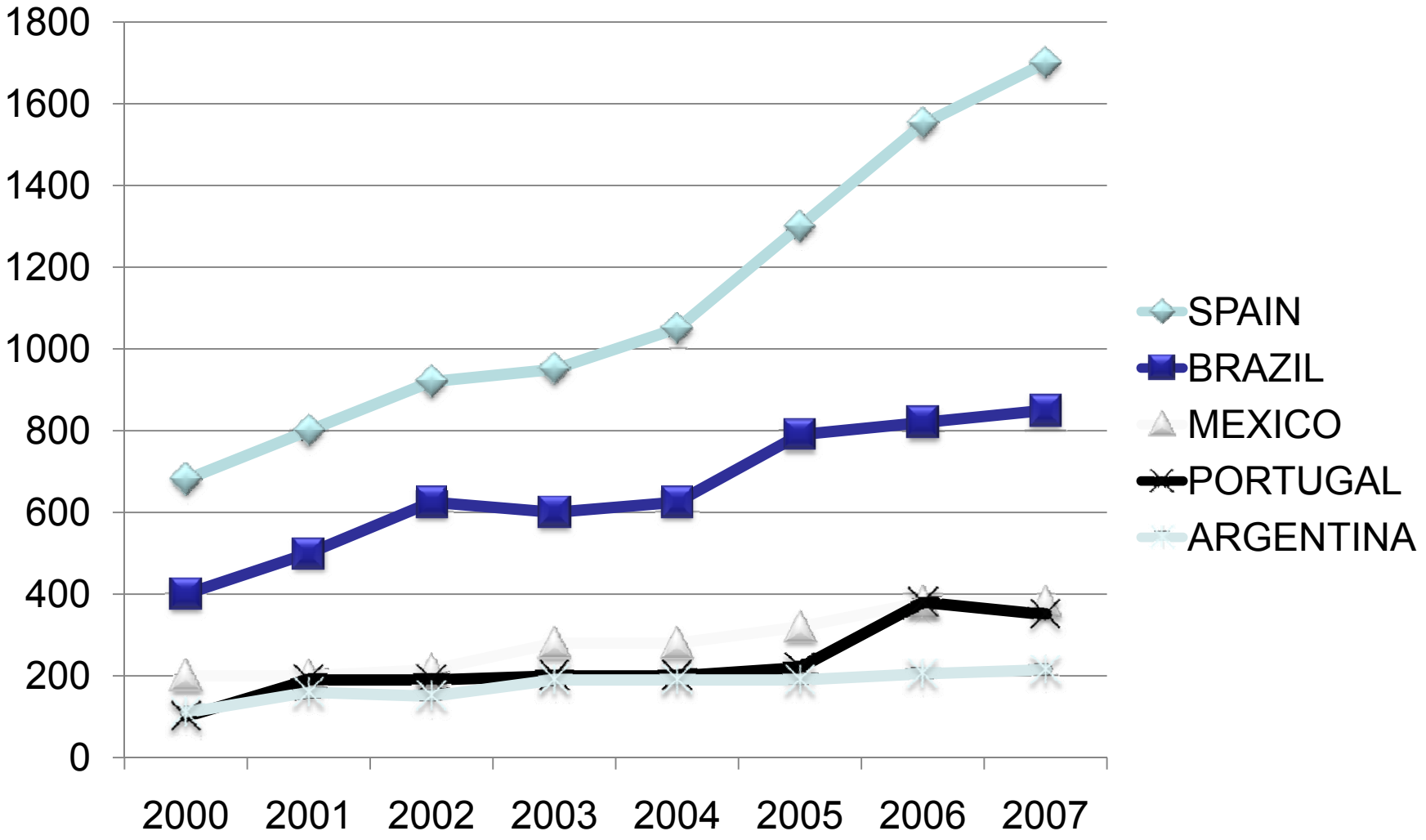
Physics in Andean countries: a perspective from condensed matter, novel materials, and nanotechnology

P. Prieto

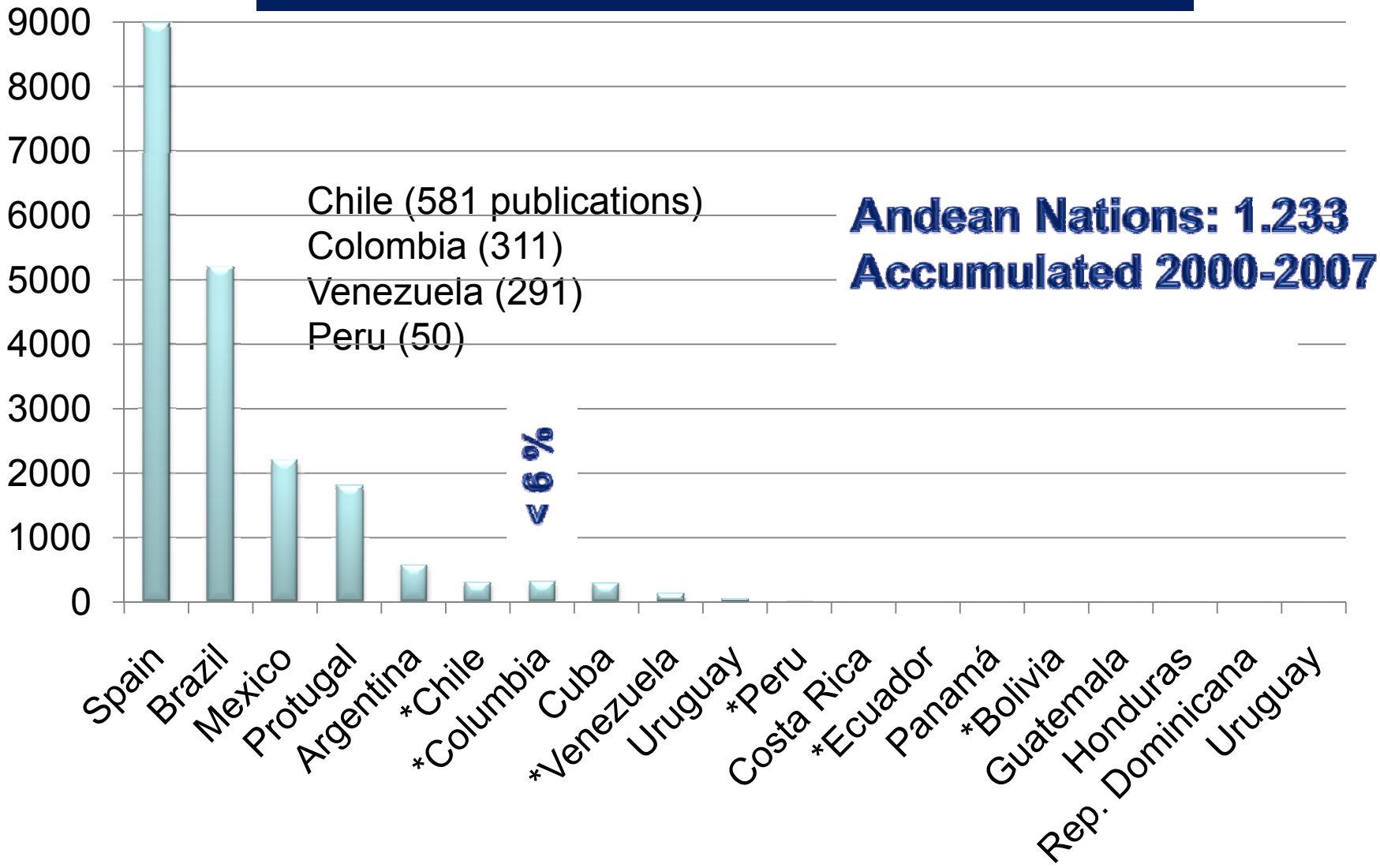
APS Fellow
Director of the Center of Excellence for Novel Materials – CENM
Universidad del Valle, Cali - Colombia

April Meeting Denver, Colorado May 2 2009

Publications in nanotechnology in the Iberian American countries



Publications in nanotechnology in Iberian American nations



* Andean Countries

Nanotech development in the region

Nanotechnology activity , measured by scientific publications, has almost doubled worldwide between 2000 & 2007

In Iberian America, Spain & Brazil pioneered and lead in scientific production & technological development in nanotech. The remaining Iberian nations show markedly lower production for the whole period.

From 2000 to 2007, Iberian America had about 20,000 documents in SCI. While the base total grew by 25%, during the same period articles on nanotech reached a 100% increase. This is 3.5% of the total # of Iberian American publications registered in SCI for the period.

Nanotech activity in Iberian America is growing, but it is still far behind worldwide figures.

Nanotech development in the region

The main Iberian American nations have implemented active policies, constituting ad-hoc institutions & instruments to support nanotech, such as: Red NANOSPAIN, the Brazilian Initiative on Nanotechnology, and the Argentine Nanotechnology Foundation (FAN)

The Iberian American institution with the highest participation in SCI is Spain's Superior Council on Scientific Research (CSIC). It participates with 11.8% of the Iberian American production in nanotech, and reveals a marked increase of over 100% between 2000 & 2007.

Leadership of Brazil and Spain has been a result of the implementation of state policies and political will to support nanotech R&D.

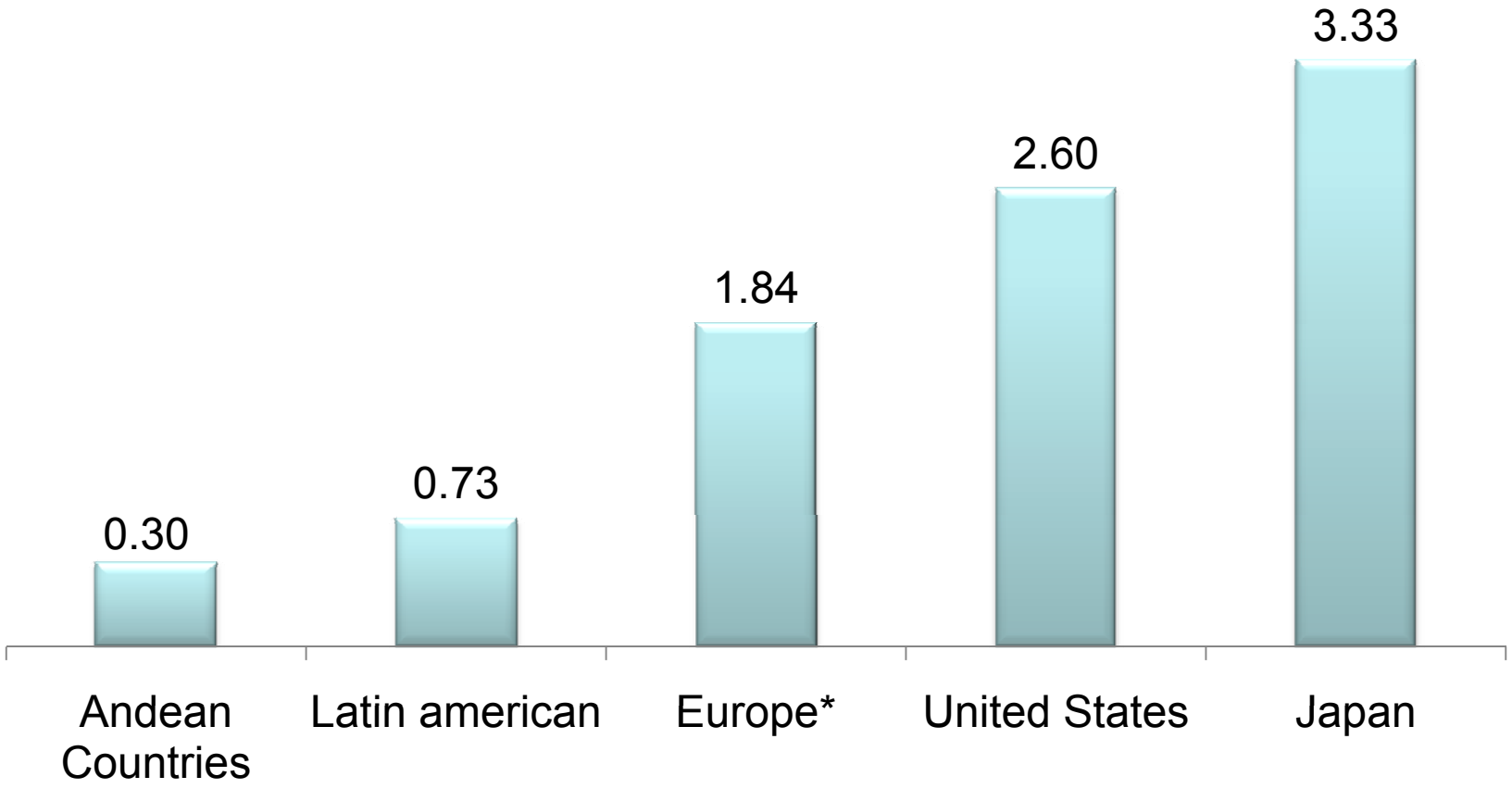
Nanotech development in the region

Given the relatively small scientific community and scant financial resources in each latin American countries , only decided regional collaboration can offer the critical mass needed to render nanotech R&D the necessary sustainability.

Iberian American collaboration is greatly important inasmuch as it has increased the scientific production of smaller nations by participating with more developed nations.

Close collaboration within and with leading nations in Nanotech development will bring marked growth in Latin America's participation.

Expenditure as % of GDP (2005)



* Includes the 27 member states

http://www.ricyt.org/interior/difusion/pubs/elc2008/InnovaEN.pdf

Current status of R&D in Andean nations

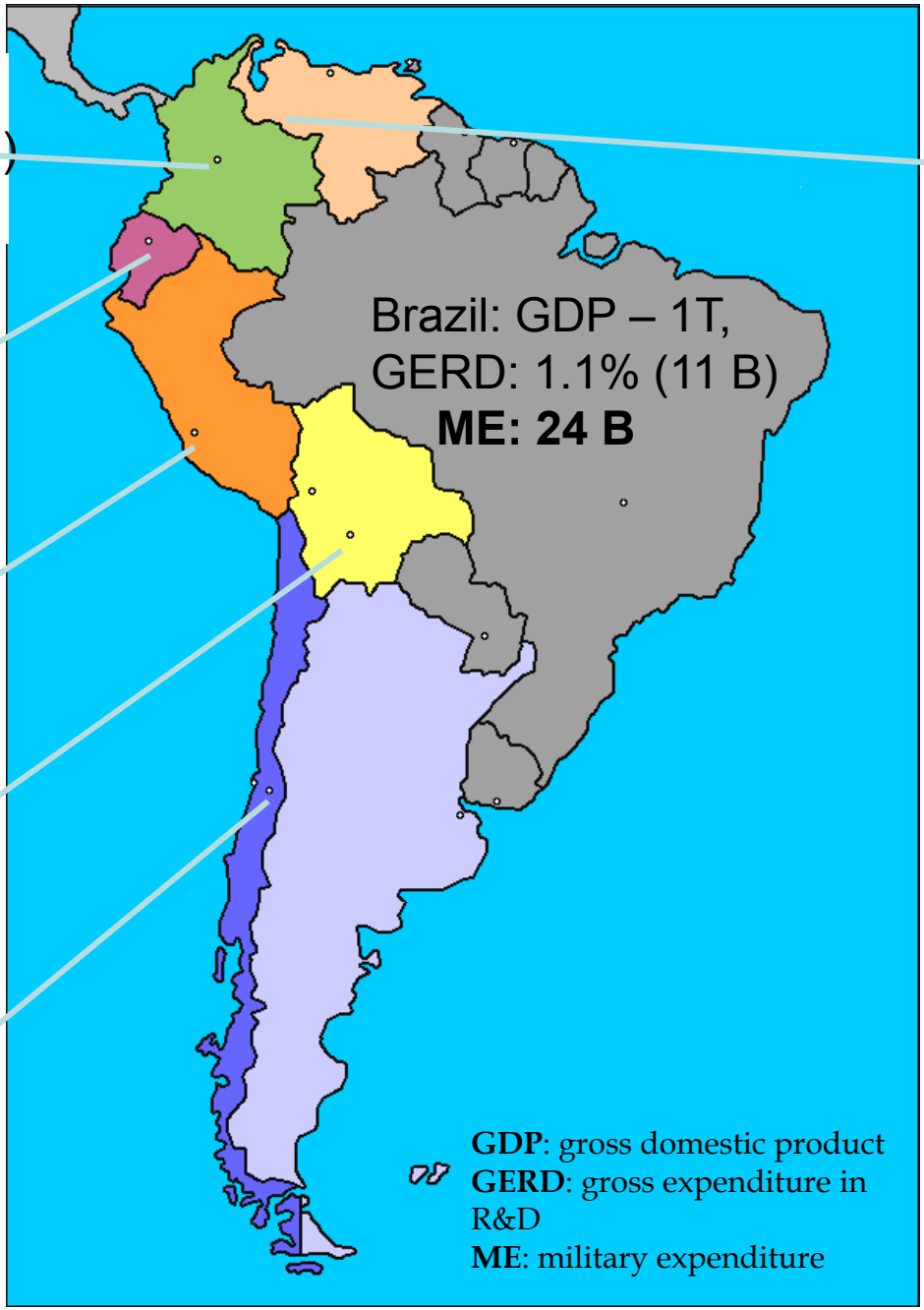
GDP: **130 B**
GERD: **0.2%** (260 M)
ME: 4.4 B

GDP: **41 B**
GERD: **0.2%**
(81M)
ME: 1.1 B

GDP: **89 B**
GERD: **0.1%**
(90M)
ME: 1.3 B

GDP: **10 B**
GERD:0.2%
(18M)
ME: 190 M

GDP: **141 B**
GERD: **0.6%**
(850 M)
ME: 3.8 B



GDP: **165 B**
GERD: **0.3%**
(500 M)
ME: 2 B

USA : GDP - 14T
GERD: 2.5% (350 B)
ME: 644 B

Total LA R&D expenditure is a small piece of a tiny pie

Total **LA ME: ~ 40 B**
Mega military expenditure without a clear enemy

RED DE INDICADORES DE CIENCA Y TECNOLOGIA IBEROAMERICANA E INTERAMERICANA ***RICYT***
http://www.ricyt.org
Adapted from: CIA World Fact Book 2009 & IMF, World Economic Outlook Database April 2006

Where is the support going?

Are Generals organizing fundraisers?

Nanotechnology in Andean Countries

Some Andean nations have instituted state policies appertaining to nanotechnology In many cases the intentions are good, but the results are poor. If not miserable!!

Nano in Ecuador

In 2005, the **National Secretariat of Science and Technology (SENACYT)**, through the office of the Vice President, published the document outlining the National Policy for Science, Technology, and Innovation 2005-2010.

Among the objectives of the policy, it seeks to fund basic sciences and natural sciences, including nanotechnology.

Results are yet to be noted!!!

Nano in Chile

CONICYT, created in 1967, advises the President on scientific issues. It grants scholarships for graduate studies and funds R&D projects. Chile has been a clear participant and is well aware of the importance of nanoscience R&D.

The **Center for Nanoscience in Valparaiso** seeks to strengthen activities in experimental research in fields related to the S&T of systems at the nano scale.

CENTRO DE NANOCIENCIAS DE VALPARAÍSO

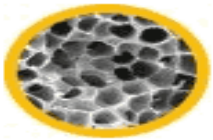
http://www.conicyt.cl/573/propertyvalue-1735.html
http://www.cenava.cl

Nano in Chile

CIMAT: Center for advanced interdisciplinary research in materials science was created in 1998, for a 10-year period, through a national effort for advanced research in priority areas

Bio-related Materials

Mechanics of Complex Materials



Catalytic & Polymeric Materials

http://www.conicyt.cl/573/propertyvalue-1735.html

Nano in Bolivia

Creation of the National System for Scientific Technological Development, **SINDECYT**, 1977 **Vice Ministry of Science and Technology**

In Bolivia, nano is truly nano

Nano in Perú

The Strategic National Plan for Science, Technology, and Innovation for Competitivity and Human Development (**PNCTI**) 2006-2021, includes the manipulation and design of nanomaterials as a thematic hub within the Materials Program (**PROMAT**). [Gutarra, 2007].

The Plan expects to increase public and private investment in nanomaterials.

Peru began with a good plan, on paper. Good plans need good cash flow and competent human resources, still lacking!

Nano in Venezuela

The government launched, in 1995, the National Plan in Science, Technology, and Innovation (PNCTI) for 2005-2030.

Venezuela wants to improve its long-term participation in ST&I. Studies are underway. Greater percentage of the GDP is promised for R&D.

Stay tuned. Aló, presidente!!!

www.mct.gob.ve

Nano in Colombia

In 2004, COLCIENCIAS selected 8 strategic areas to enhance productivity & competitivity in Colombian economy, one was "Advanced Materials & Nanotechnology".

Colombia still needs clear and long-term state policies to support Nanotech R&D. Some short-term work has proven successful, as is the case with the Excellence Center for Novel Materials

Latin American participation in innovation processes

- Mere passive receptors of scientific and technological transference of knowledge.

- Public & private investment do not support S&T Research, Innovation & Implementation in Nanotech

- Aggressive and long-term public and private investment must become state policy

In Brief

In spite of achievements, limitations persist. Studies have reviewed policy, strategy, & plans, arriving at conclusions dealing with:

- Limited impact
- Lack of real political will & decision
- Lack of funds
- Lack of culture for research and innovation
- Only good intentions

Velho, 2004; OEA, 2004; Albornoz, 2002; BID, 2001

As a summary

Many in the region are still not convinced that ST&I should be a national priority.

Many others are still not aware of what nanotechnology means or what applications it may have.

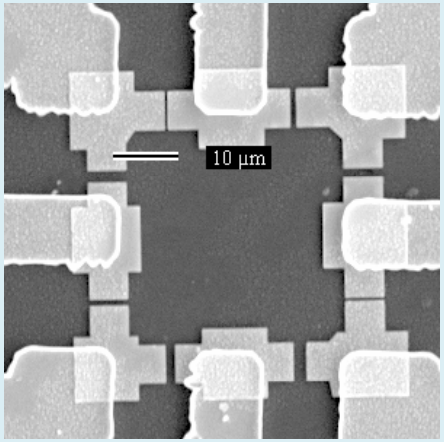
Some are reticent to accept ST&I as an instrument of change.

Most are sure that military spending is most important.

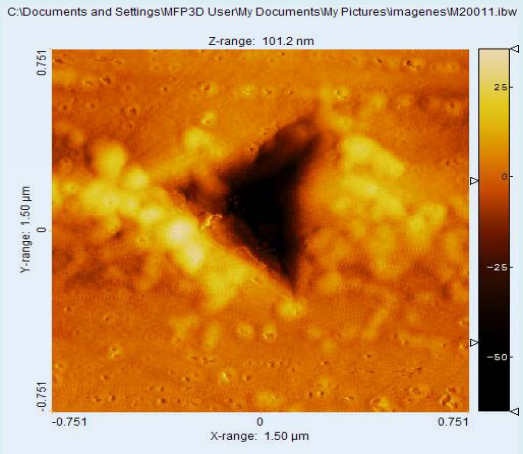
Until now, we have only had **nano policies with nano investments** for nanotech R&D; we must pave the way for **Mega-investments** and long-term commitments by state and private entities

About CENM

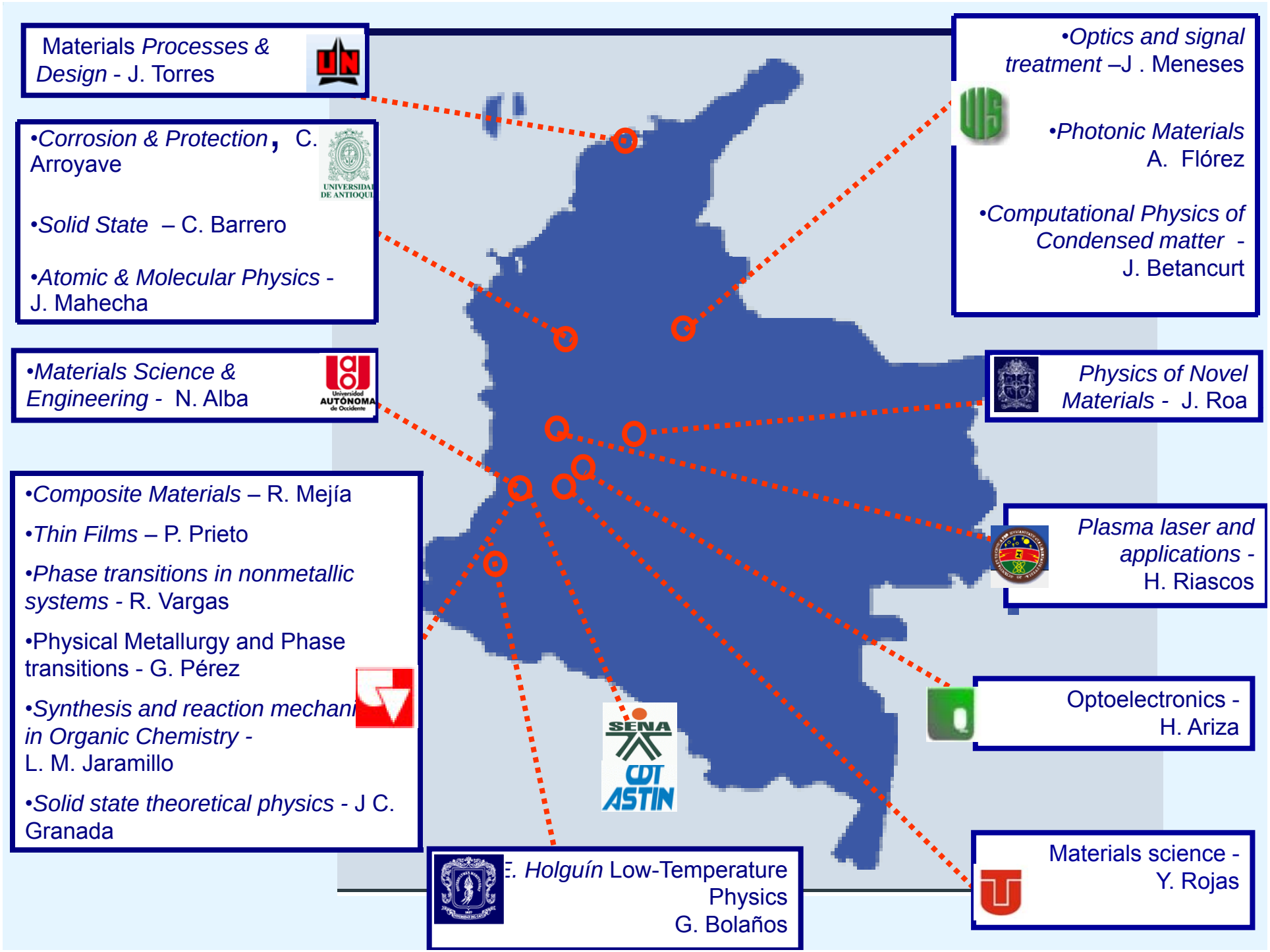
The Excellence Center for Novel Materials is part of a high-priority Colombian effort supported by 19 recognized multidisciplinary research groups from 10 universities across the nation. Additionally, the Center receives international support from world-renowned institutes on materials research.



VO_2 Pattern fabricated using e-beam and Photo lithography
CENM- UCSD



AFM image of Nanoindentation print - CENM


Materials *Processes & Design* - J. Torres
•*Corrosion & Protection*, C. Arroyave
•*Solid State* – C. Barrero
•*Atomic & Molecular Physics* - J. Mahecha
•*Materials Science & Engineering* - N. Alba
•*Composite Materials* – R. Mejía
•*Thin Films* – P. Prieto
•*Phase transitions in nonmetallic systems* - R. Vargas
•Physical Metallurgy and Phase transitions - G. Pérez
•*Synthesis and reaction mechani in Organic Chemistry* - L. M. Jaramillo
•*Solid state theoretical physics* - J C. Granada
•*Optics and signal treatment* –J . Meneses
•*Photonic Materials* A. Flórez
•*Computational Physics of Condensed matter* - J. Betancurt
Physics of Novel Materials - J. Roa
Plasma laser and applications - H. Riascos
Optoelectronics - H. Ariza
Materials science - Y. Rojas
E. Holguín Low-Temperature Physics G. Bolaños
SENA
CDT ASTIN

National and International Collaborations

General Objetives and Strategies

To aid in Colombia‘s technological & scientific development through the formation of specialized human resource working with novel materials technologies

- Greater R&D investment
- Acquisition of robust equipment
- Formation of young talents
- Support a knowledge-based economy for growth

CENM Immediate Strategies

- Establish technology transference policies from the universities to the industrial sector
- Build infrastructure to share knowledge; facilitate awareness in nanotech research and support commercialization of nano-products in the short term
- Establish close ties with industry for joint research projects
- Seek State policies to identify key interest areas for the benefit of society, industry, and academia
- Seek public and private funding to support research and increase potential coverage

Sustainability Strategies

Strategic alliances with industry

Seek benefactors

Project formulation & presentation to international entities

Strategic alliances with universities

Social responsibility efforts with NGOs and government

Strategic alliances with R&D centers

Formation of new talents

Sell services & consultancy

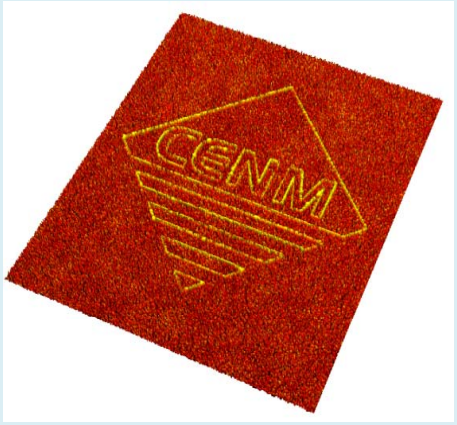
Creation of CENM foundation

National & international positioning

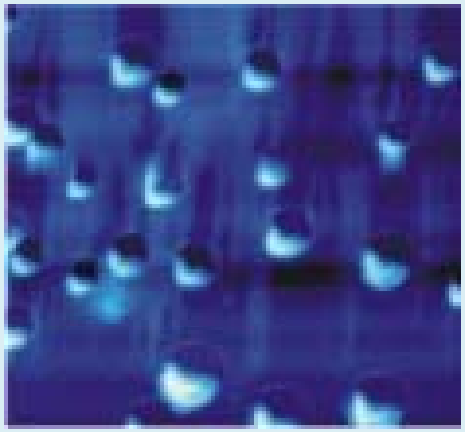
Areas of Research

Research work at CENM is organized around 4 Interdisciplinary Research Themes (IRTs):

- Composite Materials
- Advanced Coatings
- Nano-magnetism
- Solid-State Devices, Sensors, and Mesoscopic Systems



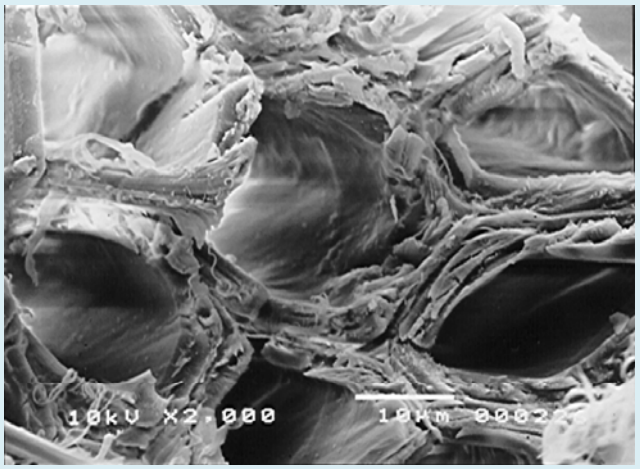
AFM image of nanolithography over a polymer surface - CENM



MFM image of magnetic nanoparticles $CoZnFe_2O_4$ - CENM

Nanocomposite Materials: Goals

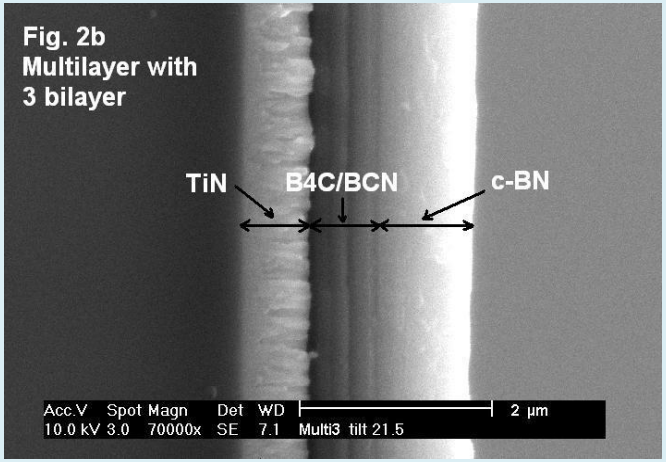
- Development of new materials for construction applications appertaining to the development of civil engineering infrastructure in Colombia
- Active nano-powders for cementitious-based materials from industrial waste and industrial by-products to produce cementing materials with high-mechanical performance and durability, contributing to environmental sustainability



Nano-powder in Cement Materials
CENM

COATING MATERIALS: Goals:

- Development of novel materials with improved resistance to corrosion and wear, with high-temperature hardness conditions:
  - ✓ Composite coatings (SiC and diamond nanoparticles in Ni and Ni-Cr matrixes and nano-sized iron oxide particles in Ni-P)
  - ✓ Multilayered coatings (W/WC and TiN/ZrN TiCN/TiCNbN Multilayers)



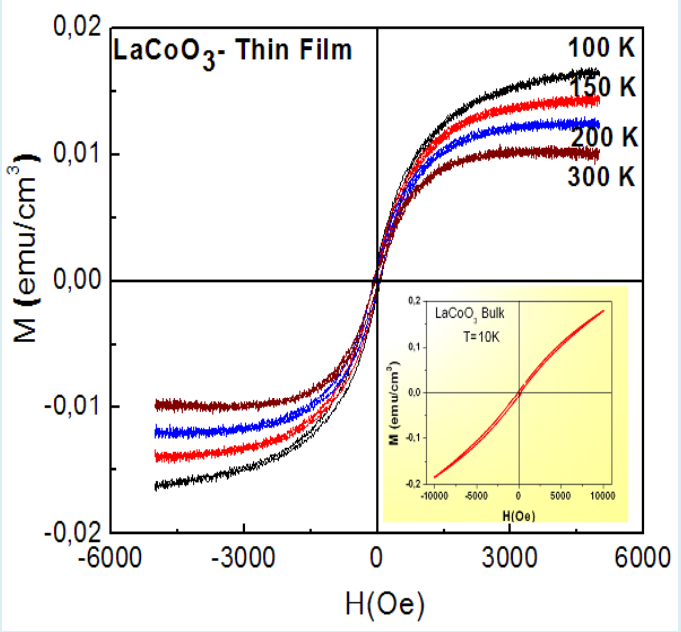
EM micrograph of a TiN/B_4C/BCN/c-BN multilayered hard coating - CENM

Nanomagnetism: Goals

- Gain basic understanding of nanoscale magnetic properties and knowledge on improving magnetic properties for broader applications in industry

- **Areas of study:**

  - ✓ Fe- and Mn-based Magnetic systems
  - ✓ Oxide-based magnetic thin films and hetero-structures
  - ✓ Theoretical and numerical simulation of magnetic behavior
  - ✓ Nanocomposite and nano-structured magnetic alloys for hard and soft magnetic materials

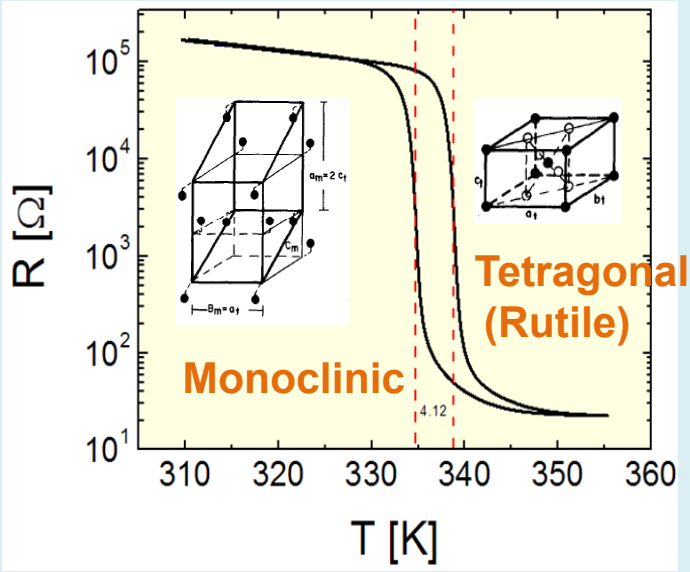


Magnetization curve of $LaCoO_3$. CENM

Solid-State Devices, Sensors, Mesoscopic Systems: Goals

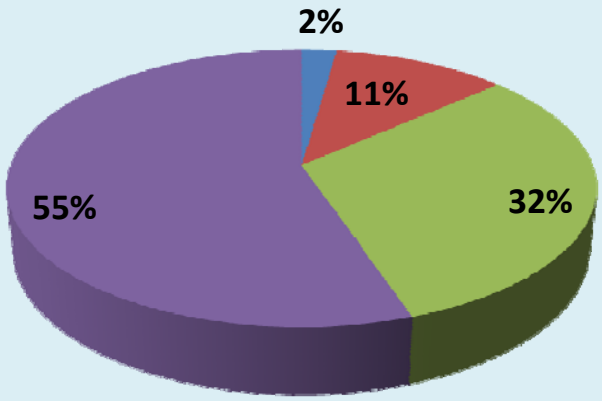
- Performance of new materials, focusing on quaternary semiconductors, ionic crystals; Mn, Sn, and Mo-based oxides
- Characterization of optical, electrical, and magnetic properties fundamental for the design of devices
- Study the effects of dimensionality reduction and the presence of confinements on properties of materials

- Development of theoretical models and simulations
- Study focuses mainly on optical, electric and magnetic properties of GaInAsSb quaternary systems, ionic materials, Photonic materials, VO_2 thin films.



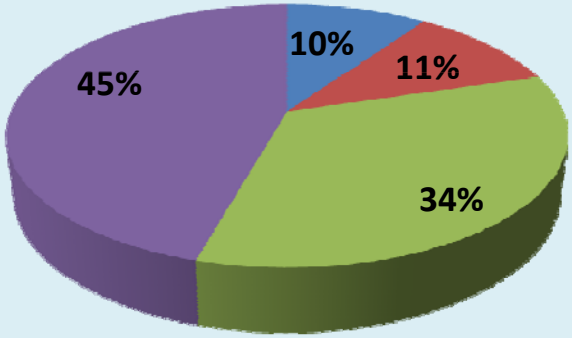
Ramirez, et al. PRL 101 (2008)

Scientific production per research area



Composite materials
Hard Coatings
Nanomagnetism
Solid-state Devices

International Papers 183



Composite materials
Hard Coatings
Nanomagnetism
Solid-state Devices

National Papers 133

CENM IN FIGURES

Participation in Scientific Events	
National	48
International	83
National, International Mobility	95
Publications in International Scientific Journals	164
Publications in National Scientific Journals	104
Participation in National Conferences	186
Participation in International Conferences	268
Agreements with Companies	6
Agreements with State Entities	2
Agreements with Educational Entities	3
Agreements with International Educational Entities	2

Students supported by CENM

PhD students	4
Masters students	4
PhD students graduated with CENM support	14
Masters students graduated with CENM support	16
Graduate students participating in projects	46
Young Researchers	6

Events held by CENM

Held in Santa Marta – Colombia, October 16 to 20, 2006.

Held in Cartagena de Indias – Colombia, October 13 to 17, 2008.

Held in Cali – Colombia, November 12 to 14, 2008.

EVENTS HELD BY CENM

Held in Cali – Colombia, August 8 to 10, 2007

Held in Cali – Colombia, April 8 to 10, 2008

Held in Cali – Colombia, February 25 to 27, 2010

EVENTS HELD BY CENM

Held in Bogotá – Colombia,

Held in Bogotá – Colombia, on April 22 and 23, 2009

Event will be held in Barranquilla – Colombia on October 21 – 23, 2010

Robust Equipment acquired by CENM

Physical Property Measurement System – PPMS Quantum Design™

Robust Equipment acquired by CENM

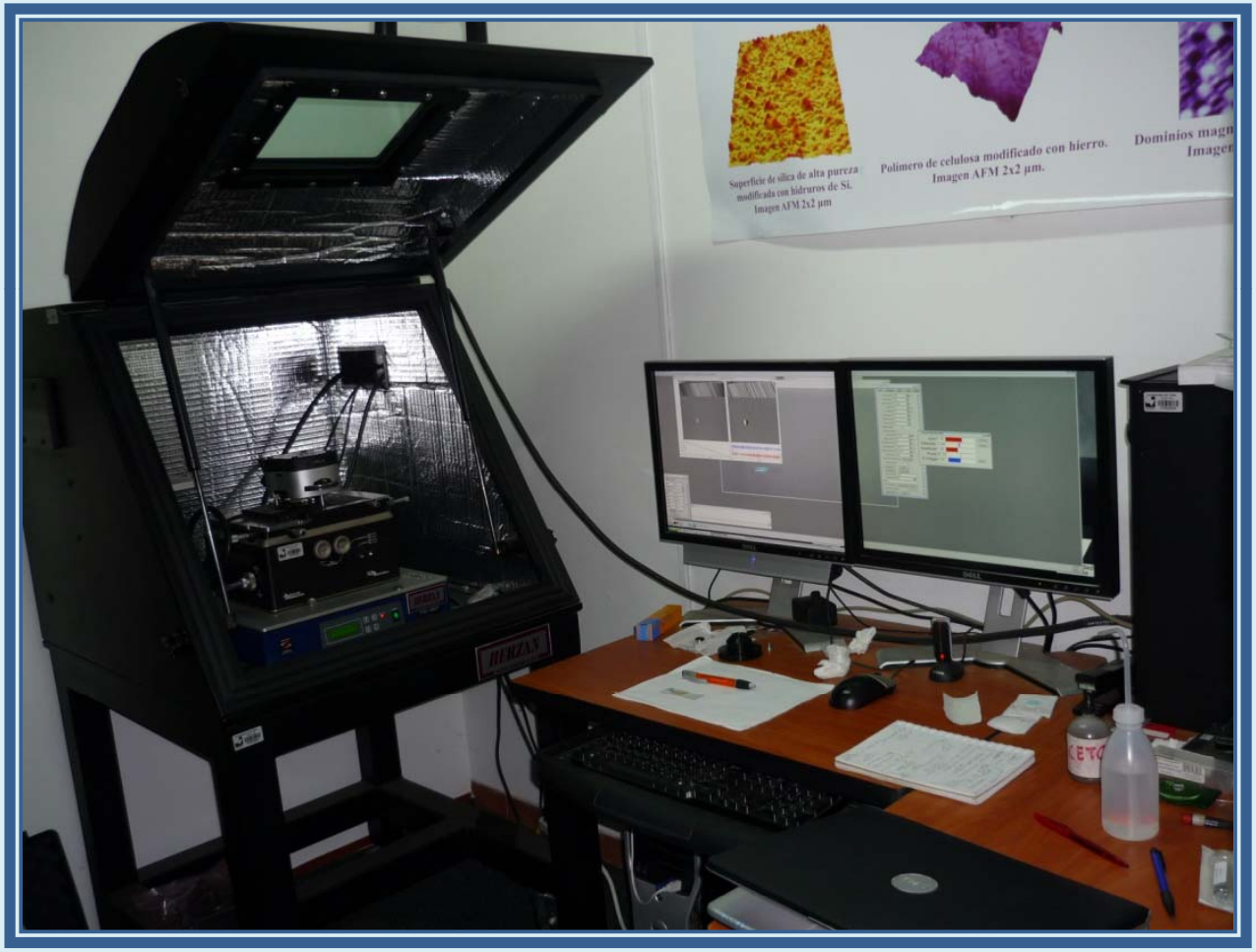
Mastersizer Laser Granulometer

Attrition Mill

Robust Equipment acquired by CENM

Universal Hystron Press

Robust Equipment acquired by CENM



Atomic Force Microscopy- AFM ASYLUM RESEARCH

Robust Equipment acquired by CENM

MICRO-RAMAN Jobin Yvon, Model Labram HR

Robust Equipment acquired by CENM

Desktop Scanning Electron Microscope – PHENOM - FEI

Robust Equipment acquired by CENM

SPECTROPHOTOMETER Jasco. Modelo V 7200

Robust Equipment acquired by CENM

DILATOMETER

Cooperation Agreements

2006 - 2009

Prodenvases Crown S. A.
Hacemos su producto más atractivo

2006 - 2008

FUNDICIONES UNIVERSO
INGENIERÍA & MANUFACTURA

2006 - 2008

cujae

Instituto Superior Politécnico
José Antonio Echeverría

2007 - 2010

Centro de Investigaciones en Tecnología Aeronáutica

2007

NRG

Nino Research Group
2007

2007 - 2010

Arrocera la Esmeralda

Cooperation Agreements

2009 - 2010

GENERAL METALICA S.A.

2008

Resortes HERCULES

2006 - 2008

CARTONES AMERICA S.A.

CAJAS DE CARTON CORRUGADO

2008 - 2010

Universidad de San Buenaventura

2007 -2010

Universidad del Tolima

2006 - 2008

IMPADOC S.A.

CARBONATOS DE CALCIO PARA LA INDUSTRIA

YESOSO Y ESTUCOS PARA LA CONSTRUCCION

CDT ASTIN

Centro Nacional de Asistencia Técnica a la Industria

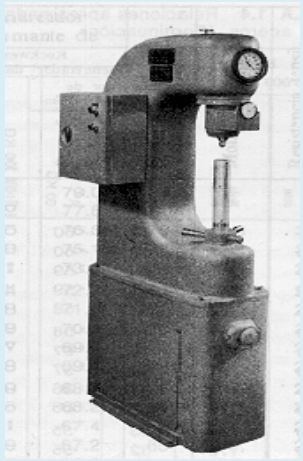
UNIVERSIDAD DE ANTIOQUIA

1803

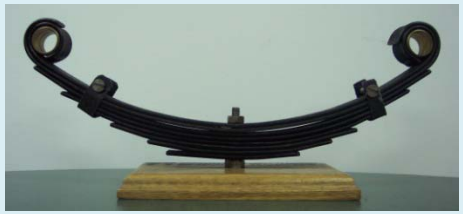
2007

Project carried out with Resortes Hércules

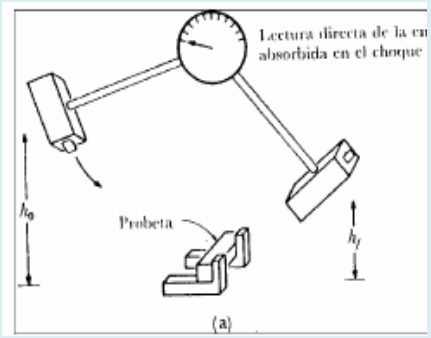
Determination of optimal parameters of the tempering process of SAE6150 steel as an alternative for the manufacture of leaf springs.



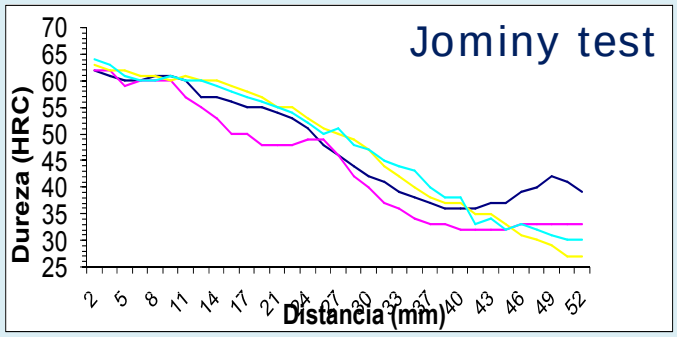
Hardness

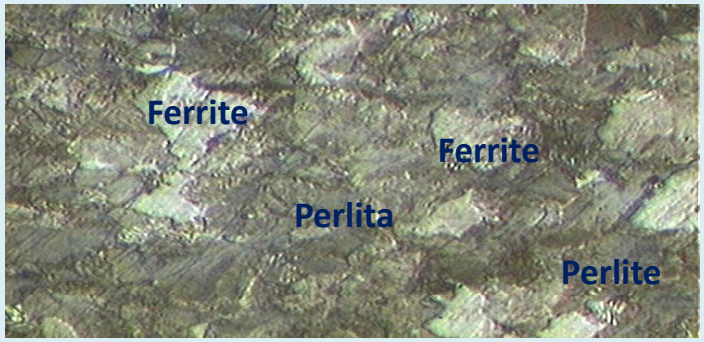


Leaf spring quality was clearly improved with SAE 6150 steel in calibers greater than 20 mm.



Charpy test





A process was begun between the university and the enterprise to support research projects

Project carried out among CDT ASTIN – CENM – AGRAF S.A.

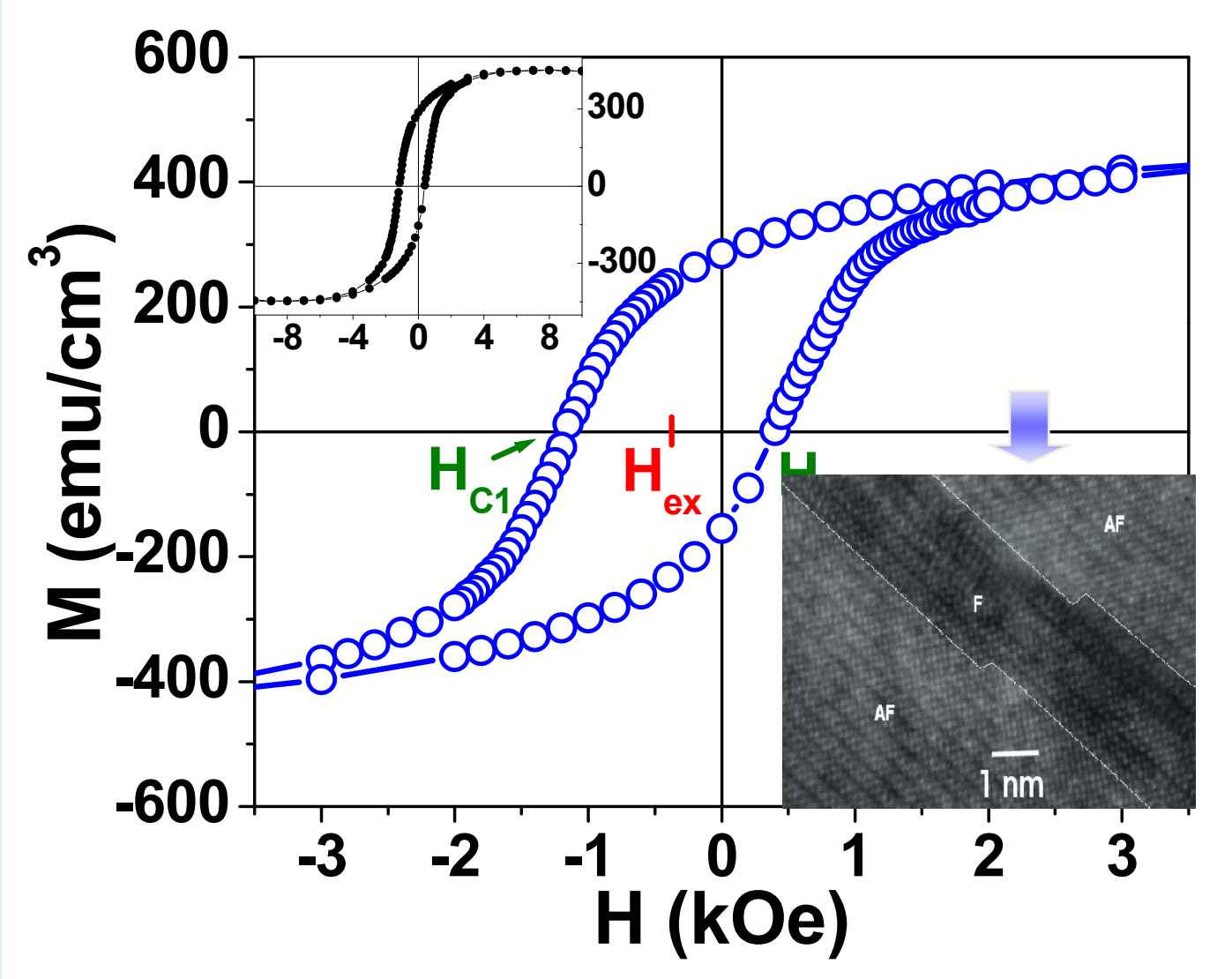
Immediate application of B_4C/BCN/c-BN multilayers

"Improvement of the design of cutting blades at AGRAF S.A via the application of B4C/BCN/c-BN, TiN/ZrN, and TiN/TiAlNbN multilayers"

General Objective: to increase the useful life of cutting blades by at least 35% at the paper conversion plant in AGRAF S.A., increasing profits in said production line by 70% by using TiN/TiAlNbN, TiN/ZrN, and B4C/BCN/c-BN multilayered hard coatings

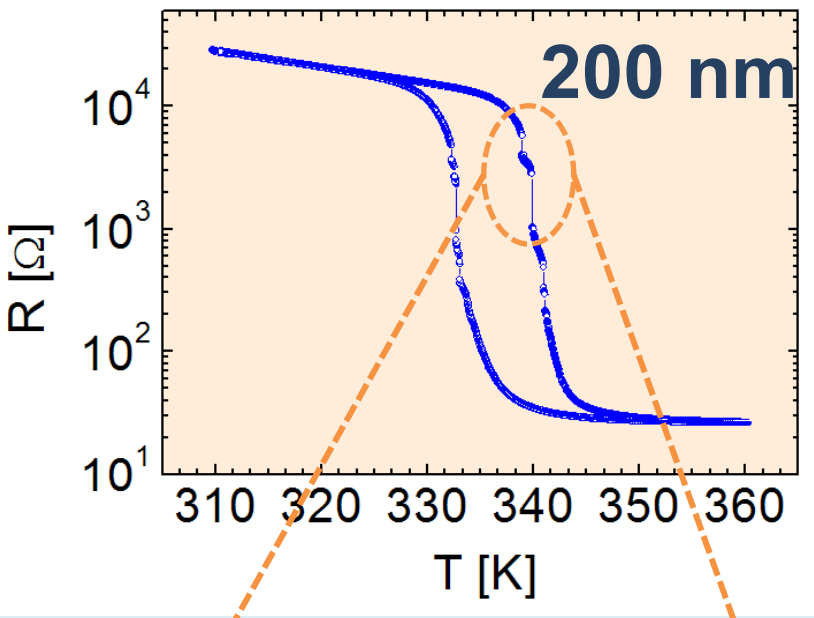
Projected savings in production costs at the AGRAF S.A. paper conversion plant for the first year: **$96,286,000**
Projected savings for the first year for Cartón Colombia:
90 hours of additional cutting
153 tons of additional paper
$382,500,000

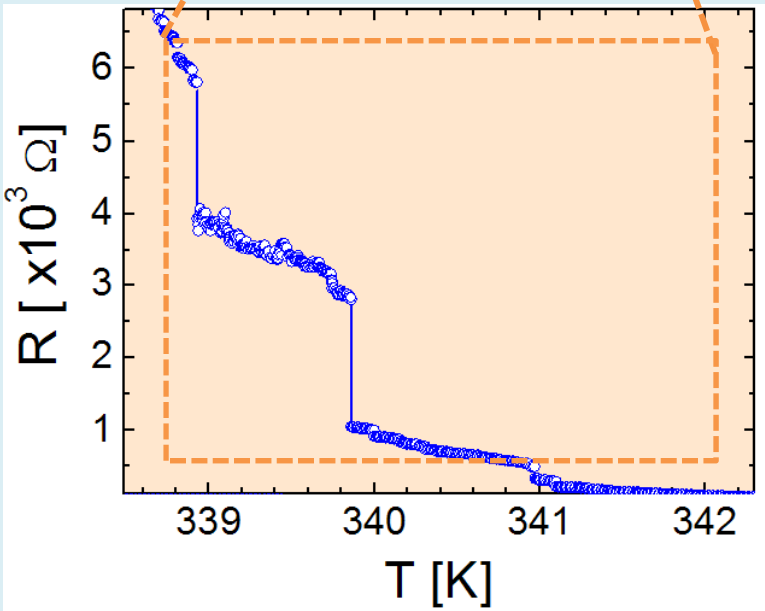
Exchange Bias in $[La_{1/3}Ca_{2/3}MnO_3/La_{2/3}Ca_{1/3}MnO_3]$ superlattices

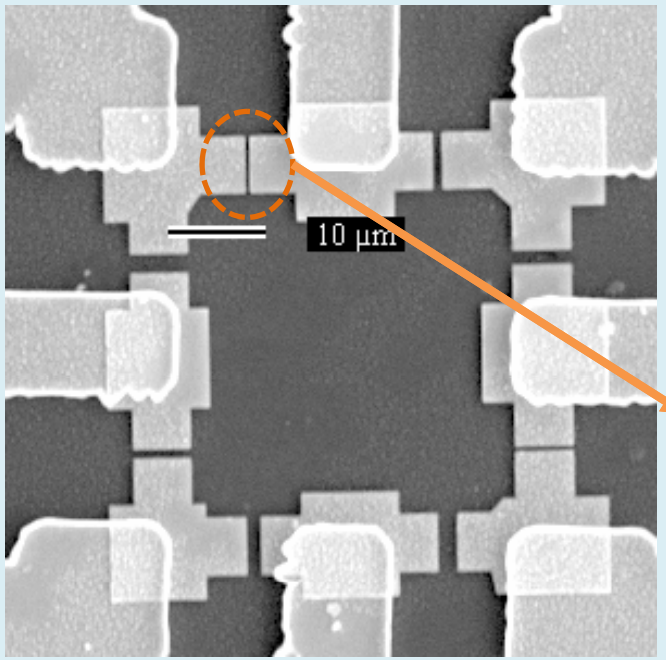


P. Prieto et al.; J. Appl. Phys. 99 08C106 (2006)

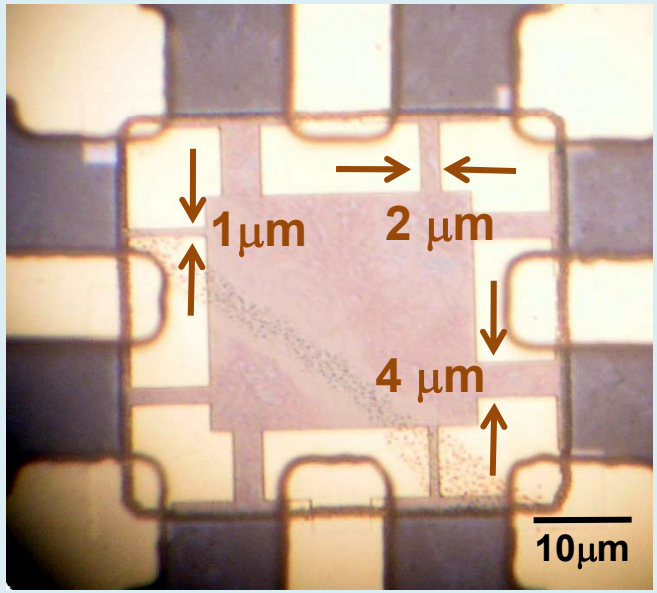
VO_2 at nano-scale

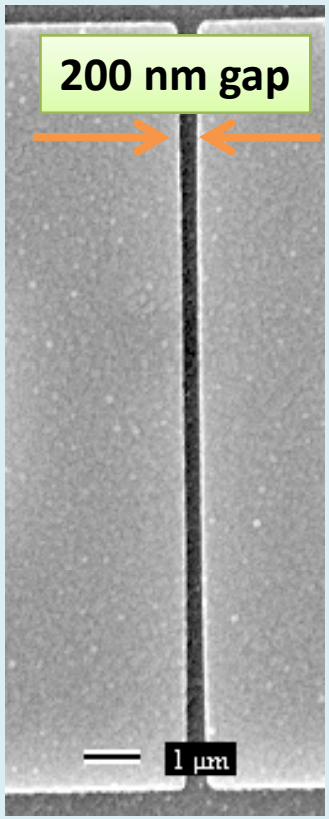






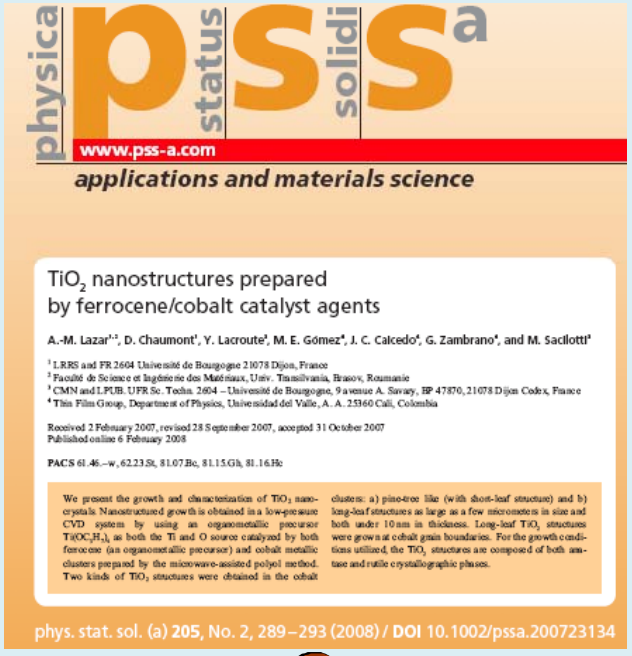
VO_2 Pattern fabricated using E-beam and Photo lithography Techniques.



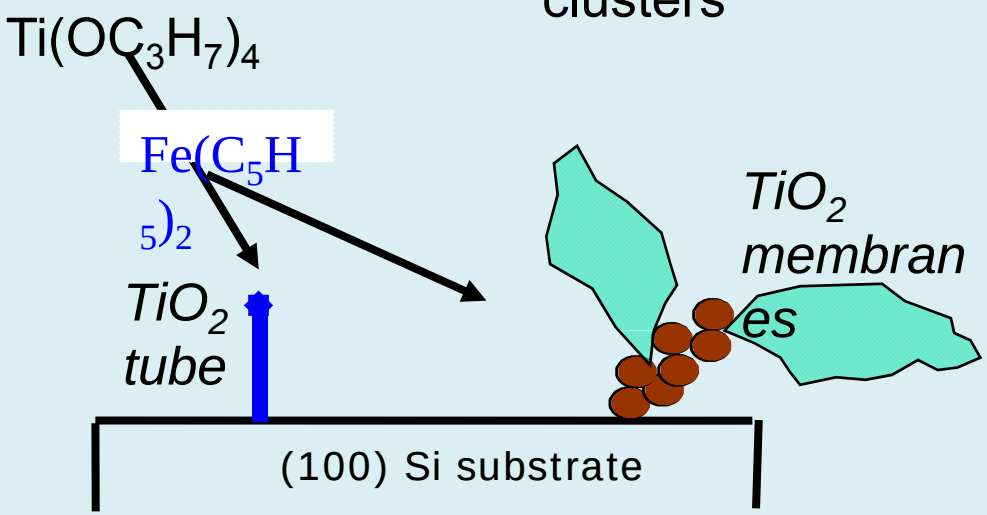


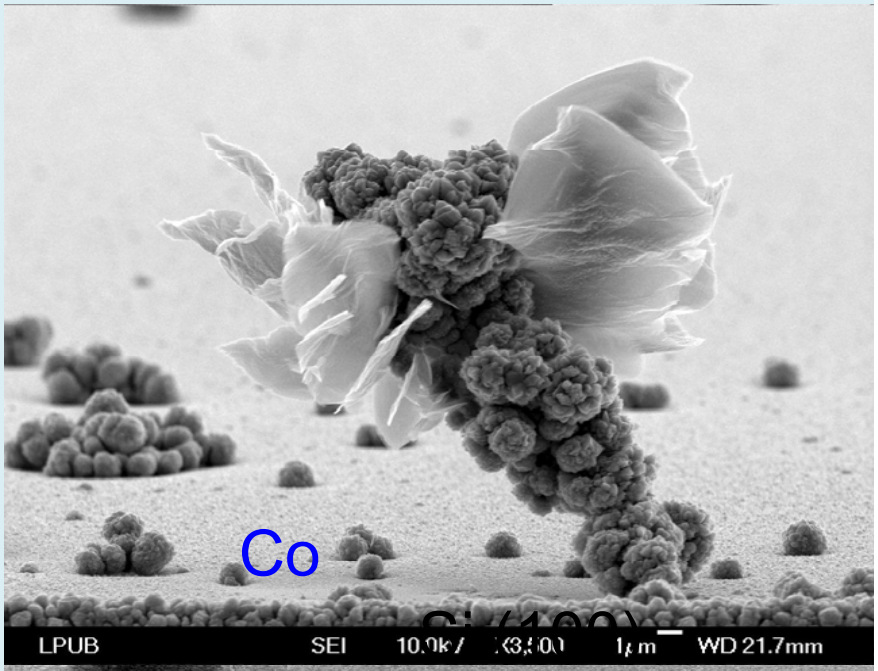
Sharoni, Ramirez, Schuller. PRL 101 (2008)

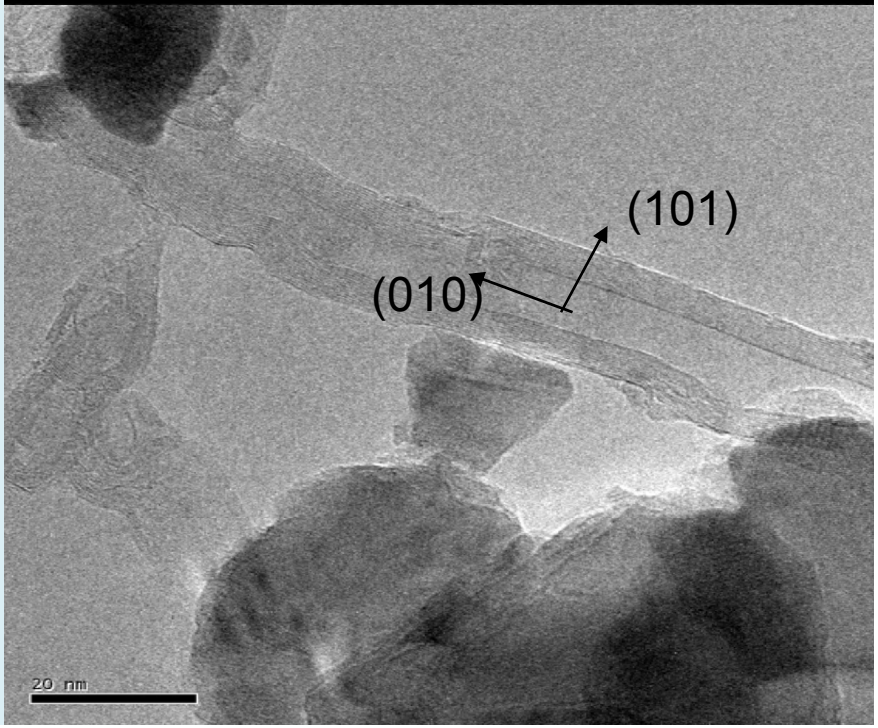
MOCVD growth of TiO_2 nanotubes and nanomembranes



= Cobalt clusters







Contents lists available at ScienceDirect

Applied Surface Science 256 (2010) 5898–5904

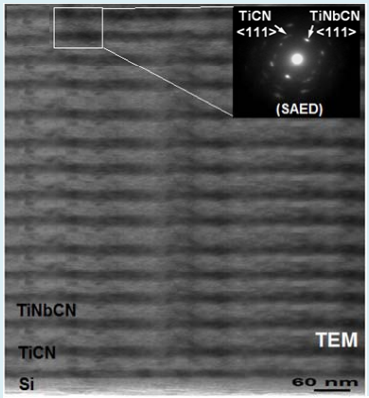
journal homepage: www.elsevier.com/locate/apsusc

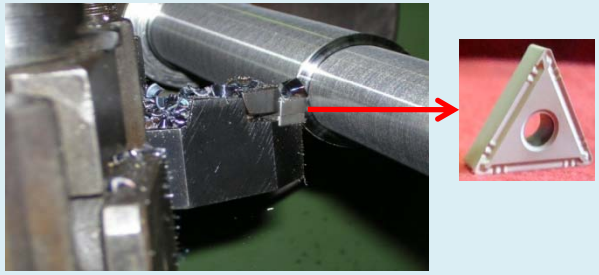
TiCN/TiNbCN multilayer coatings with enhanced mechanical properties

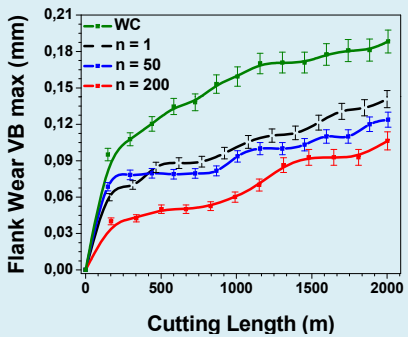
J.C. Caicedo [a,*], C. Amaya [a,b], L. Yate [c], M.E. Gómez [a], G. Zambrano [a], J. Alvarado-Rivera [d], J. Muñoz-Saldaña [d], P. Prieto [a,e]

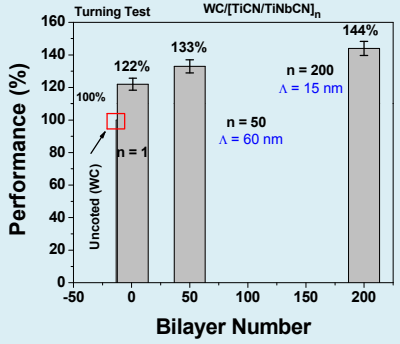
[a] Thin Film Group, Universidad del Valle, Cali, Colombia
[b] Laboratory of Hard Coatings, CDT-ASTIN SENA, Cali, Colombia
[c] Department de Física Aplicada i Óptica, Universitat de Barcelona, Catalunya, Spain
[d] Centro de Investigación y de Estudios Avanzados del IPN, Unidad Querétaro, México, Mexico
[e] Center of Excellence on Novel Materials, CENM, Calle 13 #100-00 Edificio 320, espacio 1026, Cali, Colombia

HRTEM









A B S T R A C T

Enhancement of mechanical properties by using a TiCN/TiNbCN multilayered system with different bilayer periods (Λ) and bilayer numbers (n) via magnetron sputtering technique was studied in this work. The coatings were characterized in terms of structural, chemical, morphological and mechanical properties by X-ray diffraction (XRD), atomic force microscopy (AFM), scanning electron microscopy (SEM), transmission electron microscopy (TEM) and nanoindentation. Results of the X-ray analysis showed reflections associated to FCC (1 1 1) crystal structure for TiCN/TiNbCN films. AFM analysis revealed a reduction of grain size and roughness when the bilayer number is increased and the bilayer period is decreased. Finally, enhancement of mechanical properties was determined via nanoindentation measurements. The best behavior was obtained when the bilayer period (Λ) was 15 nm (n = 200), yielding the highest hardness (42 GPa) and elastic modulus (408 GPa). The values for the hardness and elastic modulus are 1.6 and 1.3 times greater than the coating with n = 1, respectively. The enhancement effects in multilayer coatings could be attributed to different mechanisms for layer formation with nanometric thickness due to the Hall-Petch effect; because this effect, originally used to explain the increase in hardness with decreasing grain size in bulk polycrystalline metals, has also been used to explain hardness enhancements in multilayers taking into account the thickness reduction at individual single layers that make the multilayered system. The Hall-Petch model based on dislocation motion within layers and across layer interfaces, has been successfully applied to multilayers to explain this hardness enhancement.

TiCN/TiNbCN Multilayer System with Enhanced Tribological Properties

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Thin Film Group, Department of Physics, Universidad del Valle, Cali, Colombia

L. Yate, A. Lousa, J. Esteve
Department de Física Aplicada i Óptica, Universitat de Barcelona, Catalunya, Spain

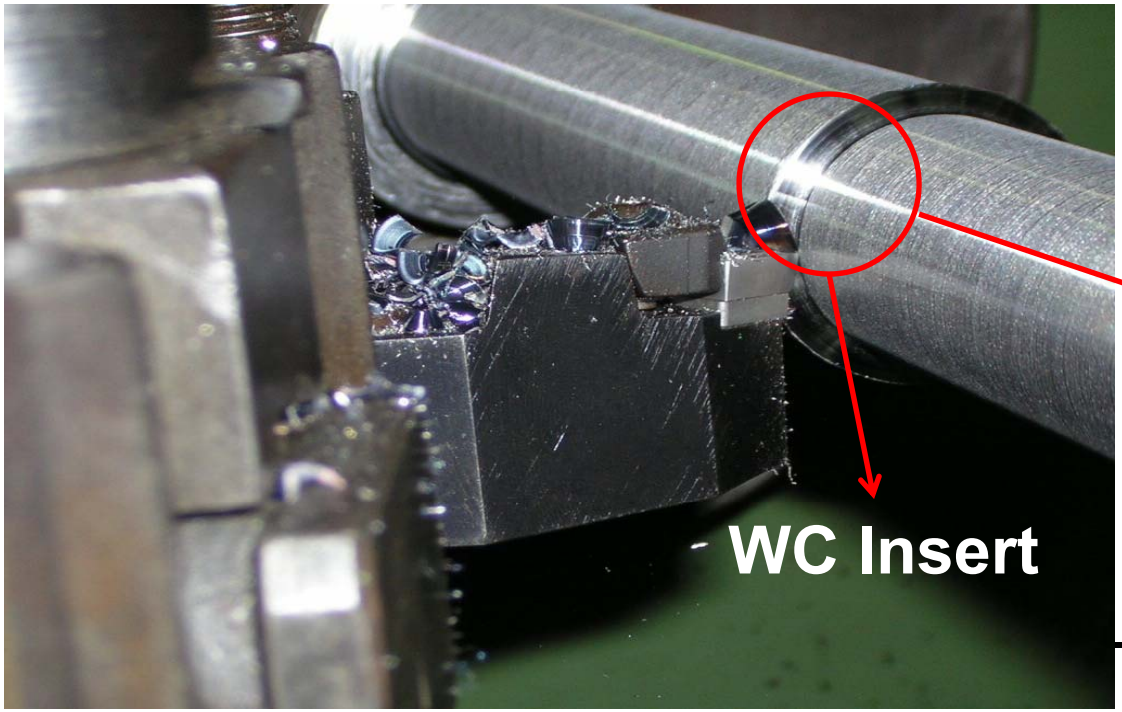
P. Prieto
Excellence Center for Novel Materials – CENM - Cali, Colombia

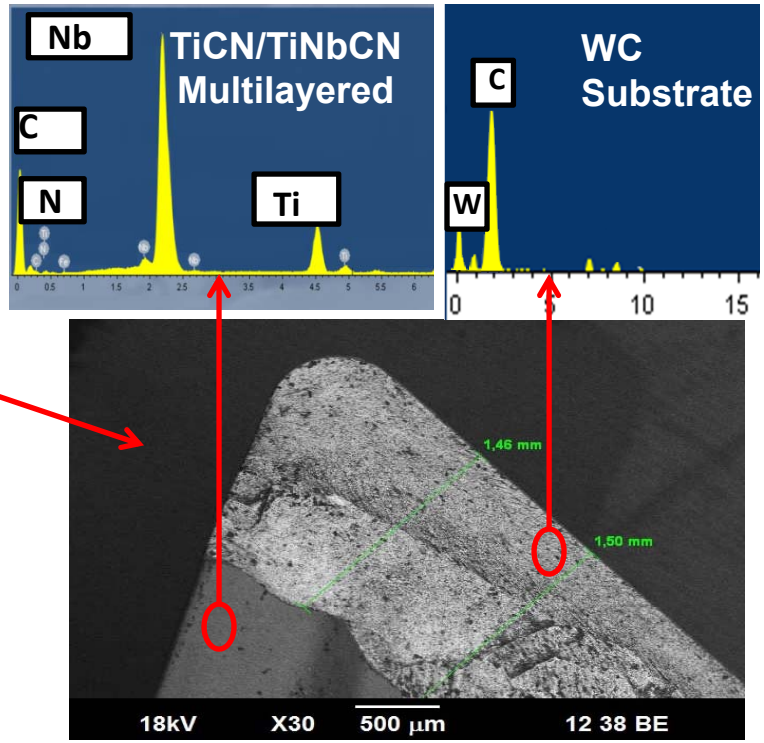
Outline

- Motivation
- Experimental Details
- Film Characterization:
- XRD, TEM, nanoindentation, pin-on-disc, wear test
- Analysis of Tribological properties
- Conclusions

Motivation

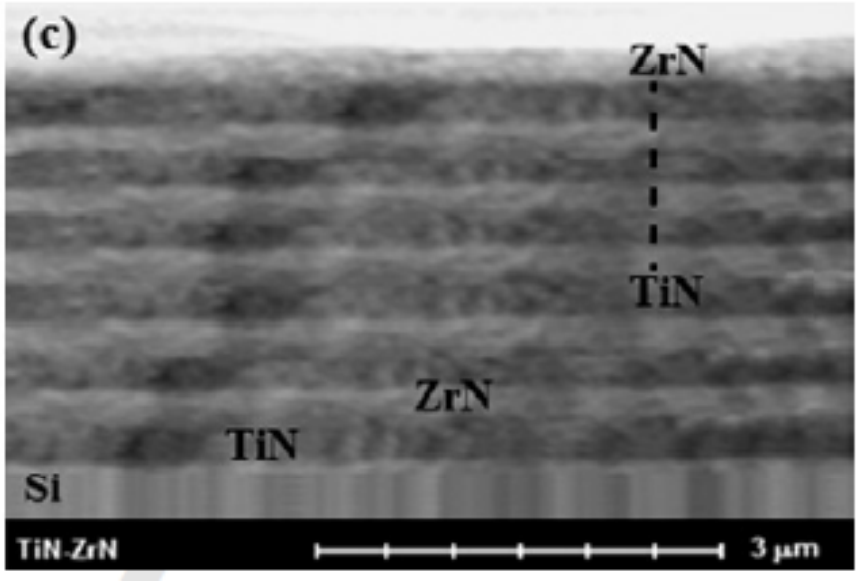
Our motivation for producing TiCN/TiNbCN multilayers is aimed at producing tough (less brittle) wear-protective films with low-friction coefficients, increased hardness, as well as a corrosion protective coatings in machining tools (WC and 4140 Steel) Our goal is to improve the mechanical properties for possible industrial applications in high-performance and aggressive environments

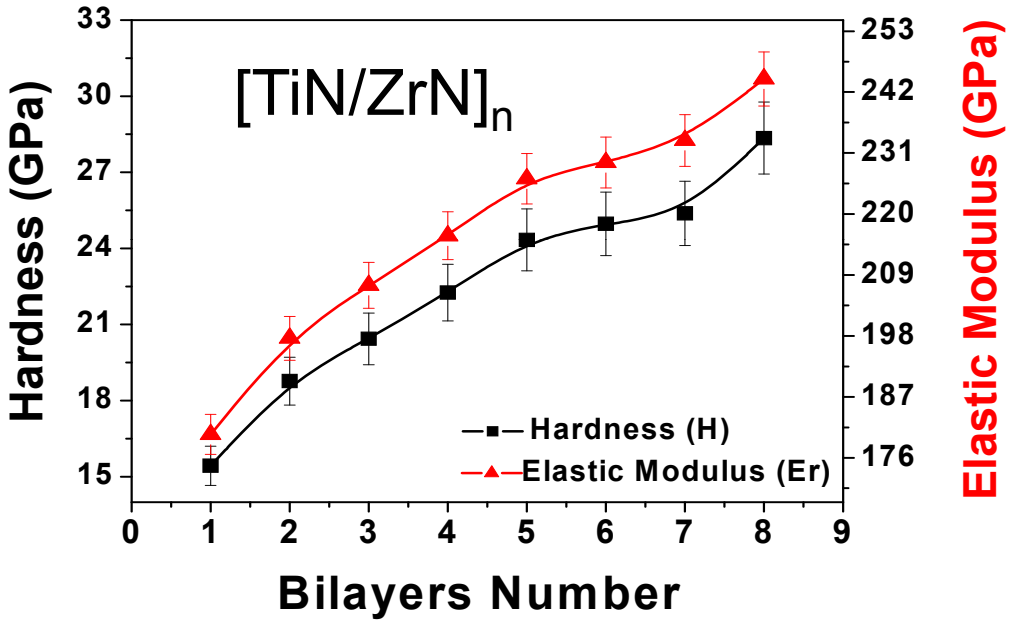




Motivation

Previous results of multilayer coatings





Contents lists available at ScienceDirect

Materials Science and Engineering B

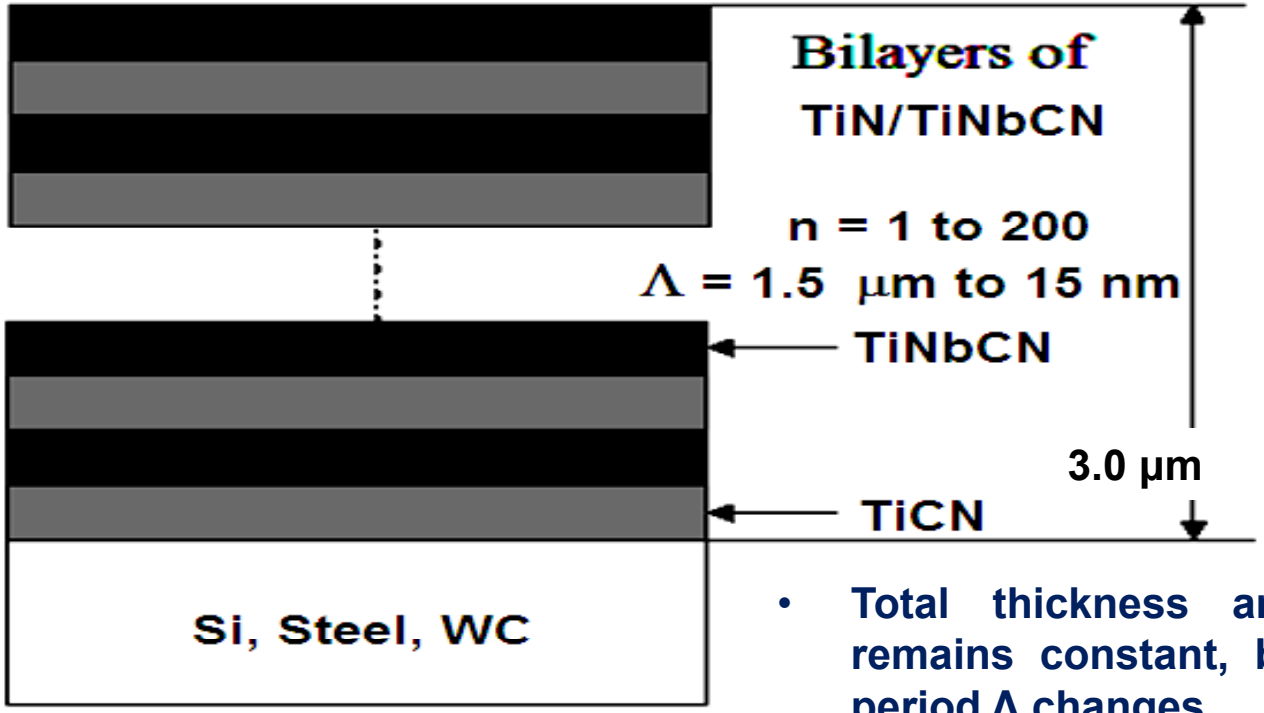
journal homepage: www.elsevier.com/locate/mseb

Mater. Sci. Eng. B (2010), doi:10.1016/j.mseb.2010.03.069

Hard coating performance enhancement by using $[Ti/TiN]_n$, [Zr/ZrN] and $[TiN/ZrN]_n$ multilayer system

J.C. Caicedo[a,*], C. Amaya[a,b], L. Yate[c], O. Nos[c], M.E. Gomez[a], P. Prieto[d]

$[TiCN/TiNbCN]_n$ multilayers ,(n = 1 to 200)



- Total thickness around 3 μm remains constant, but multilayer period Λ changes

- We analyzed the effect of number of bilayers on hardness, wear resistance, adhesion to substrate, and other tribological properties

Contents lists available at ScienceDirect

Applied Surface Science

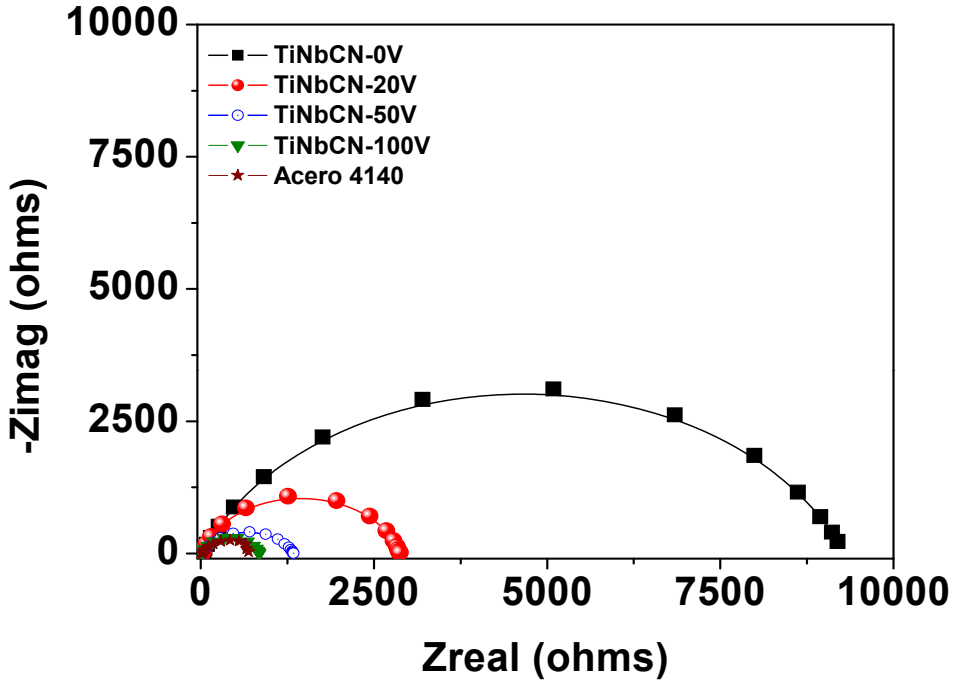
journal homepage: www.elsevier.com/locate/apsusc

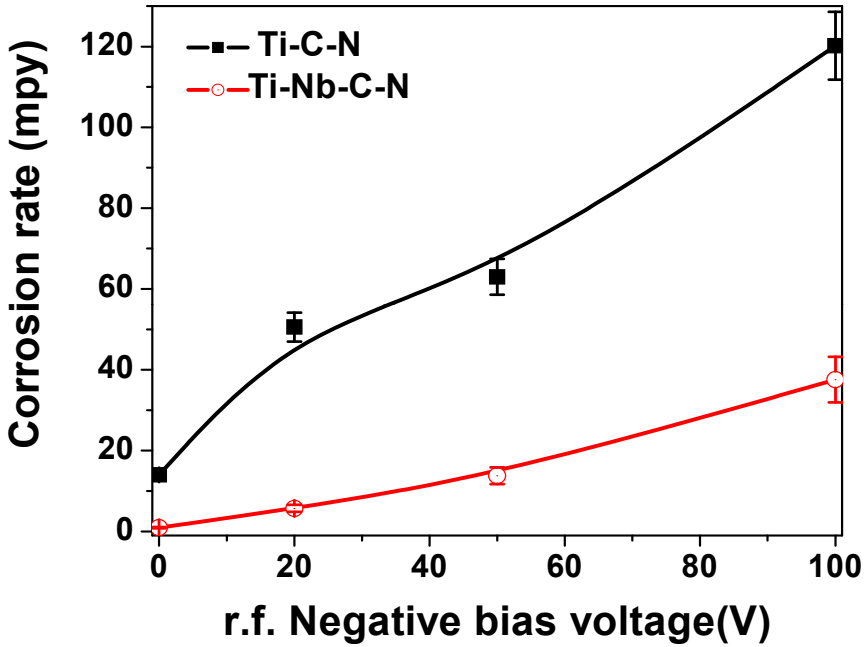
Appl. Surf. Sci. (2010), doi:10.1016/j.apsusc.2010.03.071

TiCN/TiNbCN multilayer coatings with enhanced mechanical properties

J.C. Caicedo[a,*], C. Amaya[a,b], L. Yate[c], M.E. Gómez[a], G. Zambrano[a], J. Alvarado-Rivera[d], J. Muñoz-Saldaña[d], P. Prieto[a,e]

Corrosion properties in TiCN and TiNbCN single layers





Enhancement of corrosion resistance in TiNbCN layers

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journal homepage: www.elsevier.com/locate/apsusc

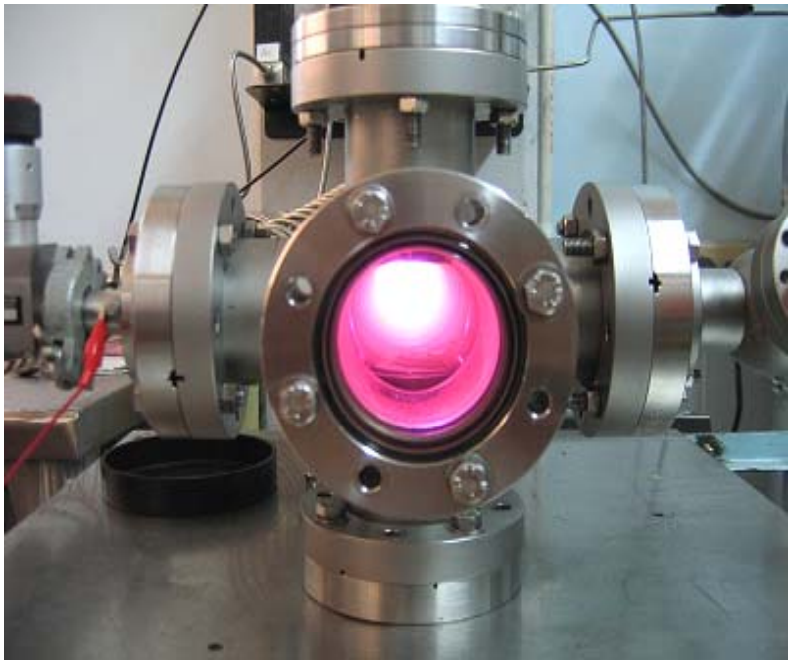
Applied Surface Science 256 (2010) 2876–2883

Effect of applied bias voltage on corrosion-resistance for $TiC_{1-x}N_x$ and $Ti_{1-x}Nb_xC_{1-y}N_y$ coatings

J.C. Caicedo [a,c,*], C. Amaya [a,b], L. Yate [c], W. Aperador [a], G. Zambrano [a], M.E. Gómez [a], J. Alvarado-Rivera [d], J. Muñoz-Saldaña [d], P. Prieto [a,e]

Experimental Details

Magnetron Sputtering



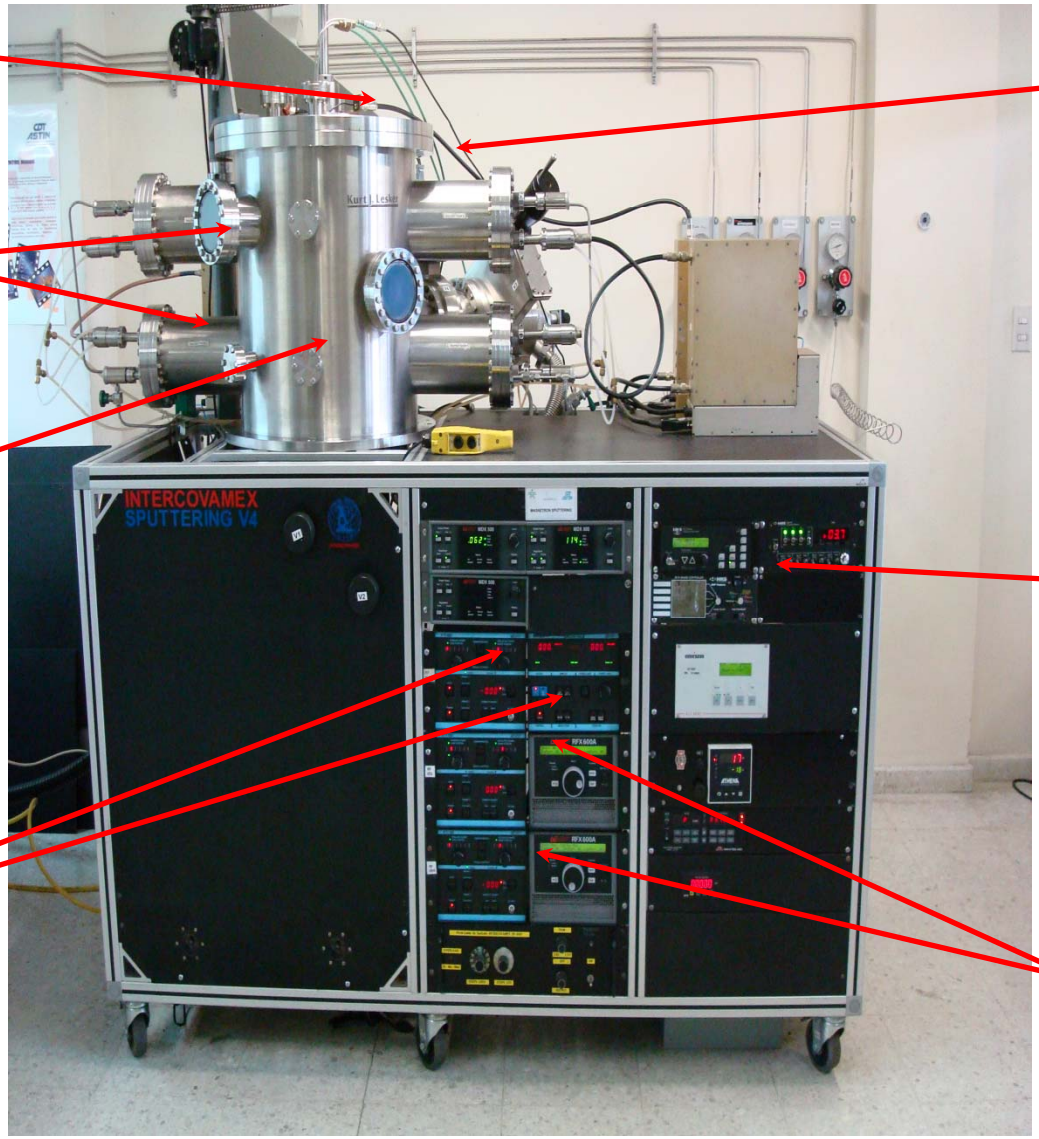
Universidad del Valle

Magnetron Sputtering System

Substrates on rotation system

Four Magnetrons (Ø 4 Inch)

Heater (700 °C)



(Bias Voltage)

Four-Channel Fluxometers

2 d.c. power

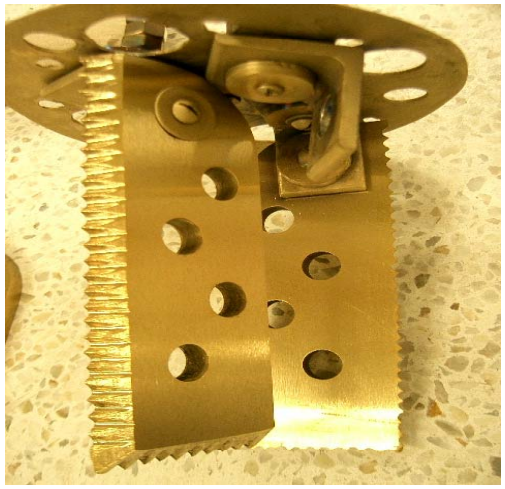
2 r.f. power

Magnetron Sputtering

$[TiN/ZrN]_n$

$[Al_2O_3/YSZ]_n$

$[Ti/TiN]_n$



$[TiN/ZrN]_n$

$[TiN/TiAlN]_n$

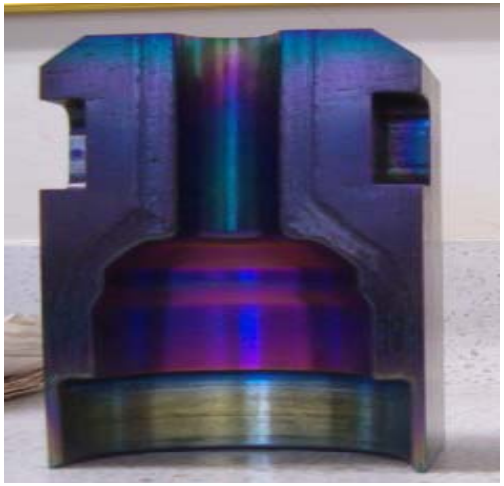
$[CrN/ZrN]_n$

Magnetron Sputtering

$[Ti/TiN]_n$

$[Ti/TiN]_n$ $[Cr/CrN]_n$

$[Ti/TiN]_n$

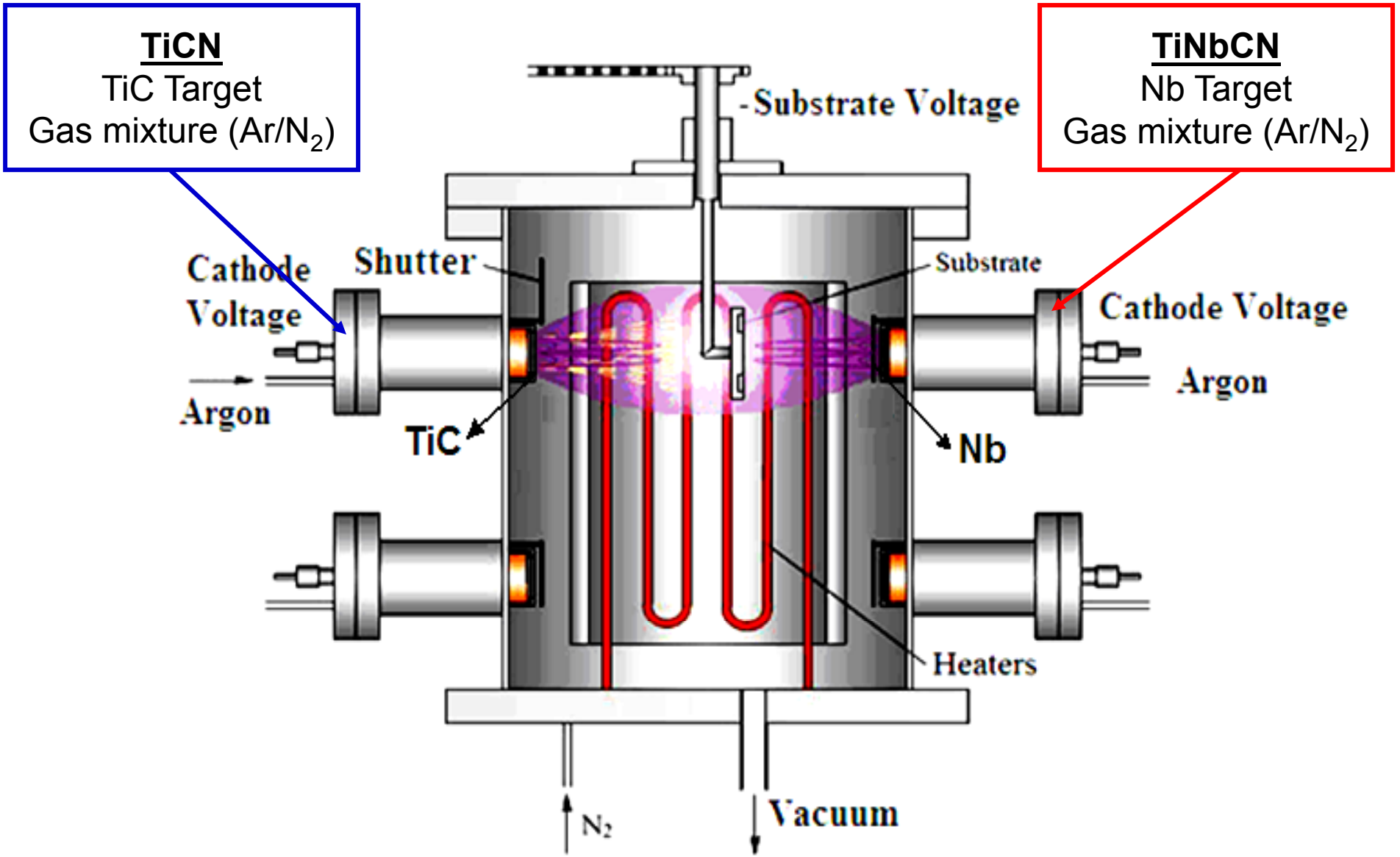


$[TiN/TiAlN]_n$

$[Zr/ZrN]_n$

$[B_4C/BCN/c\text{-}BN]_n$

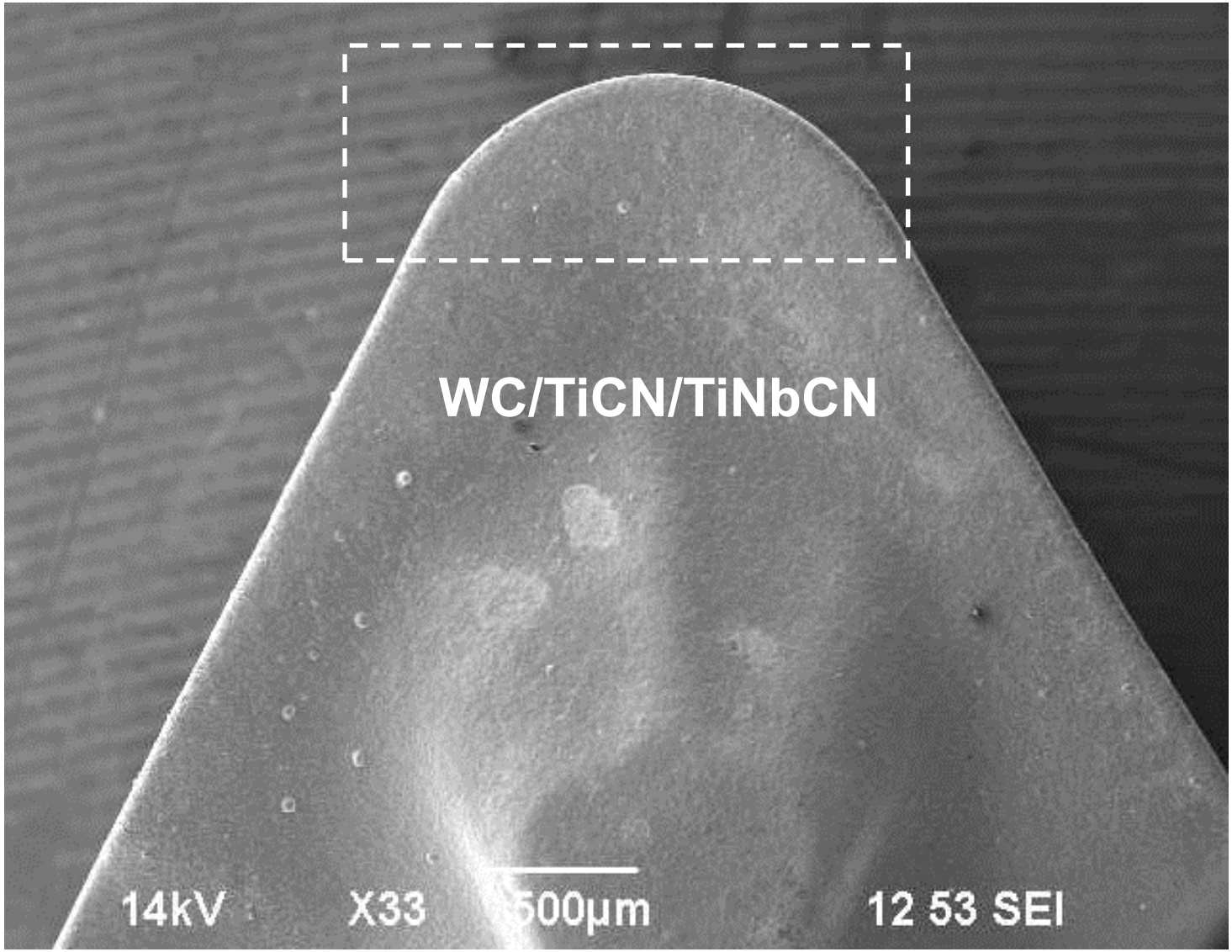
Magnetron Sputtering System Setup



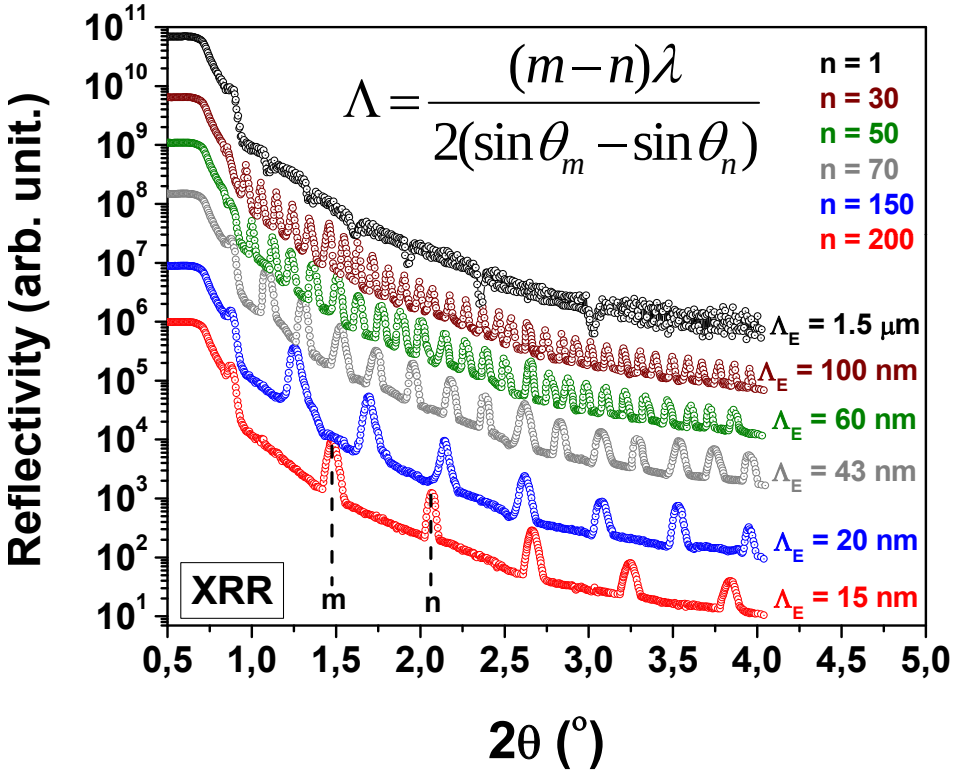
Deposition Parameters for $[TiCN/TiNbCN]_n$ Multilayers

Targets	Titanium Carbide and Niobium
Deposition system	Magnetron sputtering r.f. Reactive
Power density (W/cm^2)	80 –TiC and 70-Nb
Bias r.f. voltage (-V)	50
Target to substrate distance (cm)	7
Gas mixture (Ar/N_2)	76/24 (%)
Deposition pressure ($Ar+N_2$) (mbar)	$6x10^{-3}$
Substrate	Si (100), AISI 4140 steel and WC inserts
Substrate temperature (°C)	300

Structural and mechanical characterization



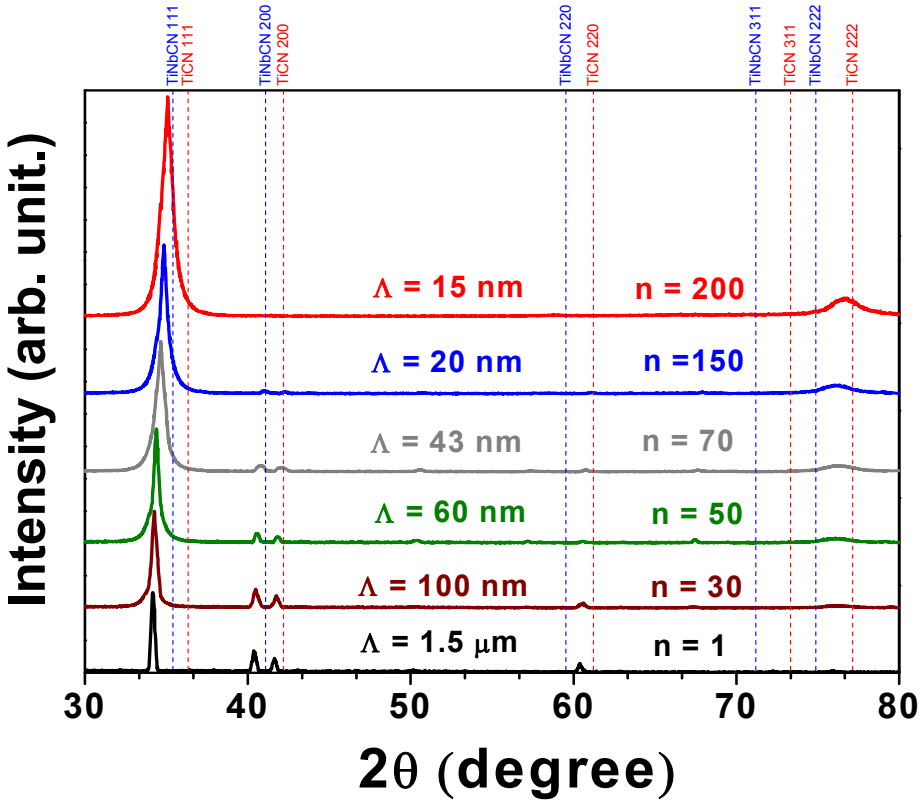
Low-angle diffraction patterns of TiCN/TiNbCN multilayers deposited on silicon substrates

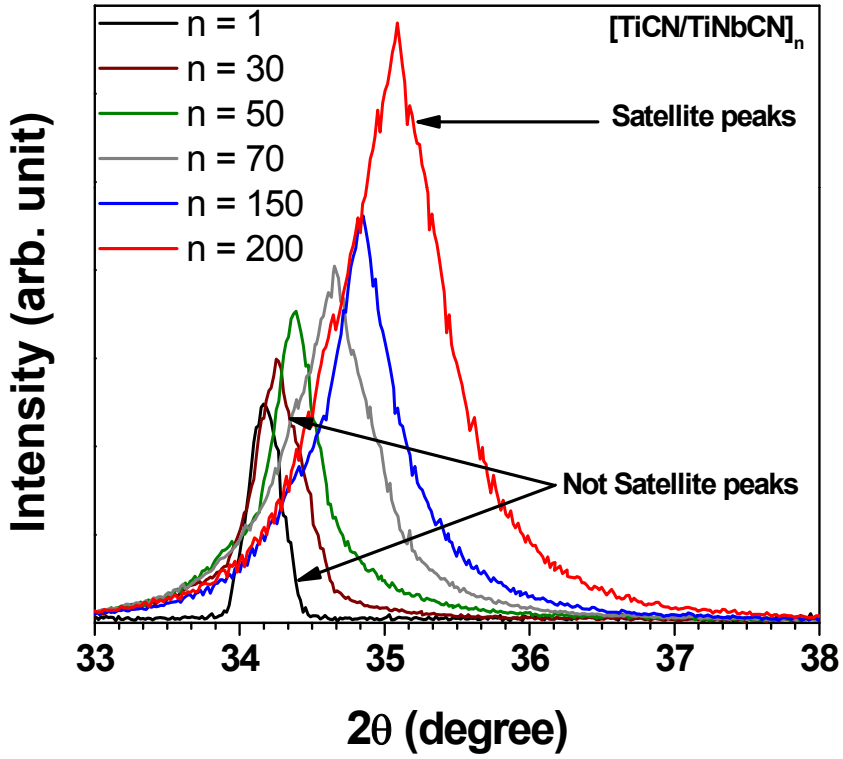


Nº of bilayers	Bilayer Period (nm) calculated from the deposition rate	Bilayer Period (nm) extracted from LA-XRD measurements
1	**1500**	-
30	**100**	96.6
50	**60**	59.9
70	**43**	41.1
150	**20**	19.7
200	**15**	14.6

Interference peaks due to the multilayer formation
Good agreement between nominal modulation and bilayer period obtained from LA XRD

High angle Diffraction patterns of TiCN/TiNbCN films deposited on silicon substrate



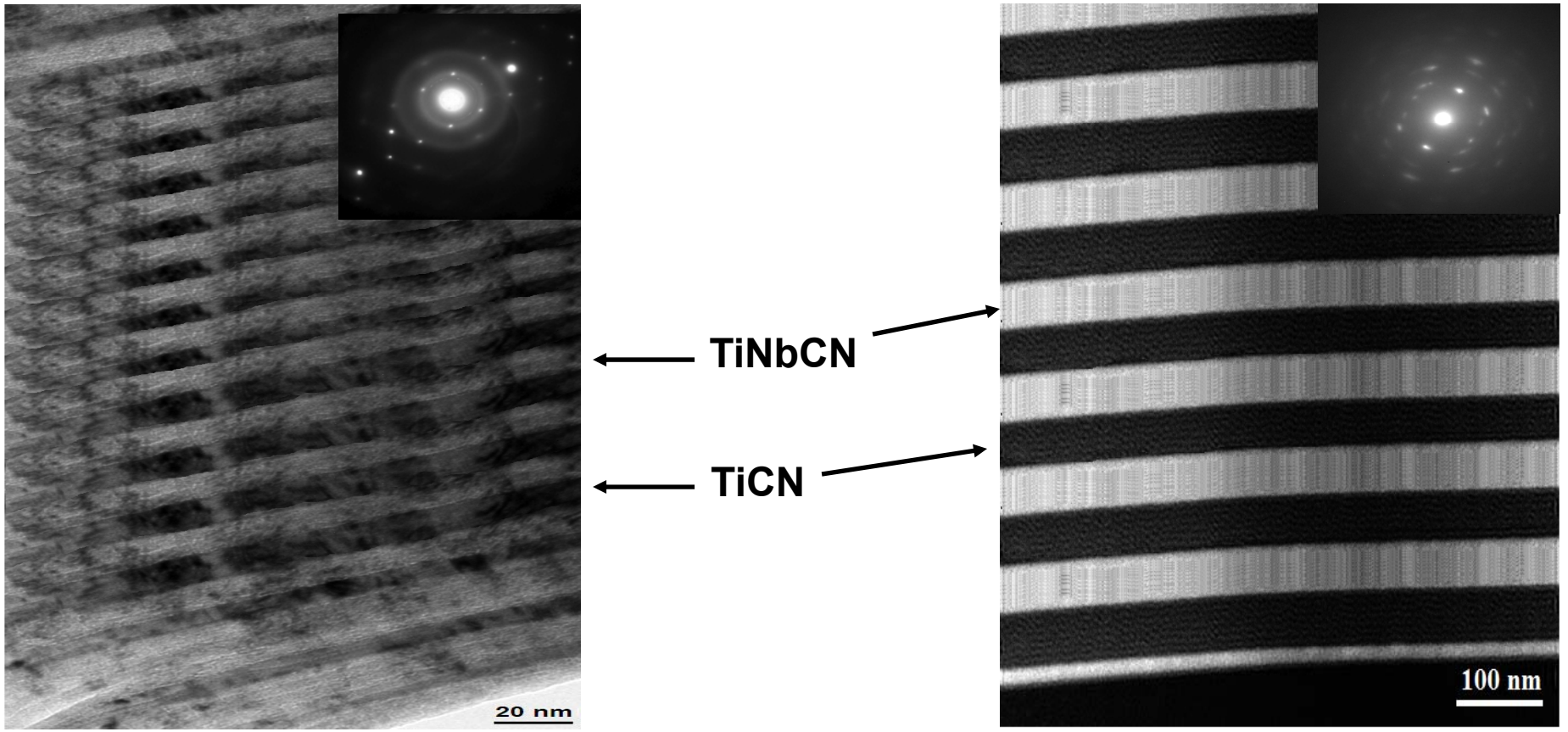


Satellite peaks as a consequence of the formation of sharp interfaces shifted from the diffraction peaks to high-angle probably due to the presence of compressive stress

Cross-section TEM Analysis

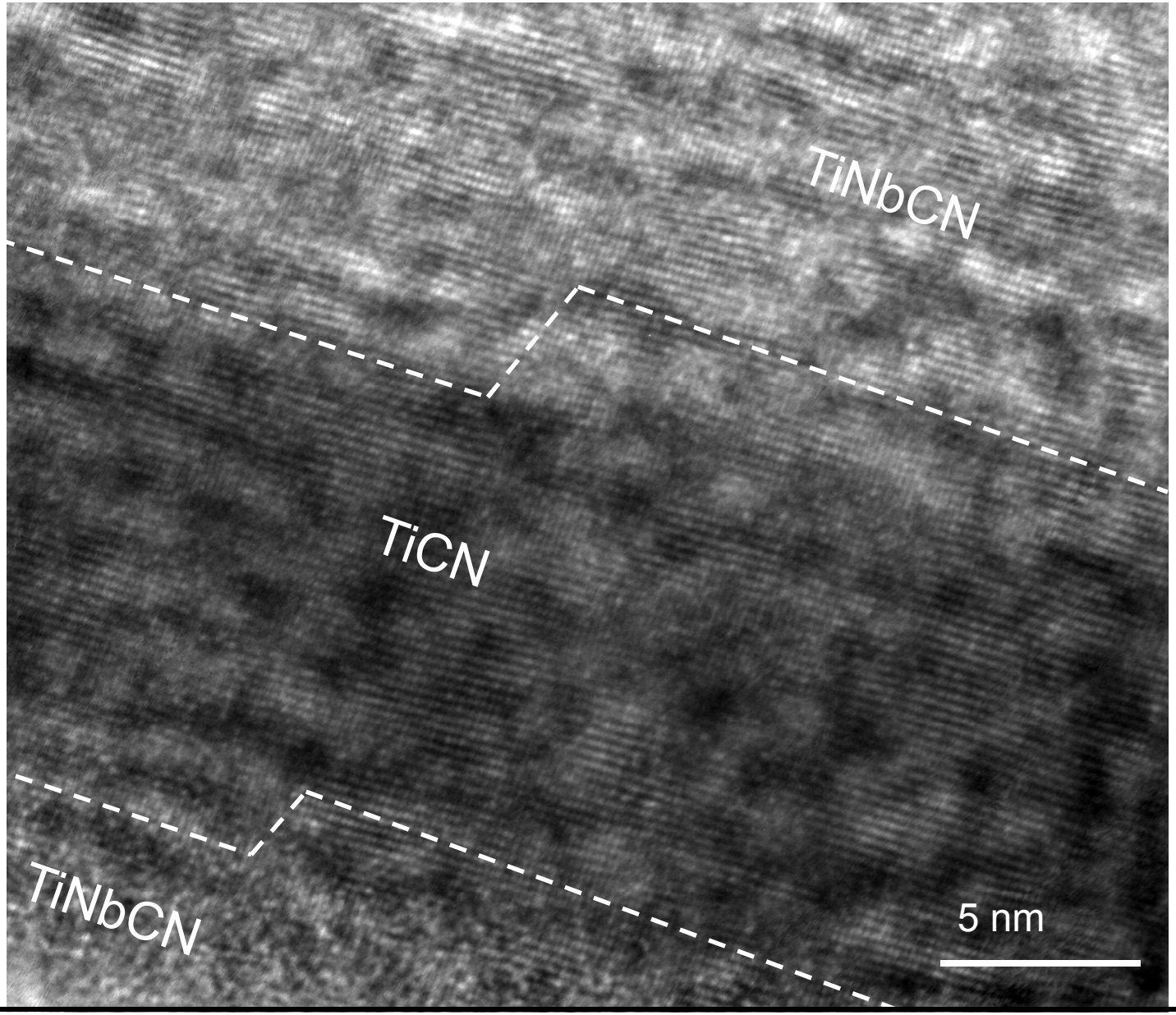
TEM n = 200, Λ = 15 nm

TEM n = 30, Λ = 100 nm



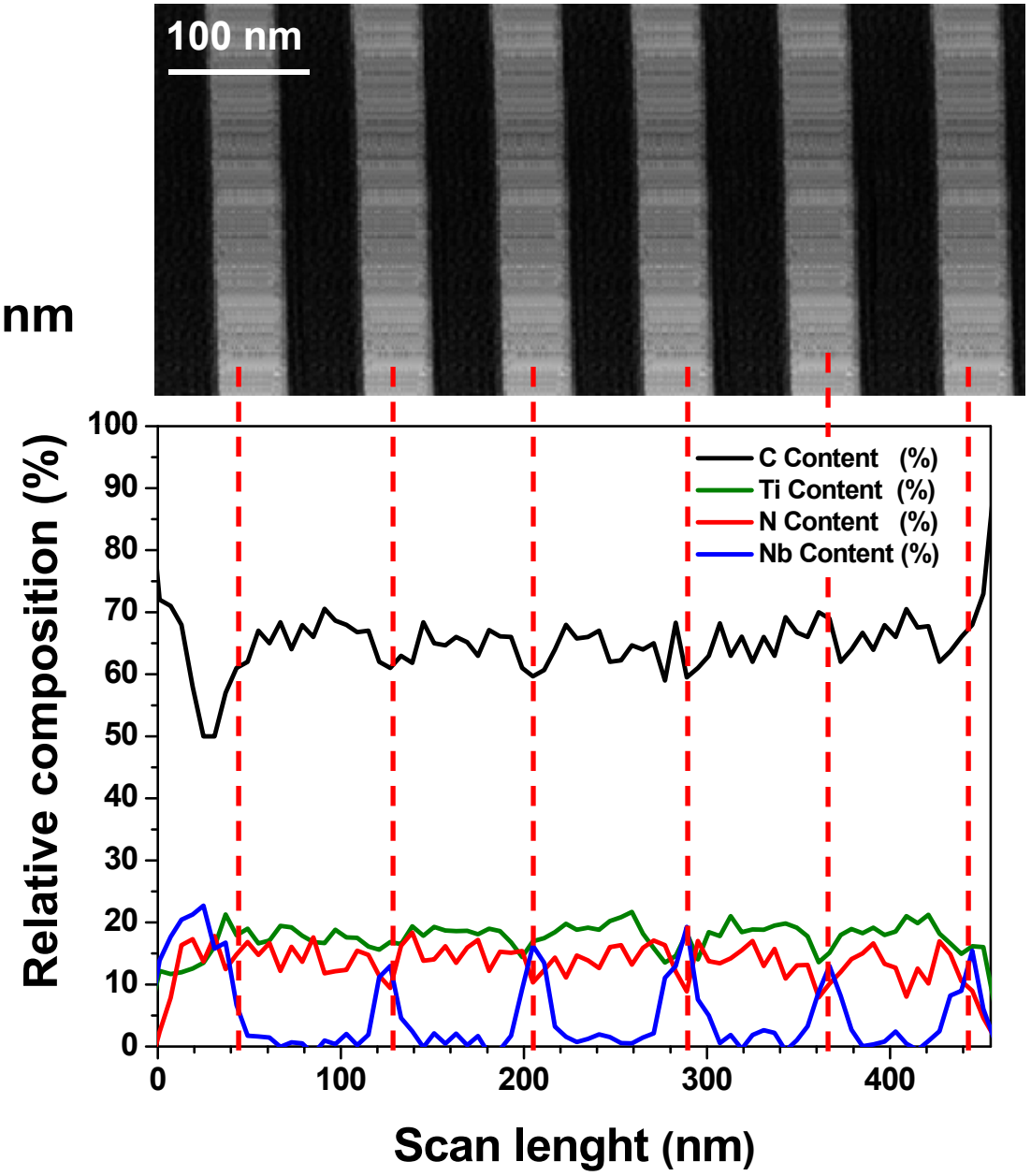
Cross-section TEM image of a TiCN/TiNbCN multilayer with 200 bilayers (Λ = 15 nm) (a) and multilayer with 30 bilayers (Λ = 100 nm). Clear interfaces are observed in all multilayers

HR TEM

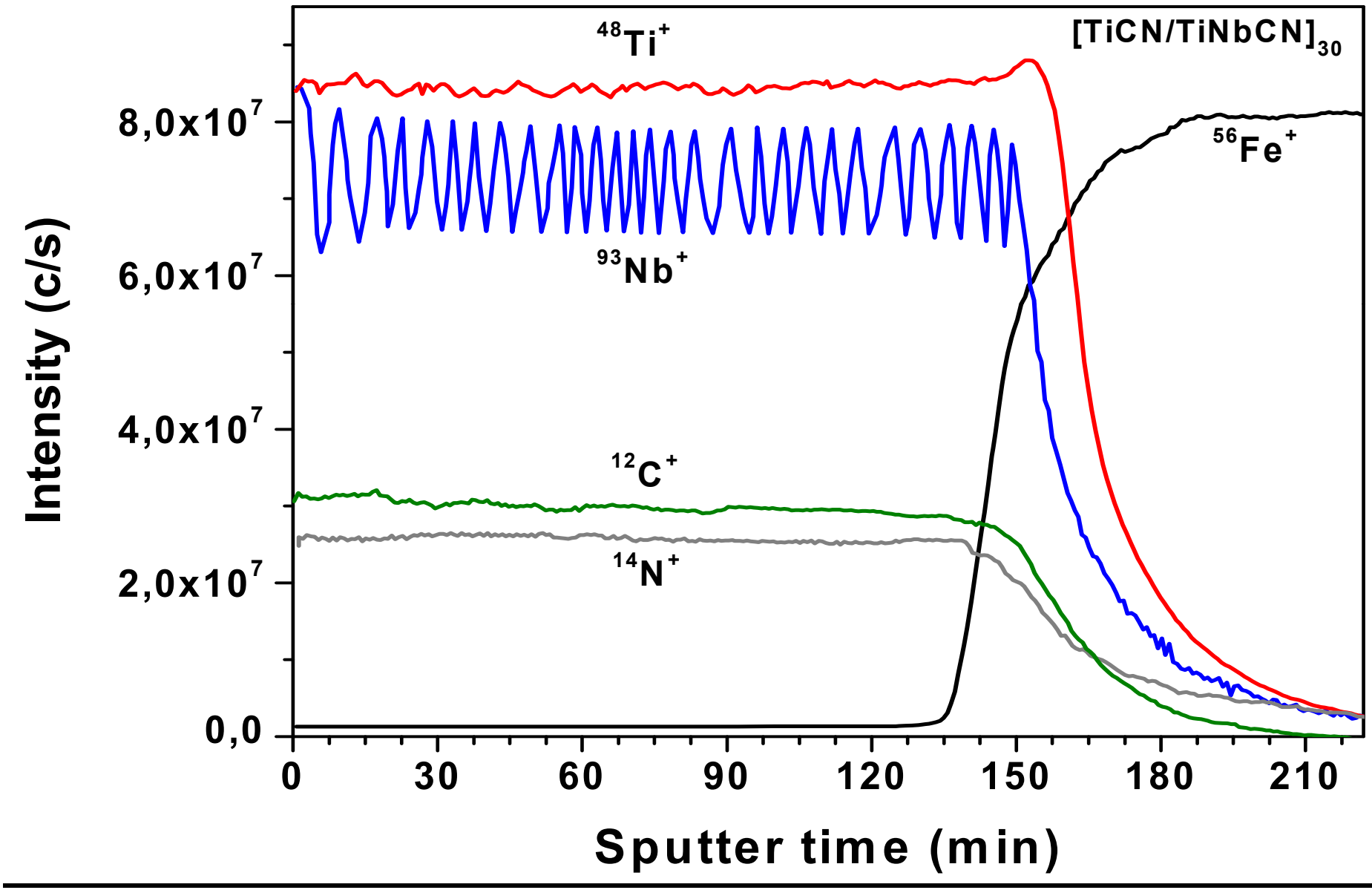


STEM (EELS) $[TiCN/TiNbCN]_n$

n = 30, Λ = 100 nm

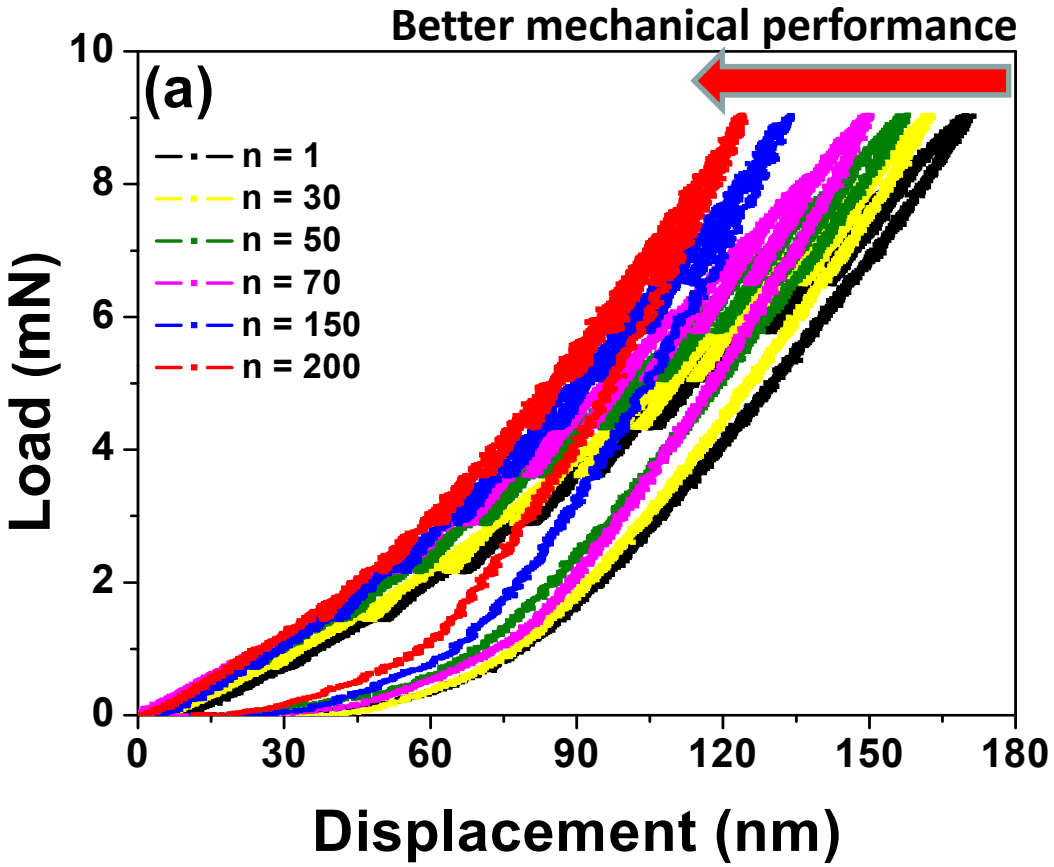


SIMS $[TiCN/TiNbCN]_{30}$

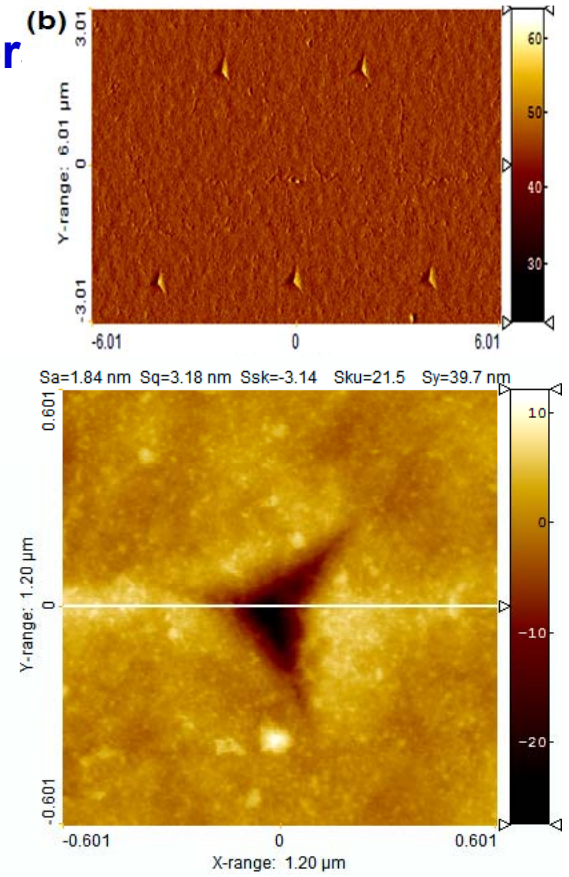


Mechanical Properties

Hardness and Elastic Modulus of $[TiCN/TiNbCN]_n$ multilayer



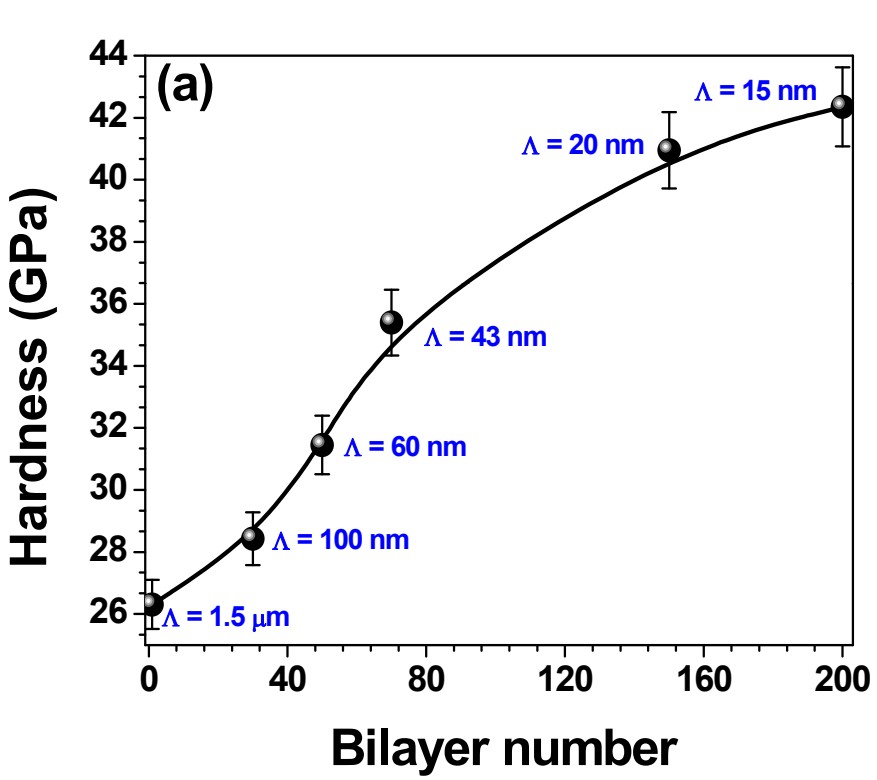
Values of elasticity modulus E and hardness H were obtained by using Oliver and Pharr's method

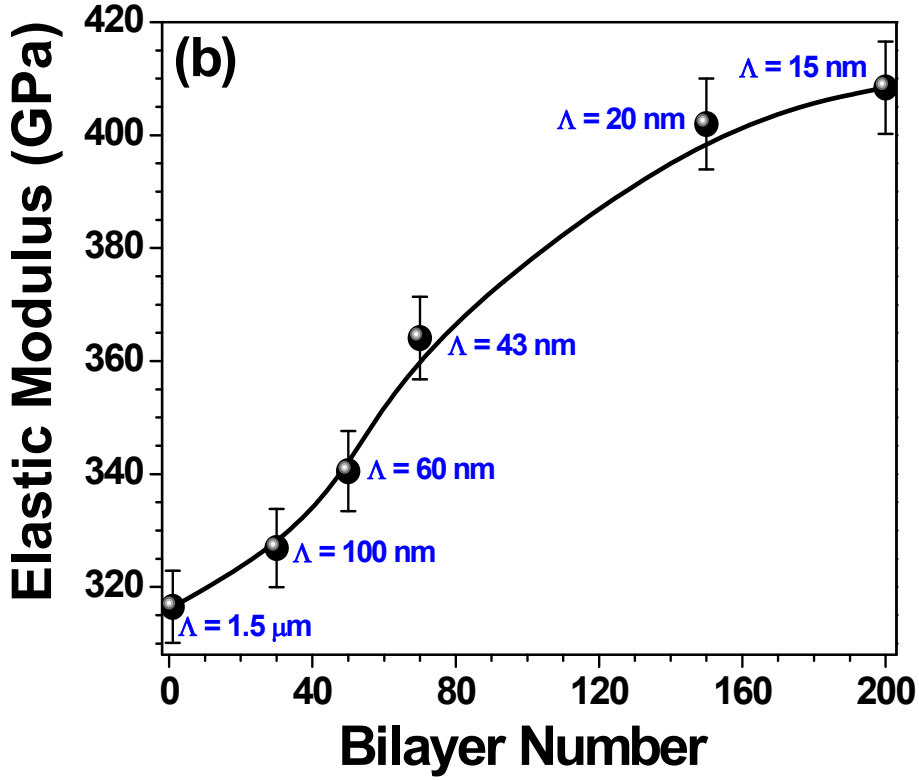


Atomic Force Microscopy (AFM)
Asylum Research MFP-3D®

Mechanical Properties

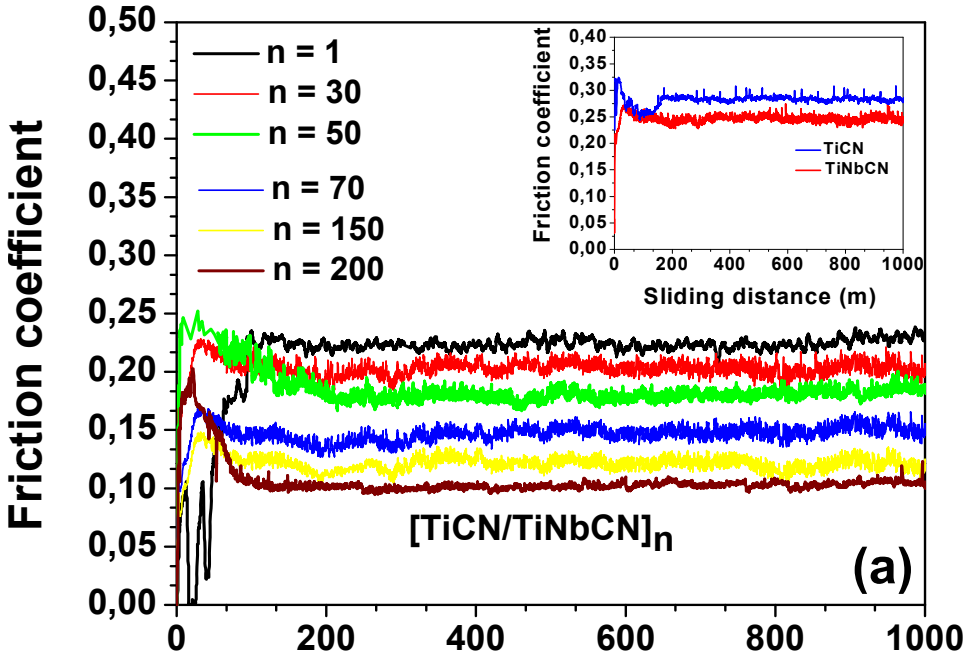
Hardness and Elastic Modulus of $[TiCN/TiNbCN]_n$ multilayers

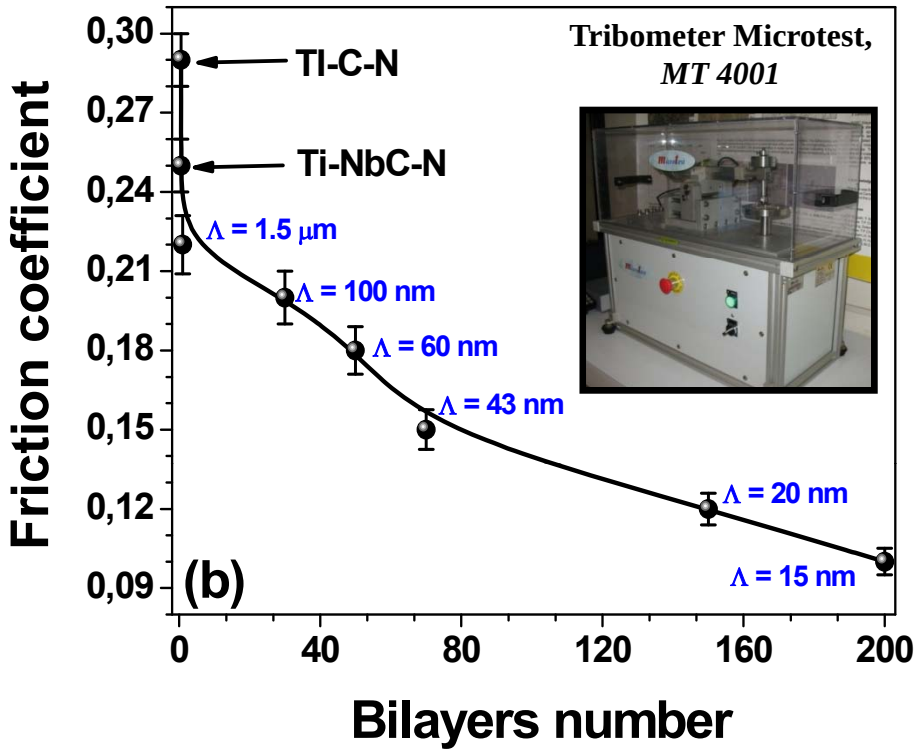


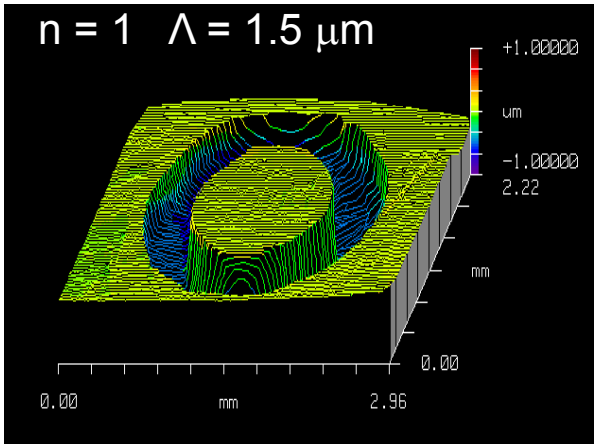


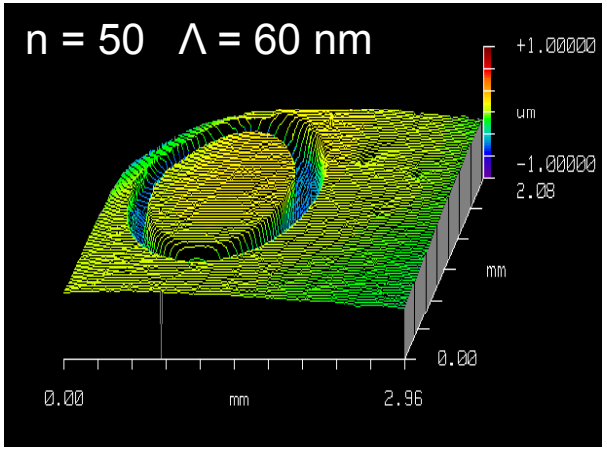
Hardness increased from 26 GPa to 42 GPa and Elastic modulus from 318 GPa to 410 GPa. Probably due to the nanometric thickness of individual layers in the multilayered structure.

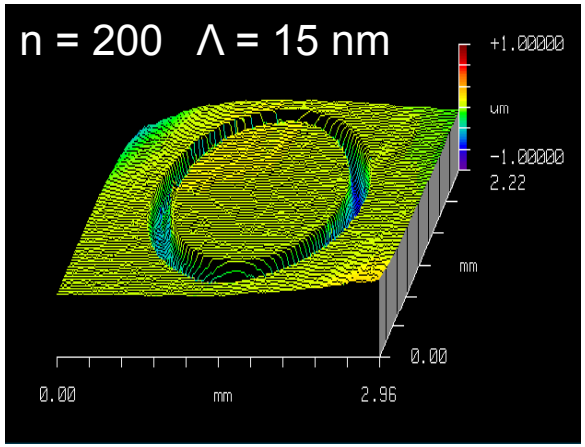
Analysis of Friction Results





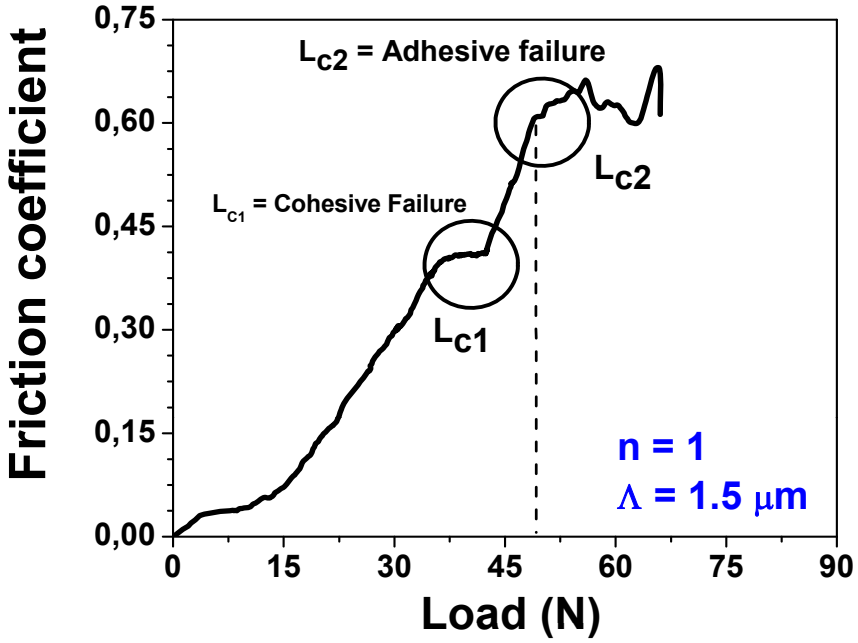


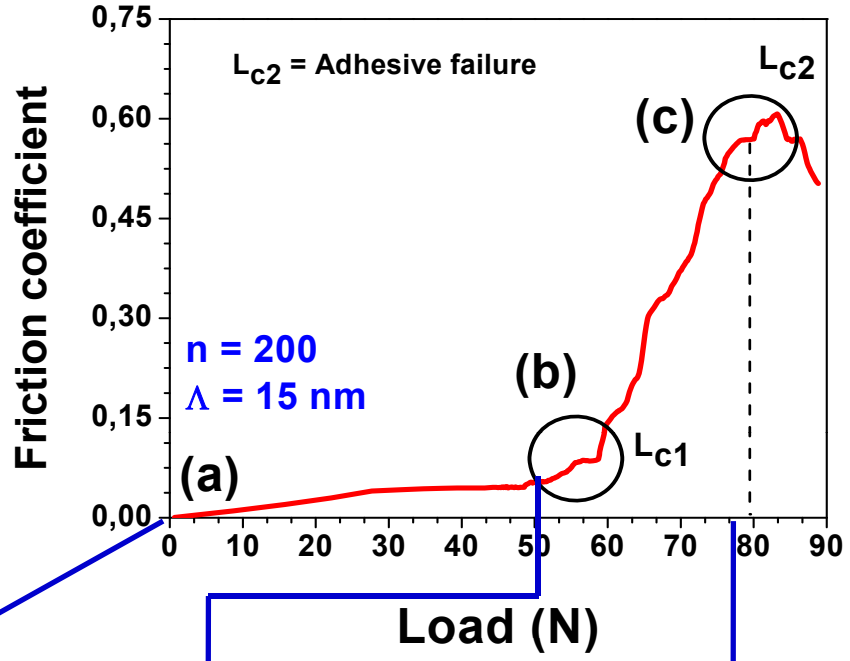




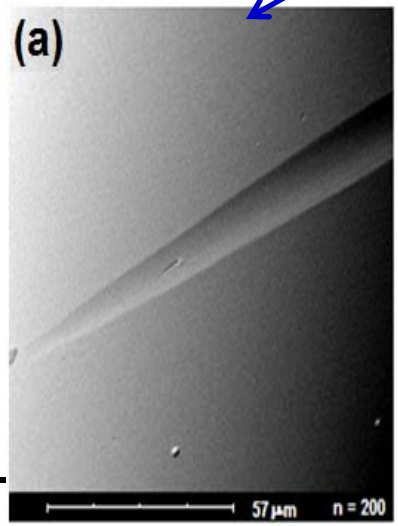
Optical Interferometry of coating wear resistance, after 2 h pin-on-disk sliding

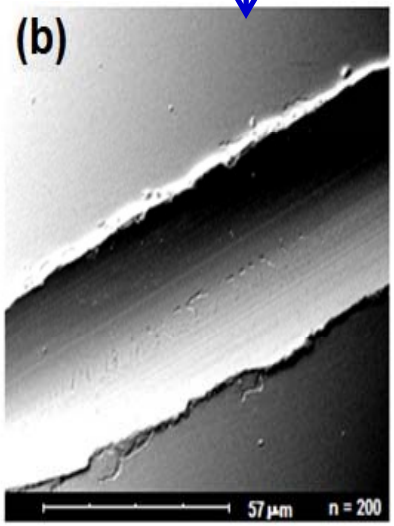
Analysis of Adhesion Results

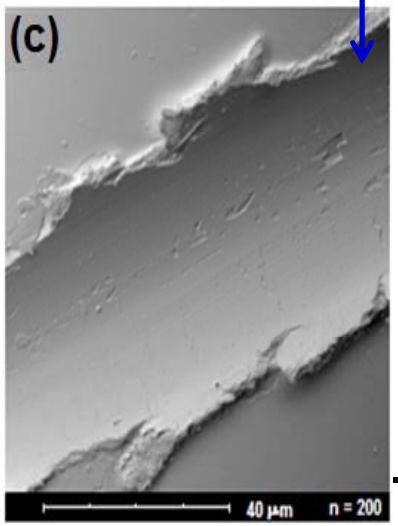




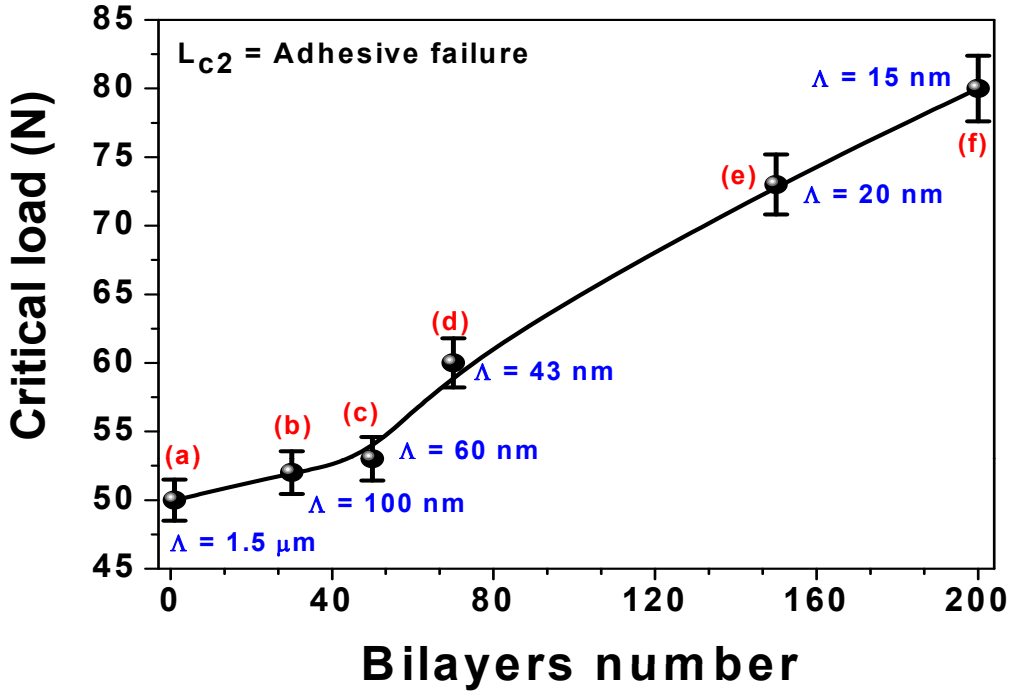
Scratch Test Microtest *MTR2*

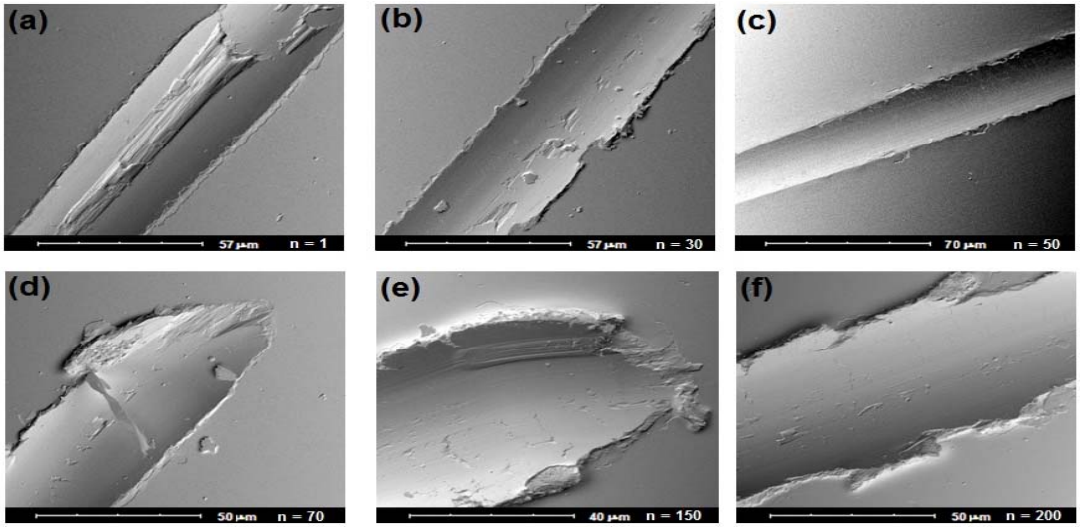






Analysis of Adhesion Results





Conclusions

Micro & nanometric TiCN/TiNbCN multilayered coatings successfully deposited by r.f. magnetron sputtering with bilayer periods ranging from 1.5 μm to 15 nm.

Highest hardness & elastic modulus, 42 & 408 GPa, respectively, observed for TiCN/TiNbCN deposited with number of bilayers at 200 and modulation at 15 nm.

Low friction coefficients observed in multilayered coatings maybe due to carbon content and to the interface effect. Furthermore, high hardness combined with carbon content lubricant presence make the TiCN/TiNbCN multilayered system a good candidate for use as a hard and low friction coating in cutting tools.

Contribution to Local & National Development, Scientific and Technological Capacity

- Work done with 19 highly qualified research groups throughout the nation has strengthened student and researcher participation in the international scientific community.
- CENM has placed scientific & technological knowledge at the highest international levels.
- The Center has done research in key areas for the nation's academic, scientific, and economic benefit.
- CENM research will lead to developing environmentally friendly manufacturing practices and devices.
- Our research represents important potentials in electronics, biomedicine, metallurgy and construction, among others.

Thank you for your kind attention