DISCURSOS

PRONUNCIADOS EN EL ACTO DE
INVESTIDURA DE DOCTOR *HONORIS CAUSA*
DEL EXCELENTÍSIMO SEÑOR

D. SORIN IOAN CRISTOLOVEANU

UNIVERSIDAD DE GRANADA

MMXXI

DISCURSOS DEL ACTO DE INVESTIDURA DEL DOCTOR
HONORIS CAUSA D. SORIN IOAN CRISTOLOVEANU
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DISCURSO DE PRESENTACIÓN PRONUNCIADO POR
DON FRANCISCO GAMIZ PÉREZ
CON MOTIVO DE LA INVESTIDURA COMO
DOCTOR *HONORIS CAUSA*
DEL EXCELENTÍSIMO SEÑOR
DON SORIN IOAN CRISTOLOVEANU

Excma. Sra. Rectora Magnífica de la
Universidad de Granada
Autoridades
Claustro de profesores y profesoras
Señoras y Señores,

En primer lugar, en nombre del Departamento de Electrónica y Tecnología de Computadores de la Universidad de Granada y en el mío propio, agradezco el apoyo recibido a la propuesta de doctorado Honoris Causa para el Prof. Dr. Sorin Ioan Cristoloveanu del Institut polytechnique de Grenoble, por parte de la Facultad de Ciencias, de la Escuela Técnica Superior de Ingeniería Informática y Telecomunicación y de la Escuela Técnica Superior de Caminos, Canales y Puertos, así como por la aprobación de la misma del Consejo de Gobierno y del Claustro de la Universidad de Granada.

La Electrónica ha cambiado nuestras vidas de manera espectacular en la segunda mitad del siglo XX y en estos primeros años del siglo XXI. Hoy se hacen cosas que eran inimaginables hace sólo unos años, y lo que es más importante, hoy no sabríamos vivir sin la Electrónica. En apenas cincuenta años, la Tecnología Electrónica ha cambiado la Humanidad tal como la conocíamos tras una evolución que duró miles de años.

Y el Prof.Cristoloveanu, que hoy recibe este doctorado, ha contribuido durante su larga trayectoria significativamente a este cambio como intentaré poner de manifiesto en esta breve intervención.

El diccionario de la Real Academia de la Lengua define la Electrónica como "el estudio y aplicación del comportamiento de los electrones en diversos medios, como el vacío, los gases y los semiconductores, sometidos a la acción de campos eléctricos y magnéticos". Es decir, la Electrónica es "el arte de jugar con electrones".

Y jugando con electrones, es posible hacer muchas cosas. Por supuesto, esta historia empezó hace muchos, muchos años. El estudio de las propiedades eléctricas de los materiales es un esfuerzo que viene de muy lejos. Ya Tales de Mileto en el 600 aC comentó la habilidad del ámbar por atraer otros objetos. Algún tiempo posterior, en el año 1600 de nuestra era, William Gilbert usó la palabra griega para ámbar, "elektron", para describir el campo que rodea a un objeto cargado, y de donde derivan los términos electrón, campo eléctrico o Electrónica. Los primeros avances hacia una comprensión racional de la electricidad y el magnetismo comenzaron a aparecer en la segunda mitad del siglo XVIII con los experimentos pioneros y teorías de Cavendish, Coulomb, Gauss, Oersted, Ampere, Faraday y otros muchos. Todos estos importantes resultados condujeron a Maxwell a formular la teoría clásica del electromagnetismo en 1864. Hacia finales del siglo diecinueve y principios del siglo veinte, el estado de la ciencia y de la ingeniería empieza a entrar en lo que podríamos llamar la era moderna: Thomson identificó el electrón hacia 1897 y Millikan midió su carga de manera precisa en 1909. Todos estos resultados condujeron a la aparición de la física del estado sólido y a una mayor comprensión de las propiedades electrónicas de los sólidos, incluyendo la teoría de bandas, y la explicación de porqué unos sólidos conducen la electricidad mientras que otros son intrínsecamente aislantes. Los primeros dispositivos electrónicos estuvieron involucrados en el desarrollo de las telecomunicaciones, que dieron lugar a inventos como el telégrafo electromagnético de Morse, las redes telefónicas, y la radio, o telegrafía sin hilos inventada por Tesla y Marconi hacia 1900 que llegaría a ser la forma de comunicación a larga distancia más utilizada en el siglo XX.

A pesar de los éxitos y avances conseguidos por los dispositivos electrónicos hasta la primera mitad del siglo XX, los dispositivos de esta época eran muy simples, esencialmente válvulas de vacío, constituidas por electrodos metálicos en una carcasa de vidrio, y electroimanes, es decir, los dispositivos electrónicos estaban constituidos por conductores (cobre) y aislantes (vidrio). Sin embargo, en la segunda mitad del siglo XX, la electrónica pasó a estar dominada por un tercer material: los semiconductores, con los que se fabrican los modernos dispositivos electrónicos.

A diferencia del resto de aislantes o conductores, que tienen un valor definido de conductividad, los semiconductores pueden cambiar en varios ordenes de magnitud su conductividad simplemente modificando la temperatura, añadiendo determinadas impurezas en concentraciones de una parte por millón, o colocando el material bajo la influencia de la luz, radiación o campos eléctricos y magnéticos. De esta forma, combinando trozos de materiales semiconductores diferentemente contaminados, pueden crearse por ejemplo estructuras que amplifiquen las señales o que actúen como conmutadores, y así en diciembre de 1947, Shockley, Bardeen y Brattain en los laboratorios Bell de New Jersey en Estados Unidos demuestran experimentalmente el funcionamiento del transistor bipolar de unión, y en noviembre de 1959 junto con el coreano Dawon Kahng, el ingeniero egipcio Mohamed Atalla fabricó con éxito el primer transistor de efecto campo Metal-Óxido-Semiconductor y que se convertiría posteriormente en la pieza clave de la tecnología electrónica actual, siendo el artefacto más fabricado en la historia de la Humanidad.

Tras el establecimiento de dispositivos discretos de estado sólido quedó claro que encontrar una forma efectiva de conectar o integrar estos dispositivos en grandes circuitos complejos sería un factor importante en el progreso continuo de la Electrónica.

A fines de la década de 1950, dos pioneros, Jack Kilby de Texas Instruments y Robert Noyce de Fairchild Semiconductor (más tarde cofundador de Intel), determinaron las ideas y procesos fundamentales que se utilizarían para integrar muchos dispositivos electrónicos y grandes circuitos en una sola pieza de cristal semiconductor. El circuito integrado resultante, fabricado utilizando silicio, es quizás el proceso tecnológico más importante inventado en la historia moderna. Desde ese momento, la tecnología microelectrónica ha ido evolucionando siguiendo la llamada ley de Moore. Gordon Moore, co-fundador de Intel, predijo en 1965 que el número de dispositivos en un circuito integrado se duplicaría cada dos años. Desde entonces, no sabemos bien si porque Moore era realmente un profeta, bien porque la Industria Microelectrónica ha hecho todos los esfuerzos posibles, acelerando unas veces, ralentizando otras, para cumplir la predicción de Moore, lo cierto es que desde 1965, el número de transistores en un circuito integrado se ha duplicado cada dos años, llegando en la actualidad a integrar mas de 1700 millones de transistores en un circuito integrado. El escalado de los dispositivos electrónicos ha sido muy importante a lo largo de los años, no sólo porque permite introducir un mayor número de transistores por área de silicio, sino también, porque intrínsecamente, al hacer más pequeño el dispositivo, éste se comporta mejor, es más rápido y consume menos energía, y es más barato; tal es así, que la máxima que "gobierna" la vida del ingeniero electrónico es la famosa "PPAC": power-performance-area-cost, es decir, menor potencia consumida, mayores prestaciones, menor área y menor coste.

Y precisamente aquí es donde el Prof.Cristoloveanu, y la tecnología de Silicio-sobre-Aislante han jugado y juegan hoy en día un papel fundamental. La tecnología de silicio sobre aislante explota una idea brillante que consiste en aislar una lámina de silicio de espesor nanométrico que alberga los dispositivos electrónicos, mediante una fina capa de material aislante, de un substrato de silicio de casi un milímetro de espesor que sirve de soporte mecánico para los circuitos. De esta forma los dispositivos pueden hacerse más pequeños, consumiendo menos energía, y trabajando a mayor velocidad. Y esta idea es una realidad hoy en día, gracias al trabajo pionero del Prof.Cristoloveanu y sus alumnos.

La excelencia científica y académica del Prof.Cristoloveanu, y de las contribuciones que a la tecnología microelectrónica ha aportado en sus más de cuarenta años de actividad profesional están, sin duda alguna, a la altura de los grandes pioneros que han jalonado el desarrollo de la Electrónica durante más de dos siglos, algunos de los cuales acabo de mencionar.

El Prof.Cristoloveanu ha supervisado más de 100 estudiantes de doctorado, y ha dirigido más de 110 proyectos de investigación en Francia, Estados Unidos y Korea y ha publicado mas de 400 artículos en revistas internacionales (37 artículos invitados) y más de 740 contribuciones en congresos internacionales. Ha impartido más de 200 seminarios en todo el mundo, varios de ellos en Granada, y posee 15 patentes internacionales, tres de ellas compartidas con miembros del Laboratorio de Nanoelectrónica, Grafeno y Materiales Bidimensionales de nuestra Universidad. Ha sido miembro (y presidente en numerosas ocasiones) del comité organizador de las principales reuniones científicas relacionadas con los dispositivos electrónicos a nivel mundial durante más de 30 años, siendo una referencia mundial en su campo. Su curriculum está jalonado por descubrimientos, modelos y teorías científicas que han contribuido decididamente a que la Nanoelectrónica, sea tal y como hoy la entendemos. Y así lo ha reconocido el Instituto de Ingenieros Eléctricos y Electrónicos de los Estados Unidos que en el año 2016 le concedió uno de sus más preciados galardones, el IEEE Andrew S. Grove Award, por sus contribuciones al avance de los dispositivos electrónicos.

La relación del Prof.Cristoloveanu con la Universidad de Granada se inicia hace más de 20 años. Tras mi incorporación al Departamento de Electrónica en los años 90, inicié mi tesis doctoral en la simulación de dispositivos electrónicos por el Método de Monte Carlo. En aquel tiempo, la simulación de dispositivos electrónicos era un tema candente en la esfera internacional. La tecnología electrónica empezaba a afrontar las primeras limitaciones físicas como consecuencia del escalado de los dispositivos, y era imprescindible para seguir avanzando, conocer microscópicamente qué ocurría dentro de los dispositivos, es decir, cómo se mueven los electrones en el interior del dispositivo, para de esa forma, poder hacer un diseño óptimo y una utilización eficiente de los mismos. El trabajar en un tema candente me permitió en muy corto plazo de tiempo conseguir publicaciones de impacto en revistas de prestigio, asistir a las conferencias internacionales más importantes en el campo, y hacernos un nombre a nivel internacional. Esto nos permitió participar en varios proyectos internacionales, y aprender de los mejores expertos mundiales en Simulación de Dispositivos, como el Dr. Massimo Fischetti del IBM TJ Watson Research Center en Nueva York, y del Prof. Sigfried Selberherr en la Technical University of Vienna, donde realicé varias estancias, o el Prof. Lino Regianni de la Universidad de Módena, uno de los padres del Método de Monte Carlo. Gracias a ello, contábamos con una herramienta potente que nos permitía explicar teóricamente el comportamiento experimental de los dispositivos electrónicos modernos.

Por supuesto, en aquella época, la tecnología de Silicio-sobre-Aislante, como posible tecnología candidata para desarrollar los siguientes nodos tecnológicos, estaba bajo la lupa de la comunidad científica, y cualquier publicación o resultado sobre la misma tenía un impacto importante; y así fue como la aplicación del método de Monte Carlo a la tecnología de Silicio sobre Aislante atrajo la atención del Prof.Cristoloveanu hacia nuestro grupo de investigación.

A principios del año 2000, el Prof. Sorin Cristoloveanu me propuso organizar en Granada una reunión europea para discutir el futuro de la tecnología de Silicio. Aquella reunión se celebró en la Facultad de Ciencias el 26 y 27 de octubre de 2000. De aquella reunión, a la que asistieron los principales investigadores europeos del campo, tanto de universidades, centros de investigación e industria, nació el germen de la red europea EUROSOI, de los proyectos europeos EUROSOI y EUROSOI+, de los que he sido coordinador, y de la serie de conferencias EUROSOI-ULIS que ha reunido año tras año, desde el año 2001 hasta la actualidad, a los principales actores europeos en el campo de los dispositivos electrónicos. La relación con el Prof. Cristoloveanu se ha mantenido desde entonces. Durante este tiempo, tres miembros de nuestro grupo de investigación, dos de ellos hoy profesores de nuestra Universidad, han obtenido el título de doctor por la Universidad de Grenoble, el "Silicon Valley Europeo", y han tenido el privilegio de contar con el Prof. Cristoloveanu como su director de tesis. Las publicaciones conjuntas entre miembros de la Universidad de Granada y el Prof.Cristoloveanu se cuentan por más de medio centenar. Hemos trabajado conjuntamente en 6 proyectos europeos de los diez en los que mi grupo de investigación ha participado hasta la fecha. Ha propiciado la firma de varios acuerdos de colaboración entre la Universidad de Grenoble y la Universidad de Granada (Memorandum of Understanding) para apoyar los estudios de doctorado en Ingeniería Electrónica (acuerdos de co-tutela INPG-UGR) y la solicitud del Campus de Excelencia Internacional BIOTIC de nuestra Universidad. El Prof.Cristoloveanu es responsable directo de que contemos en nuestra Universidad, en el Centro de Tecnologías de la Información y de las Comunicaciones, CITIC, con uno de los laboratorios y salas limpias de Nanoelectrónica más avanzadas de Europa: el ya mencionado laboratorio singular de Nanoelectrónica, Grafeno y Materiales Bidimensionales. Él nos ha alentado a dar este paso, y nos ha asesorado y ayudado en la configuración del equipamiento allí instalado, y que supone un orgullo para nuestra Universidad. El Prof. Cristoloveanu ayudó también a la internacionalización de nuestro Laboratorio, hoy “hermanado” con grupos de investigación de todo el mundo, incluyendo Europa, Estados Unidos, Japón, Taiwán, Corea del Sur y Australia

Pero si bien todos estos méritos que acabo de relatar ya hacen al Prof.Cristoloveanu, en mi opinión, un digno candidato al Título de Doctor Honoris Causa por la Universidad de Granada, lo que realmente hace al Prof.Cristoloveanu merecedor de pertenecer a nuestra Comunidad Universitaria es su calidad humana. La Universidad, nuestra Universidad, es un lugar de personas y para las personas, y aquí es donde la incorporación a nuestra Universidad de este profesor supone un verdadero lujo. El prof. Cristoloveanu, nació en Rumanía, hace casi 70 años. Con apenas 19 años ganó una beca para estudiar en Grenoble; pero una vez en Francia ya no volvió por las restricciones del régimen comunista. Allí, durante más de veinte años alejado de su familia, creció como científico y como persona. Estas circunstancias duras moldearon su carácter y lo hicieron una persona sencilla, cercana, generosa y leal.

El científico antes que científico es persona. Y no se puede ser buen científico si antes no se es buena persona. El científico tiene que ser generoso y honesto, tiene que ser leal, y sobre todo, tiene que ser agradecido. La generosidad y la honestidad están en el ADN del hombre de Ciencia. Y, la generosidad y la honestidad están en el ADN del Prof.Cristoloveanu.

Por todo lo expuesto, estoy convencido de que el Prof. Cristoloveanu con su excelencia científica y académica, pero también con sus valores humanos y personales, enriquecerá el Claustro de Profesores de esta Universidad casi cinco veces centenaria.

Muchas gracias.

Rectora Magnifica,
Autorithies,
Professors,
Ladies and Gentlmen,

First of all, on behalf of the Departamento de Electrónica and on my own behalf, I fully thank the support received for the proposal of Honoris Causa Doctorate for Prof. Dr. Sorin Ioan Cristoloveanu, by the Facultad de Ciencias, by the Escuela Técnica Superior de Ingeniería Informática y Telecomunicación and by the Escuela Técnica Superior de Caminos, Canales y Puertos, as well as by the approval of the Governing Board and the Claustro of the University of Granada.

Electronics have changed our lives dramatically in the second half of the 20th Century and in the first years of the 21st Century. Today, things are done in a way that was unimaginable only a few years ago, and what is more, today we would not know how to live without Electronics. In just fifty years, Electronic Technology has changed Humanity as we knew it after an evolution that lasted thousands of years.

And Prof Cristoloveanu, who is awarded today with this honorary doctorate, has contributed significantly during his long career to this change, as I will try to show in this brief intervention.

The dictionary of the Real Academia Española de la Lengua defines Electronics as "the study and application of the behavior of electrons in various media, such as vacuum, gases and semiconductors, subjected to the action of electric and magnetic fields." In other words, Electronics is "the art of playing with electrons."

And many things can be done playing with electrons. Of course, this story started many, many years ago. The study of the electrical properties of materials is an endeavor that goes back a long way. Thales of Miletus already in 600 BC commented on the ability of amber to attract other objects. Sometime later, in the year 1600 AD, William Gilbert used the Greek word for amber, "elektron", to describe the field that surrounds a charged object, and from which the terms electron, electric field, or electronics are derived.

The first advances towards a rational understanding of electricity and magnetism began to appear in the second half of the 18th Century with the pioneering experiments and theories of Cavendish, Coulomb, Gauss, Oersted, Ampere, Faraday, and many others. All these important results led Maxwell to formulate the classical theory of Electromagnetism in 1864. Towards the end of the Nineteenth Century and the beginning of the Twentieth Century, the state of science and engineering begins to enter what we might call the modern era: Thomson identified the electron around 1897 and Millikan accurately measured its charge in 1909. All of these results led to the emergence of solid-state physics and a greater understanding of the electronic properties of solids, including band theory, and the explanation of why some solids conduct electricity while others are intrinsically insulators.

The first electronic devices were involved in the development of telecommunications, which led to inventions such as the Morse electromagnetic telegraph, telephone networks, and the radio, or wireless telegraphy, invented by Tesla and Marconi around 1900, and which would become the system of long-distance communication most used in the Twentieth Century.

Despite the successes and advances achieved until the first half of the 20th Century, the devices of this time were very simple, essentially vacuum valves, made up of metal electrodes in a glass housing, and electromagnets, that is, electronic devices consisted of conductors (copper) and insulators (glass). However, in the second half of the 20th Century, electronics came to be dominated by a third material: semiconductors, with which modern electronic devices are made.

Unlike other insulators or conductors, which have a defined conductivity value, semiconductors can change their conductivity by several orders of magnitude simply by changing the temperature, adding certain impurities in concentrations of one part per million, or placing the material under the influence of light, radiation or electric and magnetic fields. In this way, by combining pieces of differently doped semiconductor materials, structures that amplify signals or act as switches can be created. Thus, in December 1947, Shockley, Bardeen, and Brattain in the Bell Laboratories of New Jersey in the United States demonstrated experimentally the operation of the junction bipolar transistor. A little bit later, in November 1959, Mohamed Atalla and Dawon Kahng successfully manufactured the first Metal-Oxide-Semiconductor field-effect transistor, which would later become the key piece of electronic technology, becoming the most manufactured device in the History of Humanity.

After the establishment of discrete solid-state devices, it became clear that finding an effective way to connect or integrate these devices in large complex circuits would be an important factor in the continued progress of Electronics.

In the late 1950s, two pioneers, Jack Kilby of Texas Instruments and Robert Noyce of Fairchild Semiconductor (later co-founder of Intel), determined the fundamental ideas and processes that would be used to integrate many electronic devices and large circuits into one semiconductor piece. The resulting integrated circuit, manufactured using silicon, is perhaps the most important technological process invented in modern history.

Since that time, microelectronics technology has evolved following the so-called Moore's law. Gordon Moore, co-founder of Intel, predicted in 1965 that the number of devices on an integrated circuit would double every two years. Since then, we do not know well if because Moore was really a prophet, or because the Microelectronics Industry has made all possible efforts, accelerating sometimes, slowing down others, to fulfill Moore's prediction, the truth is that since 1965, the number of transistors in an integrated circuit has doubled every two years, currently integrating more than 1.7 billion transistors in an integrated circuit. The scaling of electronic devices has been very important over the years, not only because it allows introducing a greater number of transistors per silicon area, but also because intrinsically, by making the device smaller, it behaves better, it is faster and less energy-consuming, and it is cheaper; so much so, that the leitmotif that "governs" the life of the electronic engineer is the famous "PPAC": power-performance-area-cost, that is, less power consumed, higher performance, smaller area, and lower cost.

And here is precisely where Prof. Cristoloveanu and Silicon-on-Insulator technology have played and play a fundamental role today. Silicon-on-insulator technology exploits a brilliant idea that consists of isolating a nanometer-thick silicon sheet that houses the electronic devices, by means of a thin layer of insulating material, from a silicon substrate almost one millimeter thick that serves as mechanical support for circuits. In this way, devices can be made smaller, consuming less energy, and working faster. And this idea is a reality today, thanks to the pioneering work of Prof. Cristoloveanu and his students.

The scientific and academic excellence of Prof. Cristoloveanu and the contributions that he has made to microelectronic technology in his more than forty years of professional activity are, without a doubt, on a par with the great pioneers who have marked the development of Electronics for over two centuries, some of which I just mentioned.

Prof Cristoloveanu has supervised more than 100 doctoral students, and has led more than 110 research projects in France, the United States, and Korea, and has published more than 400 articles in international journals (37 guest articles) and more than 740 contributions in international conferences. He has given more than 200 seminars around the World, several of them in Granada, and holds 15 international patents, three of them shared with members of the Nanoelectronics, Graphene, and Two-Dimensional Materials Laboratory of our University. He has been a member (and president on numerous occasions) of the organizing committee of the main scientific meetings related to electronic devices worldwide for more than 30 years, being a world reference in the field. His curriculum is marked by discoveries, models, and scientific theories that have contributed decisively to the fact that Nanoelectronics is as we understand it today. And this has been recognized by the Institute of Electrical and Electronics Engineers of the United States, which in 2016 granted him one of its most precious awards, the IEEE Andrew S. Grove Award, for his contributions to the advancement of electronic devices.

Prof. Cristoloveanu's relationship with the University of Granada began more than 20 years ago. After joining the Department of Electronics in the 90s, I started my doctoral thesis in the simulation of electronic devices by the Monte Carlo Method. At that time, electronic device simulation was a hot topic in the international arena. Electronic technology began to face the first physical limitations as a consequence of the scaling of the devices. To go on advancing, it was essential to know microscopically what was happening inside the devices, that is, how the electrons move inside the device. Working on a hot topic allowed me in a very short time to get impact publications in prestigious journals, and attend the most important international conferences in the field. We also participated in several international projects, and learn from the best World experts in Device Simulation, such as Dr. Massimo Fischetti of the IBM TJ Watson Research Center in New York, and Prof. Sigfried Selberherr at the Technical University of Vienna, or Prof. Lino Regianni from the University of Modena, one of the fathers of the Monte Carlo Method. Thanks to this, we had a powerful tool that allowed us to theoretically explain the experimental behavior of modern electronic devices.

At that time, Silicon-on-Insulator technology, as a possible candidate technology to develop the following technological nodes, was under the watchful eye of the scientific community, and any publication or result about it had an important impact;

This is how the application of the Monte Carlo method to Silicon on Insulator technology attracted Prof. Cristoloveanu's attention to our research group.

At the beginning of 2000, Prof. Sorin Cristoloveanu suggested me to organize a European meeting in Granada to discuss the future of Silicon-on-Insulator technology. The conference was held at the Faculty of Sciences on October 26 and 27, 2000. That meeting, which was attended by the main European researchers in the field, both from universities, research centers, and industry, was the germ of the European network EUROSOI, of the European projects EUROSOI and EUROSOI +, and of the series of conferences EUROSOI-ULIS that has brought together year after year, from 2001 to the present, the main European actors in the field of electronic devices. The relationship with Prof. Cristoloveanu has continued ever since. During this time, three members of our research group, two of them today professors at our University, have obtained their doctorate from the University of Grenoble, the "European Silicon Valley", and have had the privilege of having Prof.Cristoloveanu as their thesis supervisor. The joint publications between members of the University of Granada and Prof. Cristoloveanu number more than fifty. We have worked together on 6 European projects of the ten in which my research group has participated to date. He has led to the signing of several collaboration agreements between the University of Grenoble and the University of Granada (Memorandum of Understanding) to support doctoral studies in Electronic Engineering (co-tutelage agreements INPG-UGR) and the request for the Campus of Excellence International BIOTIC of our University. Prof Cristoloveanu is directly responsible for the fact that our University has one of the most advanced laboratories for Nanoelectronics in Europe: the aforementioned laboratory of Nanoelectronics, Graphene, and Two-Dimensional Materials. He has encouraged us to take this step and has advised and helped us in the configuration of the equipment installed there, and that is a source of pride for our University. Prof. Cristoloveanu also helped to internationalize our Laboratory, today "twinned" with research groups from all over the world, including Europe, the United States, Japan, Taiwan, South Korea, and Australia.

But although all these merits that I have just related already make Prof.Cristoloveanu, in my opinion, a worthy recipient of Doctor Honoris Causa's degree by the University of Granada, which really makes Prof. Cristoloveanu worthy of belonging to our Community is his human quality. The University is a place of people and for people, and this is why the incorporation of this professor into our 500 years-old University is a real luxury. Prof.Cristoloveanu, was born in Romania, almost 70 years ago. At just 19 years old, he won a scholarship to study in Grenoble; but once in France he no longer returned due to political constraints by the communist regime. There, for more than twenty years away from his family, he grew up as a scientist and as a person. These harsh circumstances shaped his character and made him a simple, close, generous, and loyal person.

The scientist before being a scientist is a person. And you cannot be a good scientist if you are not a good person first. The scientist has to be generous and honest; he has to be loyal, and above all, he has to be grateful. Generosity and honesty are in the DNA of the man of Science. And, generosity and honesty are in Prof. Cristoloveanu's DNA.

For all the above, I am convinced that Prof. Cristoloveanu, with his scientific and academic excellence, but also with his human and personal values, will enrich the Board of Profesors of this University, almost five times a century old.

Thank you.

DISCURSO PRONUNCIADO POR EL EXCELENTÍSIMO SEÑOR D. SORIN IOAN CRISTOLOVEANU CON MOTIVO DE SU INVESTIDURA COMO DOCTOR *HONORIS CAUSA*

Rectora Magnífica
Autorithies,
Professors,
Ladies and Gentlmen,

Speech of Sorin Cristoloveanu for DHC ceremony

To: ….

Buenos dias, Good morning, Bonjour Ladies and Gentlemen,

Today is a magnificent, memorable day that brings me two honors simultaneously. First one is the title of Doctor Honoris Causa. Second, this outstanding distinction comes from my dear friend, the University of Granada.

Dear Rector, dear Colleagues,

My gratitude is infinite for your kind appreciation of my work and career. More importantly, this distinction demonstrates the privileged attention the University of Granada grants to our field of research covering the nanosize electronic devices.

The nanoelectronics is not a revolution. It is the inherent sequel of downscaling to nanometers the microelectronic devices. But, the microelectronics was a massive revolution indeed. The nanoelectronic products have more impact on our society than politics and religions. Whether this is admirable or devastating does not really matter ; the progress is exponential and ineluctable, it cannot be slowed down or interrupted. We have to live with.

Ladies and Gentlemen, please let me clarify the segment of nanoelectronics our group is involved in. Our specialty is the transistor with ultrathin body, preferably fabricated with Silicon On Insulator (SOI) technology.

SOI Saga started about 60 years ago, shortly after the release of the first MOS circuits. It has been realized that they were insufficiently protected to withstand transient radiation effects. The only way to counteract the dreadful effect of incoming particles is to cut the thickness by a factor of thousand and place a thin transistor on an insulating substrate. This is how Silicon On Sapphire (SOS) was born, kind of SOS distress signal generated by the threat of the cold war. Remember, it was the time of Brejnev's music, not only that of The Beatles. Being an expensive technology, it is under impulse from defense that SOS has further been developed. It certainly did not come out from a splendid vision that 60 years later SOI will be a necessary part in all smartphones.

By the end of the 70's, it became clear that SOS was not the best choice. A horde of alternative SOI structures started to invade the arena where brilliant specialists from Europe, USA and Japan were fighting. It was the time of great creativity when the physics of SOI transistors became pretty much understood. Double-gate MOSFETs, three-dimensional monolithic circuits, gate-all-around transistor, and some carnival devices came out revealing a symphony of special SOI effects. But, when too many SOI materials keep competing, none is really convincing...

It took one more decade before Soitec company was launched as a spin-off from LETI in Grenoble and brought on the wafer market the incredibly-smart Ion Cut technology. It was of course named Smart Cut and instantly promoted as the leading SOI technology. In the last 25 years, one-by-one the other SOI materials gave up. Smart Cut provides excellent crystal quality, flexible dimensions and mass production. Although Smart-Cut encouraged new materials to bond together, the divorce of the old couple, silicon and silicon-oxide, is seemingly impossible.

The flatness of an SOI wafer with 30 cm diameter is mesmerizing, within a few angstroms only. It is like travelling from Grenoble to Granada through the Alps and Sierra Nevada mountains not higher than 1 mm.

It has been evident for a long time that fully-depleted SOI is best equipped to address the ultimate phases of the electronic device miniaturization. It was also the credo of our SOI teams in Granada and Grenoble. Devices with ultrathin body are more immune to adverse parasitic effects. SOI wafers feature nowadays a silicon film thinner than 10 nm separated from 1 mm substrate by 20 nm thick insulator. In order to fully comprehend this technological achievement, just imagine a cargo travelling an ocean just a few meters deep. No waves or tsunamis, higher speed, reduced consumption. This is exactly what happens in advanced SOI transistors where the electrons move faster and dissipate less energy. An SOI chip with hundred billions of transistors is fast, robust and energy efficient. Here is where we are today.

What is the side of the SOI story I lived within? In the mid-70s, I was desperately struggling for my PhD. The topic was a shame but paid for my bred and bed, not much more. I learned and decided two things: (i) my future PhD students will be offered captivating topics and (ii) any other area of research would be a marvel. Given my experience to manipulate magnetic fields, a nice fellow asked me to have a look at magnetodiodes made on SOS. I jumped into this topic with boundless enthusiasm. It turned out to be a very good decision. The second great decision at the same time was to fall on my knees and beg Muriel to become my wife.

Only once I put a finger in SOI, did I realize I could not escape from it. We worked hard, had some good ideas and a lot of luck. Still I wonder how we could manage to receive recognition in the SOI circus so quickly. I would like to dedicate this incomparable distinction today to all respectable colleagues of us who have produced remarkable thinking and solid work without having the chance of being rewarded.

Over the years, I got involved in lots of other thrilling subjects that, at the end of the day, were kind of hobbies because I always came back to my old SOI passion. Muriel, my perfect wife, knew how to compose with the double life of mine.

My chance was to work with more than hundred PhD students, all very good, some amazingly gifted, better than me. I learned a lot from them, albeit they were kindly feigning I was still guiding them. I would love them being here to share this unforgettable day.

Our core activity in the early period encompassed material and device developments and in-depth characterization. Our Pseudo-MOSFET technique has become an industrial standard and contributed to the rapid evolution of Smart-Cut and other materials at SOITEC and in SOI-related companies.

We anticipated quite early the potential of the fully-depleted SOI technology in the consumer market, much larger, more thrilling and more competitive than the confidential segment of radiation-hard devices. In the latter period, the centroid of our research moved toward the conception of novel devices with enhanced performance and functionality.

We assume the paternity of the simplest transistor (zero-gate) and of the most complicated one (four gates). The latter features independent gates that enable unique flexibility for reconfigurable circuits with low transistor count.

Many emerging devices wouldn't have been discovered had SOI not been around. Electrostatic doping, junctionless transistor and quantum devices are just unimaginable without an ultrathin body. Band-modulation and electrostatic doping are physics concepts unheard of 20 years ago. Volatile, non-volatile and universal memory devices, ideal transistors with abrupt switching capability, and tunneling transistors off the beaten path are selected examples of such revolutionary devices.

The 'volume inversion' mechanism was discovered too early and passed unnoticed for a while. Fortunately a decade later, strong support came from our colleagues from the University of Granada who promoted the mechanism as being inexorable in all small-body devices.

We unveiled several other effects that take place in advanced transistors, either ultrashort or ultrathin. Our world record 20 years ago was an SOI transistor comprising only three monolayers of silicon on top of each other. As impossible as it may look, this record has already been broken by other groups who demonstrated device functionality in just one monolayer.

It is in the corridors of the SOI club that I learned how to listen to bright people and also how to fight deep in the microelectronics jungle when provoked by nasty opponents to SOI. I enjoyed endless this open-minded and interactive community which, over the years, upgraded my status from 'SOI pioneer' to 'surviving SOI dinosaur'. I would prefer being considered as a tireless, faithful advocate of SOI.

I tried to spread the SOI word everywhere. The outcome was fruitful collaborations with excellent groups and about one thousand colleagues. Spread over all continents, they are more than co-authors, they are our friends. One of them likes to say that friendship is actually proportional to distance.

Our results were disseminated in many (probably too many) publications. Out of 1200, I sincerely do not regret any. We are quite proud of some of them. Ironically, the most innovative papers had a hard time to get published; they were rejected a few times because the reviewers were not prepared to understand their novelty.

In a few weeks from now, a new book dedicated to SOI will be published. I completed it during the grey months of our war against the coalition of Covid virus and insidious computer viruses.

One night about 30 years ago, we were driving back from Fuengirola beach to Grenoble. Crossing through Granada, Muriel said: ‘We cannot stop, but please bring me back some day to visit this famous castle.’

A few years later, I started to read papers produced by a young brilliant fellow, Professor Francisco Gamiz. I was astonished by the originality of his simulations, nothing but Monte Carlo in Granada, and the bright horizon he predicted for multi-gate transistors on SOI. We started immediately an exemplary cooperation which by now amounts more than 100 joined publications. This was possible through frequent mutual visits, data exchange, and financed projects. Many students from the University of Granada achieved their PhD in Grenoble, often in sandwich doctorate programs. Several are today professors. We have invented a few stunning devices, which by now are our floating-body memories. Our success story includes new characterization techniques tailored for thin semiconductor devices and the discovery of several size-related physics mechanisms. The characterization laboratory of the University of Granada is a replica of our platform in Grenoble, put together after most fruitful discussions.

Paco and I have initiated a European consortium named EuroSOI as well as a string of dedicated conferences. They run every year and attract more than 100 participants. A special issue of Solid-State Electronics journal is devoted to contributions from the conference. Several editions took place in Granada and in Grenoble but not only. Many other towns across Europe have been proud to organize the conference.

A milestone in our cooperation is worth reminding: the European project 'Reminder' dedicated to nano-memory devices. 10 institutes have been associated for 4 years, with a budget amounting circa 5 M€. Professor Gamiz was the coordinator of this successful program that proposed a paradigm shift with incredible societal implications. The domain of memory chips with increasing capacity, lower cost and reduced consumption is the most vivid segment of the microelectronics industry. The participants started with benchmarking existing devices, then selected to investigate a tremendously original variant originated from our consortium and, finally, built up convincing demonstrators. It is still a long way before competing in the terra-bit memory contest but the premises are solid. Other fascinating ramifications of this work aim at the upcoming field of brain-inspired computing.

What about the future? The development of the nanoelectronics will continue at a steady step. We will face transistors with 1001 atoms or less, one silicon atom for each night dream. The market-share gained by SOI products will grow even faster. Already present in all smartphones, SOI will next conquer the domains of smart cars and low-energy wearable electronics.

For my next life after this one, it has already been decided that I will again be working on nano-devices. My plan is to be a Professor at the University of Granada, hoping a distinction from the Polytechnic Institute in Grenoble.

Muchas gracias, Merci beaucoup,

Sorin