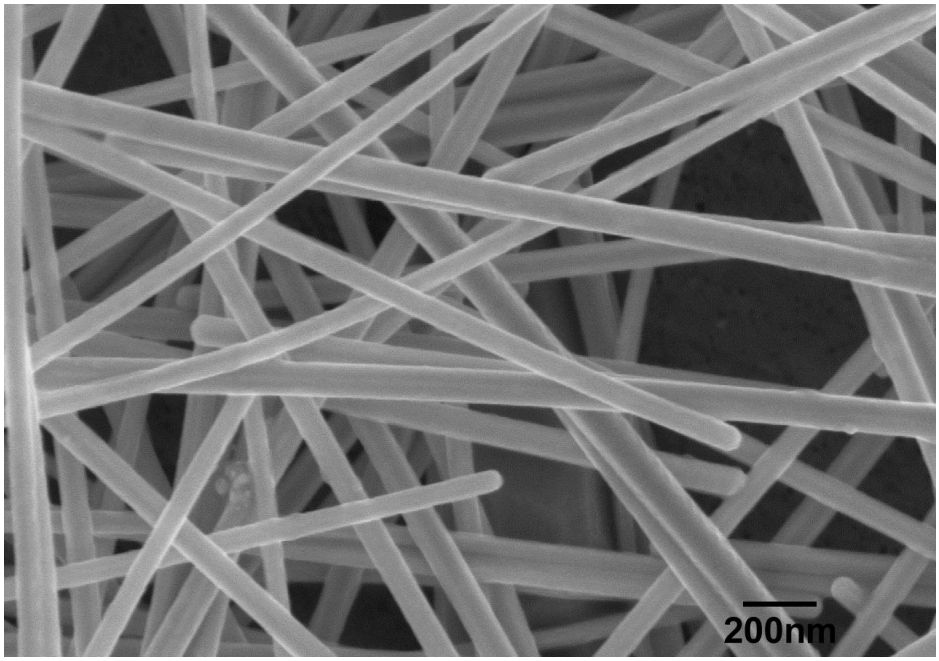
Graphene and silver nanowire hybridization for the fabrication on transparent conductors

Hibridização de grafeno com nanofios de prata para a fabricação de condutores transparentes.



Gestão de Ciência e Tecnologia
Mestrado Integrado em Engenharia Física Tecnológica, 4ºAno

Instituição Proponente:
Instituto de Engenharia de Sistemas e Computadores – Microsistemas e Nanotecnologias (INESC MN)

Grupo:
António Balula - 72735
Luís Macedo - 73633
Pedro Ribeiro – 73221

1. Identificação do projeto

1. Project description –

Domínio Científico
Scientific Domain

Ciências Exactas e da Engenharia

Área científica principal
Main Area

Ciência e Engenharia de Materiais

Área científica Secundária
Secondary area

Nanomateriais e Dispositivos

Acrónimo
Acronym

SiGrahTraCo

Título do projeto (em português)
Project title (in portuguese)

Hibridização de grafeno com nanofios de prata para a fabricação de condutores transparentes.

Título do projeto (em inglês)
Project title (in english)

Graphene and silver nanowire hybridization for the fabrication on transparent conductors.

Financiamento solicitado
Requested funding

108.126,62

Palavra-chave 1 Keyword 1
Filme fino condutor transparente-Transparent Conducting Thin Film

Palavra-chave 2 Keyword 2
Nanofios de prata-Silver Nanowire

Palavra-chave 3 Keyword 3
Grafeno-Graphene

Palavra-chave 4 Keyword 4
Integração Híbrida – Hybrid Integration

Data de início do projeto
Starting date
1-10-2015

Duração do projeto em meses
Duration in months
18

2. Instituições envolvidas
2. Institutions and their roles –

Instituição Proponente
Principal Contractor
Instituto de Engenharia de Sistemas e Computadores – Microsistemas e Nanotecnologias (INESC MN)

Descrição da Instituição
INESC Microsisteemas e Nanotecnologias (INESC MN) is a private, non-profit Research and Development institute created in January, 2002 from the former Solid State Technology group of INESC. INESC MN operates a Class 100/10 cleanroom with optical and e-beam lithography allowing nanoscale device fabrication.
INESC MN is dedicated to:

-leading edge research and development in strategic technological areas of micro- and nanotechnologies and the application of these technologies to electronic, biological and devices;

-advanced training of young and engineers at the university, post-graduate and post-doctoral levels in micro- and nanotechnologies;

-transfer of technology to both Portuguese and international industries through collaborative research, contract research, prototyping and consulting.

Research areas:

-Magnetics
-Thin Film MEMS
-Biosensor and Biomedical Applications
-Organic Electronics
-Simulation of Materials

Instituição Participante
Participating Institution
Non applicable

Descrição da Instituição
Participating Institution Description
Non applicable

Unidade de Investigação
Research Unit
Instituto de Engenharia de Sistemas e Computadores – Microsistemas e Nanotecnologias (INESC MN)

Unidade de Investigação Adicional
Additional Research Unit
Non applicable

Instituição de Acolhimento
Host Institution
Instituto de Engenharia de Sistemas e Computadores – Microsistemas e Nanotecnologias (INESC MN)

3. Componente Científica
3. Scientific Component –

3.1. Sumário (5000 caracteres)
3.1 Abstract

3.1.a Em português
3.1.a In Portuguese

A invenção de condutores transparentes veio revolucionar a indústria eletrónica de consumo, levando ao surgimento do ecrã táctil, implementado atualmente em todos os smartphones disponíveis comercialmente, e levando a novos desenvolvimentos na conversão de energia solar em eletricidade.

Devido à grande procura de condutores transparentes existente atualmente, um dos compostos necessários para fabricar estes condutores, o ITO (indium-tin oxide), tem sofrido uma enorme procura a nível mundial o que resulta numa elevada extração deste material, o que tem levado à subida imparável do preço deste recurso e à depleção das reservas existentes, que se estima que terminem em 2027. Desta forma, existe interesse em desenvolver e produzir de forma económica uma alternativa à tecnologia utilizada atualmente.

Já foram testados protótipos de condutores transparentes produzidos com vários materiais emergentes e com bons resultados, como por exemplo ecrãs fabricados com elétrodos de grafeno, nanotubos de carbono e nanofios de prata. No entanto estes protótipos não são viáveis comercialmente, principalmente devido aos elevados custos de produção destes materiais.

Propõe-se neste projeto a fabricação e teste de um condutor transparente fabricado com um híbrido entre grafeno e nanofios de prata, que se prevê que reduza a densidade necessária para a camada de nanofios de prata, o que poderá tornar um ecrã táctil fabricado com materiais alternativos comercialmente viável.

3.1.b Em ingles

3.1.b In English

The invention of transparent conductors revolutionized the consumer electronics industry, leading to the creation of the touchscreen, currently implemented on all smartphones available commercially, and to new developments on the solar-to-electric energy conversion.

However due to the increasing demand of transparent conductors nowadays, one of the materials needed in their fabrication process, ITO (indium-tin oxide), has also been subject to an increase of its already high demand, leading to the ever increasing cost of this resource and the depletion of its existing reserves, estimated to end by 2027. Thus there is great interest in developing and producing a cheap alternative to the current technology.

Prototypes of transparent conductors produced with several emerging materials, like graphene, carbon nanotubes and silver nanowires, have already been produced yielding good results. However these prototypes aren't commercially viable, due to their extremely high production cost.

In this project, our proposal is to project, manufacture and test a transparent conductor fabricated using a graphene and silver nanowire hybrid, resulting on a lower density of deposited silver nanowires and graphene, according to our predictions, allowing for a commercially viable touchscreen fabricated with alternative materials.

3.2. Descrição Técnica

3.2 Technical Description

3.2.1. Revisão da Literatura (6000 caracteres)

3.2.1. Literature Review

In a great number of electronic devices, such as liquid-crystal displays, photovoltaics, thin film transistors and touch screen panels, transparent conductive thin films (TCF) are a key component [13].

Indium tin oxide (ITO) films are widely used in these applications due to their high electrical conductivity and optical transparency, but also seriously limit flexibility and require high processing temperatures. Its rising global demand as also increased costs. Therefore, a practical, cost-effective and mechanically flexible alternative for ITO is necessary [8].

A suitable substitute for ITO is PEDOT:PSS, which is a conductive polymer system with good mechanical properties. However, its conductivity and transparency are not sufficient for many applications [14, 15].

A replacement material for ITO is required to have 1) a sheet resistance of less than 100 Ω/sq 2) optical transparency greater than 90% and 3) unlimited scalability. DC conductive to optical conductivity ratio shall be greater than 35 [12].

Silver nanowire networks, graphene thin films and carbon nanotube (CNT) thin films can overcome many of the shortcomings inherent in ITO and can be highly conductive with good transparency and extreme flexibility. [13]

Silver nanowires are small (about 100nm diameter, 20μm length) silver wires with excellent electrical properties, being studied to be used in flexible conductors. They

exhibit great stress resistance and, if deposited in low densities, high transparency but a smaller than desirable conductivity, due to a small number of connections between wires. In order to obtain ITO-grade conductivity, high density depositions are required, increasing the cost of the final device [10].
Graphene is a single layer of pure carbon, forming a 2-dimensional material in a hexagonal honeycomb lattice. It exhibits excellent electrical, thermal and mechanical properties. As with silver nanowires, a denser deposition pattern is required to achieve ITO-grade conductivity. Technological limitations result in high prices for quality graphene flakes, thus making graphene only solutions not commercially viable [16].
A carbon nanotube thin film can overcome many of the above shortcomings, as it can be made highly conductive, with good transparency and flexibility. Scale is the limiting factor in this case [17].
Hybrid materials aim to make use of the advantages of each component and to create synergies between them [1].
Previous work on silver nanowires graphene hybrids has been performed, showing improved properties, but no optimization with a computer model was performed [11, 9]

3.2.2. Plano e Métodos (10000 caracteres)

3.2.2. Plan and Methods

As it was already mentioned before, the nowadays touch screens are made by using ITO (indium-tin oxide). However, it is predictable that this material will run out within 15 years, that will cause the rise of the price of the material and so we need to find an alternative. It was already proposed the usage of Silver nanowires (AgNWs) and it was proved that this could be a good alternative to ITO. However, there are some problems that appear when using AgNWs that are related to the electron transport between each one of the nanowires, so this means that an impedance greater than the one that is desired. This could be solved by using a greater density of AgNws, but then the solution wouldn't become viable, economically speaking. The impedance can be minimized by combining the nanowires with other nanostructures.

What we propose is to combine the AgNWs with graphene, due to its mechanical and electrical properties. So, with this proposal we want to develop a sustainable alternative to ITO, improve the touch screen's impedance and transmission, reduce the cost of fabrication of this type of screens and also enlarge the utilization spectra of the touch screen, since that the ITO is a brittle material so it is only used on flat surfaces. Given the properties of graphene we believe that will be possible to enlarge the utilization spectra of touch screens also to curve surfaces.

To make this objective possible we divided our work on three main tasks:

-Theoretical study and structure modulation (main task 1)
-Manufacture (main task 2)
-Characterization (main task 3)

In the first main task we seek to develop a theoretical model to describe our structure so that we can then compare the results that we will actually obtain, after the characterization, with our theoretical model. The task leader will be António Balula.

In the second main task we will proceed to the structure manufacture using spray coating to deposit the AgNWs (since this method allows the control of a

variety of parameters such as pressure and temperature) and we will use the INESC-MN's machine of graphene deposition to create the hybrid AgNWs/graphene. The task leader will be Luís Macedo.

Spray coating is a technique that uses an arc that is formed between two electrodes in a plasma forming gas. The plasma is heated by the arc and so it will expand and is accelerated through a nozzle.

In the third main task we will then characterize our structure in terms of electrical, optical and structural properties. Also we collect this data we will compare it to the theoretical model concerning main task 1. The task leader will be Pedro Ribeiro.

When we talk about characterization there are a lot of measurements that are needed. In this work we will measure the following quantities:

-Electrical quantities
    -Impedance and reactance of the material
    -Response in frequency
    -Determination of the electrical limits for which the material has de wanted behavior

-Optical Quantities
    -Transmission coefficient for visible light
    -Study of the electrical response of the material varying the wavelength of incident light
-Structure of the material
    -Measurement of the optical and electrical response by applying torsion on the structure
    -Structural integrity of the material
-Data analysis
    -Fit of the experimental results with the theoretical model

This project has an ambitious goal but our goal is also a need since it is predictable that we will run out of ITO within 15 years, so we are confident that our AgNWs/graphene hybrid will be a reliable option to this material. Also, if our expected results are confirmed it will have an impact not only scientifically but also economically, since the touch screens will be less expensive to produce.

The partner involved in this project is INESC-MN that has a strong background on deposition and characterization of structures so it is a very good partner to this project, not only because of the knowledge but also because of the infrastructures. The principal investigator of this project will be Susana Freitas witch has extended experience on the fabrication and optimization of structural devices.

3.2.3. Tarefas

3.2.3. Tasks

Ordem	Designação da tarefa	Data de início	Data de fim	Duração	Pessoas * mês
Order	Task denomination	Start date	End date	Duration	Person * months
1	Kick-off meeting	1-10-2015	1-10-2015	0	0

Descrição da tarefa e Resultados Esperados (4000 caracteres)

Task description and Expected results

Official start of the project. This meeting will have an introductory character and will serve the purpose of discussing dates issues.

Membros da equipa de investigação nesta tarefa

Members of the research team in this task

Susana Isabel Pinheiro Cardoso de Freitas; Luís Filipe Guedelha Macedo; Pedro Manuel Quintela Ribeiro; António Samuel Ávila Balula; Pancráceo José Adelino Silva; Fracesca Toblerone Malakova; Bolseiro de Iniciação à Investigação; Bolseiro de Investigação (Licenciado) 1; Bolseiro de Investigação (Licenciado) 2

Ordem	Designação da tarefa	Data de início	Data de fim	Duração	Pessoas * mês
Order	Task denomination	Start date	End date	Duration	Person * months
2	Simulation-Stage 1	1-10-2015	30-06-2016	9	19.8

Descrição da tarefa e Resultados Esperados (4000 carcateres)

Task description and Expected results

Preparations of silver nanowire/graphene hybrid transparent conductive thin films require the definition of several parameters. To achieve ITO-grade characteristics of conductivity and transparency, these have to be carefully selected.
The main objectives of this task are to:
1) develop a simple computer model relating controllable parameters and macroscopic properties;
2) simulate a great number of possible configurations that lead to desirable properties within the model;
3) select a list of configurations to be manufactured and tested in following tasks;
4) produce documentation, describing the work performed.

The model to be developed will be based on a geometric analysis of the randomly deposited silver nanowires and graphene sheets. Chemical considerations are to be taken into account to predict the electrical connections between the two. For a given simulated random sample a graph is to be constructed, from which the material electrical and optical characteristics are to be calculated.
Simulation will use Monte Carlo methods to optimize the macroscopic properties and will require a computer cluster. Due to the parallel nature of the calculations, a GPU cluster is preferable, as it offers better performance for a given cost.

A suitable set of configurations, which take into account possible errors in the model, is to be selected, making possible to test the simulation results in experimental depositions.
This task is to be performed under the supervision of António Samuel Ávila Balula.
As the manufacturing process requires the definition of a set of specifications, this task success is key to the following tasks.

Membros da equipa de investigação nesta tarefa

Members of the research team in this task

António Samuel Ávila Balula; Susana Isabel Pinheiro Cardoso de Freitas; Pancráceo José Adelino Silva; Bolseiro de Investigação Licenciado

Ordem Order	Designação da tarefa Task denomination	Data de início Start date	Data de fim End date	Duração Duration	Pessoas * mês Person * months
3	Manufacturing-Stage 1	1-01-2016	31-08-2016	8	12.5

Descrição da tarefa e Resultados Esperados (4000 carcateres)

Task description and Expected results

This task involves using spray coating to deposit the Silver nanowires on the substrate. After this deposition is complete we will proceed to the graphene deposition using the Black Magic machine on INESC-MN

Membros da equipa de investigação nesta tarefa

Members of the research team in this task

Luís Filipe Guedelha Macedo; Francesca Toblerone Malakova; Susana Isabel Pinheiro Cardoso de Freitas; Bolseiro de Iniciação Científica

Ordem Order	Designação da tarefa Task denomination	Data de início Start date	Data de fim End date	Duração Duration	Pessoas * mês Person * months
4	Characterization – Stage 1	01-04-2016	30-09-2016	6	16.44

Descrição da tarefa e Resultados Esperados (4000 carcateres)

Task description and Expected results

Within this task, the transparent conductors that were fabricated will be tested in order to characterize the electrical, optical and other physical properties (such as the variation of the electrical and physical properties to stress and strain) in function of their density of silver nanowires and thickness of graphene. These experimental results will be adjusted and compared to their theoretical counterparts.

Electrical Measurements – A measurement of the resistivity, capacitance and inductance will be made for the various conductors with different characteristics that were produced. A study of the electrical limits of the conductor such as the maximum power that can be dissipated will be performed.

Optical Measurements – The transparency of the conductor will be measured in terms of its transmittance within the spectrum from the near-infrared to near-ultraviolet with a spectrophotometer. A study of the electrical response of the material with the variation of the incident light wavelength will also be conducted.

Other physical properties – The resistance of the material to strain and stress will be measured in terms of the variation of its optical and electrical characteristics after prolonged physical stress.

Data analysis – A relation between the measured resistance of the conductor and its respective transmittance and density of silver nanowires and graphene will be calculated and compared with the predicted data from the simulations. The disparities observed between these results will be then used by the simulation and modelling group to improve their program on the 2nd phase.

Membros da equipa de investigação nesta tarefa

Members of the research team in this task

Pedro Manuel Quintela Ribeiro; Francesca Toblerone Malakova; Susana Isabel Pinheiro de Cardoso Freitas; Bolseiro de Investigação Licenciado 2

Ordem	Designação da tarefa	Data de início	Data de fim	Duração	Pessoas * mês
Order	Task denomination	Start date	End date	Duration	Person * months
5	Simulation-Stage 2	1-07-2016	31-12-2016	6	13.2

Descrição da tarefa e Resultados Esperados (4000 carcateres)

Task description and Expected results

The model and simulation performed on task 2 (simulation stage 1) is expected to have discrepancies from real devices. By analyzing the results of the characterization stage 1, the model developed will be corrected. Goals are similar to the 1st stage.

Membros da equipa de investigação nesta tarefa

Members of the research team in this task

António Samuel Ávila Balula; Susana Isabel Pinheiro Cardoso de Freitas;Pancráceo José Adelino Silva; Bolseiro de Investigação Licenciado 1

Ordem	Designação da tarefa	Data de início	Data de fim	Duração	Pessoas * mês
Order	Task denomination	Start date	End date	Duration	Person * months
6	Manufacturing-Stage 2	1-09-2016	31-01-2017	5	8.2

Descrição da tarefa e Resultados Esperados (4000 carcateres)

Task description and Expected results

This task will be very similar to task number 2, with the exception that the deposition parameters used will take into account the results of the first stage of characterization and simulation. The same techniques will be used but with different parameters.

Membros da equipa de investigação nesta tarefa

Members of the research team in this task

Luís Filipe Guedelha Macedo; Francesca Toblerone Malakova; Susana Isabel Pinheiro Cardoso de Freitas; Bolseiro de Inciciação Científica

Ordem Order	Designação da tarefa Task denomination	Data de início Start date	Data de fim End date	Duração Duration	Pessoas * mês Person * months
7	Characterization – Stage 2	1-10-2016	31-03-2017	6	16.44

Descrição da tarefa e Resultados Esperados (4000 carcateres)

Task description and Expected results

Within this task, the transparent conductors that were fabricated will be tested in order to characterize the electrical, optical and other physical properties (such as the variation of the electrical and physical properties to stress and strain) in function of their density of silver nanowires and thickness of graphene. These experimental results will be adjusted and compared to their theoretical counterparts.

Electrical Measurements – A measurement of the resistivity, capacitance and inductance will be made for the various conductors with different characteristics that were produced. A study of the electrical limits of the conductor such as the maximum power that can be dissipated will be performed.

Optical Measurements – The transparency of the conductor will be measured in terms of its transmittance within the spectrum from the near-infrared to near-ultraviolet with a spectrophotometer. A study of the electrical response of the material with the variation of the incident light wavelength will also be conducted.

Other physical properties – The resistance of the material to strain and stress will be measured in terms of the variation of its optical and electrical characteristics after prolonged physical stress.

Data analysis – A relation between the measured resistance of the conductor and its respective transmittance and density of silver nanowires and graphene will be calculated and compared with the predicted data from the simulations. This data will be adjusted to theoretical prediction and the results condensed to be published and released to the scientific community.

Membros da equipa de investigação nesta tarefa

Members of the research team in this task

Pedro Manuel Quintela Ribeiro; Francesca Toblerone Malakova; Susana Isabel Pinheiro de Cardoso Freitas; Bolseiro de Investigação Licenciado 2

3.2.4. Calendarização e Gestão do Projeto

3.2.4. Project Timeline and Management

3.2.4.a Descrição da Estrutura de Gestão (3000 caracteres)

3.2.4.a Description of the Management Structure

The management of the project will be composed by a responsible investigator that will supervise simultaneously all three investigation groups and each group will have a coordinator that will supervise and guide the investigators and grantees working in each of the groups. These investigators will have regular reports of the developed work with the responsible investigator and between themselves to ensure that all the tasks are completed within the deadlines established in order to ensure the minimum delays possible and the consolidated advance of the project.
The responsible investigator and the three coordinators will form an executive board that can propose and decide about possible changes on the course of the investigation. The responsible investigator has the quality vote in case of a draw.
An organigram of the management structure is attached.

3.2.4.b Lista de Milestones

3.2.4.b Milestone List

Data	**Designação da milestone**
Date	**Milestone denomination**
31-03-2016	Simulation results ready for fabrication –stage 1

Descrição

Description

At this point, the simulation must have been completed and shall have produced a list of parameters to the fabrication stage to perform.

Data	**Designação da milestone**
Date	**Milestone denomination**
31-03-2016	Fabrication process optimized

Descrição

Description

The research and optimization of the fabrication process is ready. Start of the fabrication with parameters from the simulation group.

Data	**Designação da milestone**
Date	**Milestone denomination**
31-06-2016	Completion of simulation –stage 1

Descrição
Description

End of the first stage of the simulation. At this point all documentation relative to the developed model must have been produced.

Data	Designação da milestone
Date	Milestone denomination
31-07-2016	Structures ready for characterization

Descrição
Description

All the desired structures are manufactured and are ready for the characterization process.

Data	Designação da milestone
Date	Milestone denomination
01-08-2016	Completion of characterization – Phase 1

Descrição
Description

End of the first phase of the characterization of the material produced in the lab.

Data	Designação da milestone
Date	Milestone denomination
1-09-2016	Paper on manufacturing process

Descrição
Description

One paper relative to the first stage of the manufacturing process is complete.

Data	Designação da milestone
Date	Milestone denomination
31-09-2016	Simulation results ready for fabrication –stage 2

Descrição
Description

Taking into account the results produced by the characterization process, the simulation is corrected and new sets of parameters are now available.

Data	Designação da milestone
Date	Milestone denomination
01-10-2016	Elaboration of articles about characterization

Descrição
Description

Elaboration of articles and documentation about the first phase of characterization of the fabricated materials is completed.

Data	Designação da milestone
Date	Milestone denomination
31-11-2016	Second stage of manufactured structures ready for characterization

Descrição
Description

All the new manufactured structures, with different characteristics from the first ones, are ready for the characterization process.

Data	Designação da milestone
Date	Milestone denomination
31-12-2016	Completion of simulation –stage 2

Descrição
Description

End of the second stage of the simulation. At this point all documentation relative to the developed model, corrected with experimental results must have been produced.

Data	Designação da milestone
Date	Milestone denomination
31-01-2017	Second stage of manufactured structures ready for characterization

Descrição
Description

The paper relative to the second stage of manufacture is complete.

Data	Designação da milestone
Date	Milestone denomination
01-02-2017	Characterization of the material produced in the second phase

Descrição
Description

End of the second phase of characterization of the materials produced using the parameters determined by the results of the perfected computational simulation.

Data	Designação da milestone
Date	Milestone denomination
01-04-2017	Final report about characterization

Descrição

Description

Elaboration of the final report and articles about the characteristics of the materials produced completed.

3.2.4.c Cronograma

3.2.4.c Timeline

Ficheiro com a designação "timeline.pdf", no 9. Ficheiros Anexos, desta Visão Global (caso exista).
File with the name "timeline.pdf" at 9. Attachments (if exists).

File with name "timeline.pdf"at 9. Attachments.

3.3. Referências Bibliográficas

3.3. Bibliographic References

Referência Reference	Ano Year	Publicação Publication
R1	2002	Granqvist,C.G.,Hultaker,A. "Transparent and conducting ITO films: new developments and applications.", Thin Solid Films,2002,pp.411:1-5
R2	2013	Miller,M.S., et al. "Silver nanowire/optical adhesive coatings as transparent electrodes for flexible electronics." *ACS Appl. Mater. Interfaces.* 2013, pp. 5:10165-10172.
R3	2010	Yugang,S. "Silver nanowires - unique templates for functional nanostructures." *Nanoscale.* 2010, pp. 2:1626-1642.
R4	2012	van de Goep, J. et al. "Transparent conducting silver nanowire networks." 2012, pp. 12:3138-3144.
R5	2014	Wolf, E.L., "*Applications of Graphene."* s.l. : Springer, 2014. 978-3-319-03945-9
R6	2008	Xuan, W., Linjie, Z., Mullen, K., Transparent, conductive graphene electrodes for dye-sensitized solar cells." *Nano Letters.* 2008, pp. 8:323-327.
R7	2008	Bunch, J.," Mechanical and Electrical Properties of Graphene Sheets." s.l. : Cornell University, 2008.
R8	2014	Jurewicz, Izabela, et al. "Insulator-Conductor Type Transitions in Graphene-Modified Silver Nanowire Networks: A Route to Inexpensive Transparent Conductors." *Advanced Functional Materials* 24.48 (2014): 7580-7587.
R9	2013	Seo, Tae Hoon, et al. "Graphene-silver nanowire hybrid structure as a transparent and current spreading electrode in ultraviolet light emitting diodes."*Applied Physics Letters* 103.5 (2013): 051105.
R10	2012	Bergin, Stephen M., et al. "The effect of nanowire length and diameter on the properties of transparent, conducting nanowire films." *Nanoscale* 4.6 (2012): 1996-2004.
R11	2012	Shanmugharaj, A. M., and Sung Hun Ryu. "Excellent

		electrochemical performance of graphene-silver nanoparticle hybrids prepared using a microwave spark assistance process." *Electrochimica Acta* 74 (2012): 207-214.
R12	2013	Liu, Bo-Tau, and Han-Lin Kuo. "Graphene/silver nanowire sandwich structures for transparent conductive films." *Carbon* 63 (2013): 390-396.
R13	2011	Lee, Shie-Heng, et al. "Highly transparent and conductive thin films fabricated with nano-silver/double-walled carbon nanotube composites." *Journal of colloid and interface science* 364.1 (2011): 1-9.
R14	2000	Groenendaal, L., et al. "Poly (3, 4-ethylenedioxythiophene) and its derivatives: past, present, and future." Advanced Materials 12 (2000): 481-494.
R15	2008	Hong, Wenjing, et al. "Transparent graphene/PEDOT–PSS composite films as counter electrodes of dye-sensitized solar cells." Electrochemistry Communications 10.10 (2008): 1555-1558.
R16	2007	Geim, Andre K., and Konstantin S. Novoselov. "The rise of graphene." Nature materials 6.3 (2007): 183-191.
R17	2004	Wu, Zhuangchun, et al. "Transparent, conductive carbon nanotube films." Science 305.5688 (2004): 1273-1276.

3.4. Publicações Anteriores

3.4. Past Publications

Non applicable

3.5. Ressubmissão de projectos

3.5. Project Resubmission

Ressubmissão?

Resubmission?

Non applicable

4. Equipa de investigação

4. Research team –

4.1 Lista de membros

4.1. Members list

Nome Name	Função Role	Grau Degree	% %	CV nuclear Core CV	CV CV
Susana Isabel Pinheiro Cardoso de Freitas	Principal Investigator	Agregação	40	✓	FCTSIG/c
Luís Filipe Guedelha Macedo	Researcher	Phd	35	✓	
Pedro Manuel Quintela Ribeiro	Researcher	Phd	35	✓	
António Samuel Ávila Balula	Researcher	Phd	35	No	
Francesca Toblerone Malakova	Phd Student	Master	81	No	
Pancráceo José Adelino Silva	Phd Student	Master	50	No	

4.2. Lista de membros a contratar durante a execução do projeto

4.2. Members list to hire during project's execution

Membro da equipa Team member	Função Role	Duração Duration	%tempo %time
Bolseiro de iniciação à investigação	Bolseiro	13	25
Bolseiro de Investigação (Licenciado)	Bolseiro	15	83
Bolseiro de Investigação (Licenciado)	Bolseiro	12	66

5. Outros projetos

5. Other projects –

5.1. Projetos financiados

5.1. Funded projects

Non applicable

5.2. Candidaturas similares

5.2. Similar applications

Non applicable

6. Indicadores previstos

6. Expected indicators –

Indicadores de realização previstos para o projeto

Expected output indicators

Descrição Description	2015	2016	2017	Total
Livros Books	0	0	0	0
Artigos em revistas internacionais Papers in international journals	0	2	3	5
Artigos em revistas nacionais Papers in national journals	0	1	1	2
Comunicações em encontros científicos internacionais Communications in international meetings	0	1	2	3
Comunicações em encontros científicos nacionais Communications in national meetings	0	0	1	1
C - Relatórios Reports	0	4	2	6
D - Organização de seminários e conferências Organization of seminars and conferences	0	0	0	0
Teses de Doutoramento PhD theses	0	0	2	2

Teses de Mestrado **Master theses**	0	0	2	2
Outras **Others**	0	0	0	0
F - Modelos **Models**	0	0	0	0
G - Aplicações computacionais **Software**	0	2	0	2
H - Instalações piloto **Pilot plants**	0	0	0	0
I - Protótipos laboratoriais **Prototypes**	0	1	1	2
J - Patentes **Patents**	0	0	1	1

Acções de divulgação da actividade científica

Scientific activity spreading actions

The project results will be presented to the scientific community through papers in international and national journals, as well as communications in international and national meetings. The thesis from the BI students will also serve as a way to diffuse our results to the scientific community.

INESC-MN is also widely-known by very articles published in important international journals (Journal of Applied Physics). Also, INESC-MN provides summer internships that will help to diffuse the results of this work.

INESC-MN is also involved in many European projects, and so it is a way to get our results and papers to reach the groups which are also involved on those projects.

We will also have a patent on the end of our work, and so we will also have that way to spread our results.

The results of this project are also shared with the courses of Técnicas de Micro e Nanofabricação and Electrónica de Spin, at Instituto Superior Técnico.

7. Orçamento

7. Budget

Instituição Proponente

Principal Contractor

Instituto de Engenharia de Sistemas e Computadores- Microsistemas e Nanotecnologias

Descrição **Description**	**2015**	**2016**	**2017**	**Total**
Recursos Humanos Human resources	2.896,56	26.263,44	3.395,52	32.555,52
Missões Missions	0	6.000,00	12.300,00	18.300,00
Consultores Consultants	0	0	0	0
Aquisição de bens e serviços Service	0	16.100,00	2.400,00	18.500,00

procurement and acquisitions				
Registo de patentes Patent registration	0	0	5.000,00	5.000,00
Adaptação de edifícios e instalações Adaptation of buildings and facilities	0	0	0	0
Gastos gerais Overheads	579,31	9.672,69	4.619,10	14.871,10
TOTAL DESPESAS CORRENTES TOTAL CURRENT EXPENSES	3.475,87	58.036,13	27.714,62	89.226,62
Equipamento Equipment	2.100,00	16.800,00	0	18.900,00
Total	5.575.87	74.836,13	27.714,62	108.126,62

Instituições Participantes

Participating Institutions

Non applicable

Orçamento Global

Global budget

Descrição Description	**2015**	**2016**	**2017**	**Total**
Recursos Humanos Human resources	2.896,56	26.263,44	3.395,52	32.555,52
Missões Missions	0	6.000,00	12.300,00	18.300,00
Consultores Consultants	0	0	0	0
Aquisição de bens e serviços Service procurement and acquisitions	0	16.100,00	2.400,00	18.500,00
Registo de patentes Patent registration	0	0	5.000,00	5.000,00
Adaptação de edifícios e instalações Adaptation of buildings and facilities	0	0	0	0
Gastos gerais Overheads	579,31	9.672,69	4.619,10	14.871,10

TOTAL DESPESAS CORRENTES TOTAL CURRENT EXPENSES	3.475,87	58.036,13	27.714,62	89.226,62
Equipamento Equipment	2.100,00	16.800,00	0	18.900,00
Total	5.575.87	74.836,13	27.714,62	108.126,62

Plano de financiamento

Finance plan

Descrição Description	**2015**	**2016**	**2017**	**Total**
Financiamento solicitado à FCT Requested funding	5.575.87	74.836,13	27.714,62	108.126,62
Financiamento próprio Own funding	0	0	0	0
Outro financiamento público Other public-sector funding	0	0	0	0
Outro financiamento privado Other private funding	0	0	0	0
Total do Projecto Total of the project	5.575.87	74.836,13	27.714,62	108.126,62

8. Justificação do orçamento

8. Budget rationale –

8.1. Justificação dos recursos humanos

8.1. Human resources rationale

Tipo Type		**Nº de pessoas No. of persons**
(BIC) Bolsa de investigação científica		1
Duração (em meses) Duration (in months)	**Custo envolvido (€) (calculado) Total cost (€) (estimated)**	**Outros custos (€) Other costs (€)**
13	5.005,00	1.481,48
Justificação do financiamento solicitado Rationale for requested funding		
A young researcher with knowledge in fabrication of structures and some experience in working in the cleanroom. The student will work on the task of manufacture. The BI will cover salary and social insurance expenses on a tax of 29.6%.		

Tipo **Type**		**Nº de pessoas** **No. of persons**
(BI) Bolsa de Investigação (Licenciado)		1
Duração (em meses) **Duration (in months)**	**Custo envolvido (€) (calculado)** **Total cost (€) (estimated)**	**Outros custos (€)** **Other costs (€)**
15	11.175,00	3.307,80
Justificação do financiamento solicitado **Rationale for requested funding**		
A young researcher with knowledge on nanostructures modulation and experience in programming. The student will work on the task of programming and modulation. The BI will cover salary and social insurance expenses on a tax of 29.6%.		

Tipo **Type**		**Nº de pessoas** **No. of persons**
(BI) Bolsa de Investigação (Licenciado)		1
Duração (em meses) **Duration (in months)**	**Custo envolvido (€) (calculado)** **Total cost (€) (estimated)**	**Outros custos (€)** **Other costs (€)**
12	8.940,00	2.636,24
Justificação do financiamento solicitado **Rationale for requested funding**		
A young researcher with knowledge in characterization techniques. The student will work on the task of characterization. The BI will cover salary and social insurance expenses on a tax of 29.6%.		

8.2. Justificação de missões

8.2. Missions rationale

Tipo Type	Nº de deslocações No. of participations
International	4
Local Venue	Custo envolvido (€) Cost (€)
Barcelona, Spain	6.000,00
Justificação do financiamento solicitado Rationale for requested funding	
Presentation of the simulation results.	

Tipo Type	Nº de deslocações No. of participations
National	3
Local Venue	Custo envolvido (€) Cost (€)
Braga,Portugal	1.800,00
Justificação do financiamento solicitado Rationale for requested funding	
Presentation of the manufacture results.	

Tipo Type	Nº de deslocações No. of participations
International	3
Local Venue	Custo envolvido (€) Cost (€)
Istambul, Turkey	4.500,00
Justificação do financiamento solicitado Rationale for requested funding	
Presentation of the manufacture results.	

Tipo Type	Nº de deslocações No. of participations
International	4
Local Venue	Custo envolvido (€) Cost (€)
Munich, Germany	6.000,00
Justificação do financiamento solicitado Rationale for requested funding	
Presentation of the results to the scientific community.	

8.3. Justificação de consultores

8.3. Consultants rationale

Non applicable

8.4. Justificação de aquisição de bens e serviços

8.4. Service procurement and acquisitions

Tipo

Type

Consumables for the diverse applications needed for this project

Custo (€)

Cost (€)

18.500,00€

Justificação do financiamento solicitado
Rationale for requested funding

Our process will have a lot of nanotechnological processes in the fabrication tasks. Wafers and materials to deposit to proceed to the structures fabrication will be needed. It is also considered machines maintenance as well as clean room maintenance.

8.6. Justificação do Equipamento
8.6. Equipment rationale

8.6.1. Equipamento já disponível para a execução do projecto
8.6.1 Available equipment

The equipment already available is:

-AIXTRON Black Magic
-Spray nozzle for spray coating
-Regulated voltage and current source
-Precision multimeter
-Computer

8.6.2. Discriminação do equipamento a adquirir
8.6.2. New equipment requested

Tipo de equipamento
Equipment type

Computer with peripheral without GPU (2)

Fabricante
Manufacturer

Asus

Modelo
Model

M32AD

Custo (€)
Cost (€)

1300

Tipo de equipamento
Equipment type

GPU (2)

Fabricante
Manufacturer

NVIDIA

Modelo
Model

GTX 970

Custo (€)
Cost (€)
800

Tipo de equipamento
Equipment type
Microspectrophotometer

Fabricante
Manufacturer
CRAIC

Modelo
Model
508PV

Custo (€)
Cost (€)
8000

Tipo de equipamento
Equipment type
Micropositioner (2)

Fabricante
Manufacturer
Signatone

Modelo
Model
SP-150

Custo (€)
Cost (€)
800

Tipo de equipamento
Equipment type
Impedance Analyzer

Fabricante
Manufacturer
Agilent Technologies

Modelo
Model
4291A

Custo (€)
Cost (€)
8000

8.7. Justificação de registo de patentes
8.7. Patent registration
The patent will allow us to secure the intellectual property of the new conductor that we will produce. If the results that we expect are achieved our conductor will be of great value since it'll become a reliable option to the material that is used today to make touch screens. Also, in the future this transparent conductor may have other applications such as solar panels.

8.8. Justificação de adaptação de edifícios e instalações
8.8. Adaptation of buildings and facilities
Non applicable

9. Ficheiros Anexos
9. Attachments
-organigram.pdf
-timeline.pdf

10. Possíveis conflitos de interesse
10. Possible Conflicts of Interest
Non applicable