Processed Text

material review multifunctional integration optical fiber nanomaterials aircraft system carlosmarques1 arnaldoleal júnior2 andsantoshkumar3 1 i3n physicsdepartment universityofaveiro 3810 193aveiro portugal 2 mechanicaldepartmentandgraduateprograminelectricalengineering federaluniversityofespírito santo espíritosanto29075 910 brazil 3 shandongkeylaboratoryofopticalcommunicationscienceandtechnology schoolofphysicsscienceand informationtechnology liaochenguniversity liaocheng252059 china correspondence carlos marque ua pt c arnaldo leal ufes br l j abstract smartsensingforaeronauticalapplicationsisamultidisciplinaryprocessthatinvolvesthe developmentofvarioussensorelementsandadvancementsinthenanomaterialsfield theexpansion research fueled development commercial military aircraft aeronautical field opticaltechnologyisoneofthesupportingpillarsforthis aswellasthefactthattheunique high techqualitiesofaircraftsalignwithsustainabilitycriteria inthisstudy amultidisciplinary investigationofairplanemonitoringsystemsemployingopticaltechnologiesbasedonopticalfiber andnanomaterialsthatareincorporatedintoessentialsystemsispresented thismanuscriptreports themultifunctionalintegrationofopticalfibersandnanomaterialsforaircraftsectordiscussingtopics suchasairframemonitoring flightenvironmentsensing fromtemperatureandhumiditytopressure sensing sensorsfornavigation suchasgyroscopesanddisplacementorpositionsensors pilotvital healthmonitoring andnovelnanomaterialsforaerospaceapplications theprimaryobjectiveofthis reviewistoprovideresearcherswithdirectionandmotivationtodesignandfabricatethefutureof theaeronauticalindustry basedontheactualstateoftheartofsuchvitaltechnology therebyaiding theirfutureresearch keywords structuralhealthmonitoring aviation smartmaterials opticalfibersensors aircraft security flight light citation marque c leal júnior kumar multifunctionalintegration ofopticalfibersandnanomaterials foraircraftsystems materials2023 1 introduction 16 1433 http doi org 10 3390 ma16041433 morethanevensustainabilityisastrongwordusedindifferentareasofresearchin ordertoorientate intherightway theprogressofdigitalizationforobtaininguniqueand academiceditors theodore smarthigh techqualitiesindifferentindustrialsectors oneofthemostcriticalsectorsis e matikasandpatriciakrawczak aerospace wheretheaeronauticalindustryneedstoaligntheprogress sustainability received 11december2022 photonics inthisway advancesinsmartsensorsandnanomaterialsarecrucial inthe revised 6february2023 lastyear photonicshasbroughtagrowingroleinaeronauticalandaviationfields accepted 7february2023 head updisplaystoonboardopticalfibernetworks improvingaircraftmonitoringand published 8february2023 maintenanceinameansthatisnotpossiblewithcopper basedelectricalsystems although numerousdevelopmentsincommercialaircraftstakeplaceinzonesofaplanethattravelers donotsee stillsomeenhancementsthatoccurinsidethepassengercabinarerequired asledillumination communicationbetweencrewandpassengers orelectrochromatic copyright 2023 author dimmingofthewindows licensee mdpi basel switzerland theimplementationofthe fly wire perceptionhassignificantlyreduced article open access article theweightandcomplexityoftraditionalelectro mechanicalsystems alsoincreasingthe distributed term stability safety airplane 1 typical commercial military aircraft involve conditionsofthecreativecommons attribution ccby license http huge number control monitoring system demanding big quantity sensor creativecommons org license distributedalongtheaircraft fromacoppercablenetwork theoutputofelectricalsignals 4 0 isroutedforthecommandingcomputers whichactivatetheactions overthelastfew materials2023 16 1433 http doi org 10 3390 ma16041433 http www mdpi com journal materialsmaterials2023 16 1433 2of29 year theaeronauticalindustryhaschangedalot duetotheclimateconcernsgrowing order decrease emission progress fuel efficiency hard job beenachievedbytheprogressofcompositefuselagestoreplacethetraditionalmetallic material thusbuildinglightweightaircraftmodels whilethisseriouschangealsotakes reducedmanufacturingandoperatingcosts compositestructuressubjectavionicsystems toabitofaseverelevelofIightning inducedvoltageandcurrent actually oneofthemain factor leading airplane failure subsequent electrical wire damage 2 context opticaltechnologieshaveendorsedthemigrationofcopperharnesstoopticalfiber basedsystems followingthe fly light perception duetothehighelectromagnetic immunity 3 4 wheresuchaconcepthasbeenbroughtunderhugeaffirmation intermsof reliabilityandsecurity 4 themodernaircraftshavehigheroperationalrequests drivenbytheincrease notonlyintermsofsafetyoncriticalsystemsforflightandengine control butalsoinnon safetycriticalsystems suchascabinenvironmentalcontrolsystems structural engine health monitoring ehm system structural health monitoring shm 5 etc whichareansweredmorethanjustintheopticaldomain 4 8 presentlytheopticalfibersensors ofs areseen ingeneral bythescientificcommu nityandindustrialandend usercommunitiestobethetechnologywiththemaximum potentialforthecontinuousreal timemonitoringofairplanestructuresindifferenttop ic 4 5 9 11 fromflightenvironmentsensingorsensorsfornavigationtopilotvitalhealth monitoring theadditionalpotentialforintegratingofsintocompositematerialsduring thelayupprocesswouldalsoenablethemonitoringofcompositestructuresduringtheir entirelifecycle improvingtheirsafety costefficiency reliability andalsospreadingthe operational life addition ofs largely known particular characteristic suchaselectromagneticfieldsimmunity compactness multiplexingcapabilities passive operation biocompatibility andchemicalstability 11 particular profit measure report data using sensor include reducing aircraft weight replacing bulky system decreasing cost cheaperthanothertypes duetoparticularcharacteristics suchasmultiplexingormulti pointfeatures 11 andprovidingpredictivedatathatcanhelptheflightsbecomefurther fuel efficient suchsensorsandsystemscouldoffercapacitiesandmeasurementsthatare notconceivablewithothercomponents 5 9 10 inadditional ofscanbeinstalledina smallerportionoftime comparedwiththeiralternatives fromthenatureofhowoptical fiberworks numeroussensorscanbecombinedusingauniqueopticalfiber whichmeans non complexityinstallationinvolvingjustonefibertobeattachedtotheaircraftstructure consequently linkedtothedataacquisitionequipment inthisway thispaperreviewssomecriticalaspects inordertoseethatthefutureis expectedtoseeanenlargedeffortontheuseofofsandnanophotonicmaterialspotential intheaircrafttoexpandontheindustry ssafetyandalsointhehumansthatarelinked withsuchindustry suchasflightattendants pilot theairportmaintenancecrew etc wellastoextendtheaircrafts life decreasetherequirementfortimeconsumptionand expensivemaintenanceactions andincreasetheflights efficiency inordertopavetheway forsustainablestructuresandtransportation seefigure1 materials2023 16 1433 3of29 figure 1 illustration overall content considering problem advance photonicsandnanomaterialsforaeronauticalsector 2 airframemonitoring asiswell known thestronguseofcompositestructuresintheaerospaceindustry overthelastfewdecades withneweraircraftsuchasboeing787andairbusa350made largely respectively50 and503 12 13 ofcompositematerials broughtconsiderable numberofnewsuccessfulcontributionstotheprogressoftheshmfieldforcomposite structure thisdevelopmentcanbeattributedtoseveralresearchperformeduntilnow many researcher achieved material particular mechanical property instance highstrength weightratioandcorrosionresistance therefore suchuseof compositestructuresinaircraftpermitustocondensetheoperationalcosts duetolessfuel consumptionandlessmaintenanceprotocols althoughseveraladvantagescanbereached whenisusedcompositestructuresforaircrafts theirperformanceorcomportmentpose challenge namelyintheinspectionandmonitoringofdamageintheaircraftstructure wherethedamagemaybepresentinside butnotdiscernableuponvisualcheckupofthe outsidelayersfromaircraftstructurethroughmaintenanceprotocols inaeronauticalandaerospaceindustriestheapplicationofshmhasstillimmature 14 andspecificallyitsapplicationtocompositestructuresisverychallenging forarealaircraft maintenancesituation afulldamagediagnosticonallfourshmlevels ratherthanasingle level seefigure2 isrequired itmeans damagedetection b damagelocalization c damagetypeidentification damageseverity theshm withsuccessapplicationto aircraftneeds twosituations aprofitable process airline operator reducing economic loss caused unproductive downtimesandprovideaccurateandreliabledataabouttheconditionofthestructure growingthesecurityofcriticalcomponentstoconsequentlyavoiddisasters therefore fromindustryandacademia anextensiverangeofpotentialshmtechnologiesisbeing developedtosatisfytheseconditions 15 wherethemostcapableoptionsareacoustic emission method micro electro mechanical system mem electrical strain gauge crackwires optical basedtechnologies andcomparativevacuummonitoring 16 ever fromtheextensiveworksperformeduntilnow theopticaltechnologieshavebeenthe futurefortheaircrafts airframe intermsofshm materials2023 16 1433 4of29 figure2 diagramwithfourshmlevelsforafulldamagediagnostictoobtaintheprognostic ofs suchastheonesbasedonfiberbragggrating fbg andopticalmeasurement systemshavepreviouslyfoundarangeofexcitingpracticalapplicationsinthedamageand loadmonitoringofaircraftcompositestructures namelyingroundtestsanddesign well knownfromtheliterature 9 thefbgsensor soperationprincipleisbasedonthe braggwavelengthshift relatedtovariationsongratingperiodandrefractiveindex ri generally thesevariationsoccurduetostrain ε andtemperature effectsonthefbg asshowninequation 1 thetemperaturevariationsleadtothermalexpansion leadstoagratingperiodvariation proportionaltothetemperatureandthermalexpansion coefficient α andthermo opticeffect rivariationproportionaltothetemperatureand thermo opticcoefficient ξ thestrainleadstothevariationonthegratingperiodfrom theappliedstrainandthephotoelasticeffect rivariationproportionaltothestrainand photoelasticconstant p e λ 1 p ε α ξ λ 1 b e b someaircraftareinactionwithintegratedofsnetworksachievingmeasurements duringflights airbusreportedin2013thatthelong termideaisthatallnewaircraftwillfly withdistributedfbgopticalsensors 17 indeed someofthedevelopedsolutionsarecon sideredrelativelymature atatechnologyreadinesslevel trl of5 6 forinstance ithas provedtheviabilityandeffectivityusingfbg basedlocaldamagedetection whenapplied tocompositepartsofaircraftasbondedrepairs 1 nevertheless thebroaderacceptanceof theuseofsuchsensingsystemsisstillhinderedbythefollowingissues sensorperformance whenembedded capabilityofdetection maintainability availableinterrogationequipment aslow costsolution lackofstandardization andcertificationframework one main challenge multipoint fbg based distributed detection technique point view ability detect damage continues developmentofcontrolledmethodstomonitorthemainparametersrelatedtotheonset andgrowthofdamageovertimeoflargestructures withadequatephysicalandspatial resolution even position damage known precisely enough aeronauticcompaniesandentitiesaddresstheissuesofreducingoperatingcosts achievinggreateraerodynamicefficiencyandimprovingthesafetyandthereliabilityof futureaircraft aircrafthealthmonitoringinvolvesusingsensorstomonitortheintegrity advanced structural material expected become backbone next generationairframes graphite reinforcedcompositesgivethepotentialforlargerstrength andstiffness weightratiothanaluminumalloys ofsofferthepotentialforhigh density sensor coverage slight weight penalty numerous sensor used load strain shape monitoring 9 11 wing shape measurement landing gear reported opticaldevicesforapplicationsrelatingtothehealthmonitoringofcompositematerials2023 16 1433 5of29 materialshavealsobeenreported 18 graphite epoxypanelsweremanufacturedwith integratedopticalfibersofdifferenttypes thepanelswerethermallyandmechanically tested ass composite strength sensor durability experimental result evaluatetheabilityofsurface mountedandembeddedopticalfiberstomeasurestrainand temperaturewerereported theofsperformancewascompareddirectlybytheresults fromtraditionalinstrumentation suchexperimentalresultsindicatethatofs integrated composite potential application monitoring structural integrity criticalpartsinaerospaceandaeronauticalvehicles inthisway fibersweresuccessfully embeddedinhigh performancegraphite polyimideandgraphite epoxyparts achieving thepotentialforaircraftstructuralapplications 18 anddemonstratingtheuseofsingle modeopticalfiberstomeasurestrainandtemperatureincomposites figure3showsa representativeoverviewaboutsensorelementsalongtheopticalfiberthatcanbeusefulto measuretheelongationofanaircraftflap wingsshape straindistribution andstructural damagecondition aswellasalldatacollectedbyadatalogger itispossiblethatthe understandingofcompositeagingusesthecapabilitytomeasureandcorrelatechemicaland physicalpropertychanges fromthisinformation predictivedecisionscanbemade taking intoaccountthestateofhealthofacompositepartandunderstandingwhatproceduresto doasarequirement

thusavoidingcatastrophicfailure figure3
schematicrepresentationofsensorelementsalongtheopticalfiberthatcanbeusefulto measuretheelongationofanaircraftflap straindistribution andstructuraldamageconditionand alldatacollectedbydatalogger 3 flightenvironmentsensing 3 1 criticalenvironmentalsensing differentengineeringstructuresareexposedtoenvironmentalconditionsrelatedto theoperation oreventhenaturalaspects oftheenvironment theenvironmentalsensing playsanimportantrolenotonlyonthestructuralanalysis butalsointhenavigationand controlsystems 19 itisalsoimportanttomentionthatthedynamicsoftheenvironmental condition suchastemperatureandrelativehumidity directlyaffecttheoperationaland structuralanalysisinaircraftsinbothcorrectiveandpredictivemaintenanceconditions 20 furthermore theenvironmentalmonitoringiscriticalforthestress strainsensors since manysensorspresenttemperaturecross sensitivity wherethestructuralfailurescanbe alsorelatedtothetemperaturedistributiondynamics 21 materials2023 16 1433 6of29 inaircraftoperation theenvironmentalmonitoringiscrucialforthenavigationand instrumentationequipment wheretheairdatasystemisresponsibletoprovidetheflight datatothecrew 22 consideringanimportanttechnologyforthesystem snavigation especially external measurement speed pitot tube technology widely employed 23 suchasensorusestheairpressureindynamicandstaticintakeconditions inwhichtheoperationintheharshenvironmentsoftheflightconditionscanleadtofreezing ofthedevice sorificethatcanultimatelyleadtocriticalissuesinthesensorreadingandeven accident 22 tothatextent thefederalaviationadministrationprovidesinstructions fortheatmosphericconditionsthatcanleadtosuchcriticalissuesintheinstrumentation whichalsoindicatesthenecessityofmeasuringtheatmospheric environmentalconditions flight 22 itisalsoimportanttonoticethattheenvironmentalconditions includingtemperature moistureconcentration andph canleadtoincreasesinmaintenancecostsanddowntime duetocorrosionindifferentpartsoftheaircraft 24 forthisreason environmentalanal ysisalsoplaysanimportantroleinthestructuraldefects duetoenvironmentaleffects mainlythecorrosionoftheaircraftstructureandcomponents 25 insummary thecor rosionisanelectrochemicaldeteriorationofmetallicstructures whichiscausedbythe chemicalreactionsofthematerialwiththeenvironmentalconditions 26 theextreme environmentalconditionsinaircraftoperation suchasthefreezingconditionsinconjunc tionwithextremeheatingofsomeparts exposestheaircraftstructureandcomponents toavarietyofcorrosionmechanisms 25 suchascenarioincludesadditionalcriteriaon theaircraftmaterialsselections wherethedesigncanbeperformedwhilealsoconsidering thecorrosionresistance 24 however achievingsuchcorrosionresistanceinconjunction withthecriticalperformanceaspects suchasstiffness weight andstrength leadtothe multi objectiveproblemofoptimizationinthematerialfeaturesthatmaynotbecompletely fulfilledwithasinglematerial tothatextent thecorrosiondetectiononthestructuresandcomponentshavebeenin vestigated 24 ingeneral thedetectionisbasedonvisionsystems whichhavedrawbacks ontheanalysisofinaccessibleareas forthisreason theuseofenvironmentalsensorsfor indirectcorrosiondetection wheretheenvironmentalorlocalconditionscanbeusedto correlatethecorrosionparameters suchaslocation time andrates 27 inthiscase environmentalparametersmonitoring namelytemperature humidity andevenchemical compoundsconcentration canbeassociatedwithcorrosion aswellasitsearlydetection orestimation 28 despitetheinfluenceoftheatmosphericpollutantsandcompounds suchasacidsulfatesandacidchlorides aswellasseasaltsdiffusedintothemoisture moisturedetectionandtemperatureplaycriticalroleinthecorrosionanalysis 24 inthe dynamicmeasurementofmoisture thetimeatwhichthereareatmosphericconditions forsurfacelayerofmoistureisknownasthetimeofwetness anditisusedasafactorfor corrosiongrowthandinitiation 28 inaddition thetemperatureisanimportantparameter inthecorrosionanalysis sinceitnotonlyrelatestothecorrosioninitiation butalsoonthe typeofthecorrosion 24 differenttemperaturethresholdswereanalyzedintheliterature fortheircorrelationwiththetypeofcorrosion whichindicatethenecessityofcontinuous temperaturemonitoringinaircraftstructuresandcomponents especiallytheoneswith directcontactwithmoistureoratmosphericpollutants 24

itisalsoimportanttomentionthattheclimateconditionsareimportantintheaircraft application notonlyontheexternalenvironmentalconditions assessment butalsothe internal environmental condition since thermal comfort cockpit crew membersandpassengers inthecaseofcommercialflights areimportantparameters 29 many case exposure long period seated position crew member passenger lead skin maceration general injury due tothemicroclimateconditions 30 intheliterature threeregionsofthermalcomfortin microclimateconditions e interfacebetweenthelimbandtheseat weredefined suchregionsincludethecomfort temperaturesfrom29 cto34 candrelativehumidity 70 neutral comfort temperature 27 c 36 c relative humiditymaterials2023 16 1433 7of29 below80 anddiscomfort temperatureslowerthan27 corhigherthan36 cwith humidityhigherthan80 31 therefore theapplicationsoftemperatureandhumidity sensor used important indicator thermal comfort cabin interface limb seat considering necessity temperature andhumiditysensorsindifferentpositionsandscenariosinanaircraftinstrumentation figure 4a present schematic representation sensor position significanceateachapplication positionwasalreadydiscussed figure4 schematicrepresentationofsensorspositionsfortemperatureandmoistureassessment b schematic representation sensor position engine oil pressure compressor pressure b fuelpumppressureforfuelregulation c hydraulicsbrakingsystem airdatameasurement inpitottubes e environmentalairconditioningandpressurization materials2023 16 1433 8of29 amongdifferentsensorstechnologies opticalfiber basedsensorsareagrowingre searchfieldinthesensorcommunity duetotheiradvantages suchascompactness electro magneticfieldsimmunity passiveoperation multiplexingcapabilities chemicalstability andbiocompatibility 32 asmentionedbefore forthesereasons theyareusedforapplica tionsindifferentareas suchasindustry 33 shm 34 biochemical 35 andmedicine 36 ahighversatilityisfoundinofs sincemanyapproacheswereemployedthroughoutthe year wheretheintensityvariation 37 fluorescence absorbance 38 longperiodgrat ings 39 fbgs 14 40 non uniformgratings 41 nonlineareffects 42 specklegrams 43 interferometer 44 andsurfaceplasmonresonance 45 sensorsaregenerallyemployed asanimportantadvantageofopticalfibersensingapproaches relatedtotheirmaterial feature whichincludeaflexibility compactness andchemicalstability suchsensorsare ableofbeingembeddedinrigidandflexiblestructures 46 aswellastheintegrationin differentdyes 47 anddopants 48 theembedmentorintegrationofdifferentmateri alsinofsisespeciallyimportantinhumiditysensorsdevelopmentusingsilicaoptical fiber sincesuchanopticalmaterialisnotintrinsicallysensitivetohumidity moisture absorption 49 aninterferometer basedapproachforhumidityassessmentusesamach zehnder interferometer mzi fabricatedfromataper whereacompositefilmcomposedofgraphene oxideandpvaiscoatedontheopticalfibersensor 50 theappliedcoatingissensitiveto relativehumidityvariation inwhichthereisarivariationasafunctionoftheenvironmen talhumidity whichleadstothepossibilityofhumiditysensing duetomzitransmitted spectrumvariationasafunctionoftheri inanotherinterferometersensorforhumidity measurement fabry perot interferometer fpi proposed 51 case interferometer scavityisobtainedonthetipofthefiber whereati thinfilm 168nm 3 5 thickness additional humidity sensitive film 1621 nm thickness made sio whichisenclosedwithanotherti filmwith168nmthickness thus theti 2 3 5 3 5 filmsareusedasreflectivesurfacestocreatethefpicavity whereasthesio filmpresents 2 variationsintheriasafunctionoftherelativehumidity wheresuchrivariationsleadto awavelengthshiftonthefpi sreflectedspectrum similarly theuseofextrinsicfpifor humiditymeasurementcanalsobeachievedusingopticaladhesiveorpolymerfilmsthat presentswellingwiththemoistureabsorption whichalsoleadtospectralvariationsofthe fpi 52 consideringthefbgsensorsdevelopmentsinhumidityassessment theuseofsilica opticalfibersisalsorelatedtotheopticalfibercoatingwithdifferenthumidity sensitive material 53 tothatextent thefbgcanbecoatedwithpolymerfilmswithhumidity sensitivity wherethefilmswellingduetothemoistureabsorptionleadstoanincreasein thestrainonthefiber whichleadstoabraggwavelengthshiftinthefbg inthiscase useofpeg pvacompositewasinvestigatedin 54 forthehumiditysensitivityusingthe aforementionedprinciple itisalsoworthnotingthatthecladdingremovalofthefbg usingchemicalprocesssuchastheetching 55 resultsinasensitivityofthefbgwiththe externalri

whichleadstothepossibilityofusingthinfilmswithrivariationasafunction oftherelativehumidityforfbg basedhumidity moistureassessmentapproach
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astrainmeasurement range 1000 με may expanded 5000 με capacity function
temperaturesrangingfrom40 cto 250 c fpisensorsareextremelycompact ranging
inlengthfrom1mmto20mm andcanbeincorporatedincertainstructuralcomponents
withoutincurringanyweightpenaltyornegativeimpacts however itslowmultiplexing
capacityisadisadvantage materials2023 16 1433 12of29 stated sofo interferometric sensor successful
low coherent interferometric sensor structural health monitoring shm
successfullyplacedinhundredsofstructures includingbridges building oilpipes tunnel
sofointerferometricsensorsarelong gaugesensors incontrasttofpisensors measurement range beginning
0 25 extending 10 even 100m withamicrometer levelresolutionandtemperatureinsensitivity
highprecision andstability however theycanonlymeasureelongationsandcontractionsatlowspeeds 0 1hz

1hz andareunabletodetectimpactdamageinaircraftstructures
therearethreetypesofdistributedfiberopticsensors rayleigh basedopticaltime domainreflectometry otdr
raman basedopticaltime domainreflectometry rotdr andbrillouin basedopticaltime domainreflectometry
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followingrecovery andevenafterimmunization covid 19patients reported variety neurologic complication including encephalitis encephalopathy stroke headache lossofsmellandtaste dizziness seizure refractory status epilepticus myelitis myopathy acute disseminated encephalomyelitis leukoen cephalopathy kawasakisyndrome guillain barrésyndrome andneurolepticmalignant syndrome 158 inarecentcasestudy a43 year oldhelicopterpilotwassenttotheemergencyde partment duetoinfluenza likesymptoms afterreceivingtreatmentforcovid 19 recoveredandreturnedtoflying duringflight pilotsexperiencedmomentsofdizziness andunconsciousness althoughtheco pilotsalvagedthehelicopter ithasbeendetermined thatrobustsensoryelementsarerequiredtoidentifythepilots presenthealthcondition duringflightoperations 158 monitoringthepilot svitalsignsisessentialforensuringthesafetyofanaircraftand itsoccupants inthisinstance acockpitequippedwithahealthmonitoringsystemprovides 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flight multiple type sensor pulse oximetry sensor
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surface coating also safeguard aircraft component fromseverehazards inaddition
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consequentlyreducingtheoperationalcosts anditisquiteimportanttoconsider
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oflightweighttechnologiessuchasofs increasingpublicconcernaboutclimatechange
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brown rogowski r jensen b fiberopticsensorsforhealthmonitoringofmorphingairframes bragggrating strainandtemperaturesensor smartmater struct 2000 9 163 crossref materials2023 16 1433 23of29 19 nguyen x b rosser k chahl j areviewofmodernthermalimagingsensortechnologyandapplicationsforautonomous aerialnavigation j imaging2021 7 217 crossref 20 zheng liu wu h wang j temperatureandpressuredynamiccontrolfortheaircraftenginebleedairsimulationtest usingthelpidcontroller aerospace2021 8 367 crossref 21 wang x si c wang z li displacement field reconstruction structure thermal mechanical loading environment aerosp sci technol 2021 117 106914 crossref 22 ribeiro l saotome amore r deoliveirahansen r high speedandhigh temperaturecalorimetricsolid state thermalmassflowsensorforaerospaceapplication asensitivityanalysis sensors2022 22 3484 crossref 23 prosser j advancesinsensorsforaerospaceapplications sen actuatorsaphys 1993 37 38 128 134 crossref 24 li l chakik prakash r 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chichester uk 2008 pp 165 200 32 cusano cutolo albert j fiberbragggratingsensors marketoverviewandnewperspectives benthamsciencepublishers potomac md usa 2009 33 qiao x shao z bao w rong q fiberbragggratingsensorsfortheoilindustry sensors2017 17 429 crossref pubmed 34 kinet mégret p goossen k qiu l heider caucheteur c fiberbragggratingsensorstowardstructuralhealth monitoringincompositematerials challengesandsolutions sensors2014 14 7394 7419 crossref pubmed 35 guo liu f guan b albert j invited tiltedfibergratingmechanicalandbiochemicalsensors opt lasertechnol 2016 78 19 33 crossref 36 mishra v singh n tiwari u kapur p fibergratingsensorsinmedicine currentandemergingapplications sen actuator aphys 2011 167 279 290 crossref 37 teng c min r zheng j deng li hou l yuan l intensity modulatedpolymeropticalfiber basedrefractiveindex sensor areview sensors2022 22 81 crossref 38 leal junior guo j min r fernandes j frizera marque c photonicsmartbandageforwoundhealingassessment photon re 2021 9 272 crossref 39 anemogiannis e member glytsis e n transmission characteristicsof long period fiber grating havingarbitrary azimuthal radialrefractiveindexvariations j light technol 2003 21 218 227 crossref 40 marque c f min r junior l antunes p fasano woyessa g nielsen k rasmussen h k ortega b bang fastandstablegratingsinscriptioninpofsmadeofdifferentmaterialswithpulsed248nmkrflaser opt express2018 26 2013 crossref 41 li h li k li h meng f lou x zhu l recognitionandclassificationoffbgreflectionspectrumundernon uniformfield basedonsupportvectormachine opt fibertechnol 2020 60 102371 crossref 42 mizuno hayashi n fukuda h song k nakamura k ultrahigh speeddistributedbrillouinreflectometry light sci appl 2016 5 e16184 crossref 43 fujiwara e cabral optical fiber specklegram sensor multi point curvature measurement appl opt 2022 61 6787 6794 crossref 44 pospori webb j stresssensitivityanalysisofopticalfiberbragggrating basedfabry pérotinterferometricsensors j light technol 2017 35 2654 2659 crossref 45 jing j liu k jiang j xu wang j zhang z zhang w liu performanceimprovementapproachesforoptical fibersprsensorsandtheirsensingapplications photon re 2022 10 126 147 crossref 46 zhang yan j jiang sui q zhang l luo visualreconstructionofflexiblestructurebasedonfibergratingsensor arrayandextremelearningmachinealgorithm optoelectron lett 2022 18 390 397 crossref 47 guo j niu yang c highlyflexibleandstretchableopticalstrainsensingforhumanmotiondetection optica2017 4 1285 1288 crossref 48 jiang j zhang n min r cheng x qu h hu x recentachievementsongratingfabricationsinpolymeropticalfibers withphotosensitivedopants areview polymers2022 14 273 crossref pubmed 49 xu k li h liu wang tian j wang l du j z song q opticalfiberhumiditysensorbasedonwater absorptionpeaknear2 µmwaveband ieeephotonicsj 2019 11 7101308 crossref materials2023 16 1433 24of29 50 wang shen c lou w shentu f fiberoptichumiditysensorbasedonthegrapheneoxide pvacompositefilm opt commun 2016 372 229 234 crossref 51 xie w yang cheng li zhang zhuang z opticalfiberrelative humiditysensorwithevaporateddielectric coatingsonfiberend face opt fibertechnol 2014 20 314 319 crossref 52 oliveira r bilro l nogueira r fabry pérotcavitiesbasedonphotopolymerizableresinsforsensingapplications opt mater express2018 8 2208 crossref 53 bai w yang dai j yu h wang g qi c novelpolyimidecoatedfiberbragggratingsensingnetworkforrelative humiditymeasurements opt express2016 24 3230 crossref 54 wang liu zou f jiang c mou c wang humiditysensorbasedonalong periodfibergratingcoatedwithpolymer compositefilm sensors2019 19 2263 crossref 55 hu h bang janting j polymeropticalfibertipmassproductionetchmechanismtoachievecpcshapeforimproved biosensorperformance sensors2019 19 285 56 pospori ioannou kalli k temperatureandhumiditysensitivityofpolymeropticalfibresensorstunedbypre strain sensors2022 22 7233 crossref pubmed 57 theodosiou komodromos kalli k carboncantileverbeamhealthinspectionusingapolymerfiberbragggrating array j light technol 2018 36 986

992 crossref 58 luo yan b zhang q peng g wen j zhang j fabricationofpolymeropticalfibre pof grating sensors2017 17 511 crossref pubmed 59 zhang w webb j peng g enhancingthesensitivityofpoly methylmethacrylate basedopticalfiberbragggrating temperaturesensors opt lett 2015 40 4046 4049 crossref 60 rajan g noor liu b ambikairaja e webb j peng g afastresponseintrinsichumiditysensorbasedonan etchedsinglemodepolymerfiberbragggrating sen actuatorsaphys 2013 203 107 111 crossref 61 woyessa g nielsen k stefani markos c bang temperatureinsensitivehysteresisfreehighlysensitivepolymeroptical fiberbragggratinghumiditysensor opt express2016 24 1206 crossref 62 liu z zhang z f tam h tao x multifunctionalsmartopticalfibers material fabrication andsensingapplications photonics2019 6 48 crossref 63 mizuno theodosiou kalli k liehr lee h nakamura k distributedpolymeropticalfibersensors areviewand outlook photon re 2021 9 1719 1733 crossref 64 lopez sarigul klijn n review uncertainty flight vehicle structural damage monitoring diagnosis control challengesandopportunities prog aerosp sci 2010 46 247 273 crossref 65 ivanov v caldas p rego g highsensitivitycryogenictemperaturesensorsbasedonarc inducedlong periodfiber grating sensors2022 22 7119 crossref 66 chen e dong b li li z wang x zhao xu w zhao w wang opticaltunablefiberfilterbasedonafew mode opticalfibermodeinterferometercoatedwithgrapheneepoxyresincompositematerial opt commun 2021 497 127140 crossref 67 ukil braendle h krippner p distributedtemperaturesensing reviewoftechnologyandapplications ieeesens j 2012 12 885 892 crossref 68 lazaro r c marque c castellani c e leal junior fbg basedmeasurementsystemsfordensity specificheatcapacity andthermalconductivityassessmentforliquids ieeesens j 2021 21 7657 7664 crossref 69 munghen iacobellis v behdinan k incorporationoffiberbragggratingsensorsinadditivemanufacturedacrylonitrile butadienestyreneforstrainmonitoringduringfatigueloading int j fatigue2022 154 106485 crossref 70 shao l canning j wang cook k tam h viscosityofsilicaopticalfibrescharacterizedusingregeneratedgratings actamater 2013 61 6071 6081 crossref 71 xu pang zhao x li qin z liu z lu p bao x opticalfibersensorsforhigh temperaturemonitoring review sensors2022 22 5722 crossref 72 fu r luo w nazempour r tan ding h zhang k yin l guan j sheng x implantableandbiodegradable poly l lacticacid fibersforopticalneuralinterfaces adv opt mater 2018 6 1700941 crossref 73 shen zhao w j sun grattan k v fluorescencedecaycharacteristicoftm dopedyagcrystalfiberforsensor application investigatedfromroomtemperatureto1400 c ieeesens j 2003 3 507 512 crossref 74 zhu wu liu duan w linefiberopticinterferometricsensorsinsingle modefibers sensors2012 12 10430 10449 crossref pubmed 75 zhu wang surface mountsapphireinterferometrictemperaturesensor appl opt 2006 45 6071 crossref 76 li w liang jia p lei c hong li yao z liu w xiong j fiber opticfabry perotpressuresensorbasedon sapphiredirectbondingforhigh temperatureapplications appl opt 2019 58 1662 crossref pubmed 77 marque c f leal junior g min r domingues leitão c antunes p ortega b andré p advancesonpolymer opticalfibergratingsusingakrfpulsedlasersystemoperatingat248nm fibers2018 6 13 crossref 78 polz l dutz f j maier r r j bartelt h roth j regeneratedfibrebragggratings acriticalassessmentofmorethan20 yearsofinvestigations opt lasertechnol 2021 134 106650 crossref materials2023 16 1433 25of29 79 dragomir nikogosyan n zagorulko k kryukov p g dianov e inscriptionoffiberbragggratingsbyultraviolet femtosecondradiation opt lett 2003 28 2171 crossref 80 yang hu wang point pointfabricationandcharacterizationofsapphirefiberbragggratings opt lett 2017 42 4219 crossref 81 elsmann habisreuther graf rothhardt bartelt h inscriptionoffirst ordersapphirebragggratingsusing400nm femtosecondlaserradiation opt express2013 21 4591 crossref 82 leal junior frizera díaz c marque c ribeiro pons j materialfeaturesbasedcompensationtechniquefor thetemperatureeffectsinapolymerdiaphragm basedfbgpressuresensor opt express2018 26 16 crossref 83 poeggel tosi fusco f ippolito j lupoli l mirone v sannino leen g lewis e fiber opticefpipressuresensors forinvivourodynamicanalysis ieeesens j 2014 14 2335 2340 crossref 84 leal junior g díaz c r marque c pons j frizera 3d printedpofinsole developmentandapplicationsofa low cost highlycustomizabledeviceforplantarpressureandgroundreactionforcesmonitoring opt lasertechnol 2019 116 256 264 crossref 85 phillips p diston aknowledgedrivenapproachtoaerospaceconditionmonitoring knowl basedsyst 2011 24 915 927 crossref 86 wiech l calibrationofaloadmeasurementsystemforanunm annedaircraftcompositewingbasedonfibrebragggratingsand electricalstraingauges aerospace2020 7 27 crossref 87 javed mansoor shah areviewofprinciplesofmemspressuresensingwithitsaerospaceapplications sen rev 2019 39 652 664

crossref 88 hassoon tarfoui elmalk numericalsimulationoffiberbragggratingspectrumformode idelaminationdetection int j mech aerosp ind mechatron eng 2015 9 144 149 89 diaz c r leal junior g andre p b antunes p f pons j frizera neto ribeiro r n liquid level measurementbasedonfbg embeddeddiaphragmswithtemperaturecompensation ieeesens j 2018 18 193 200 crossref 90 xiong l jiang g guo liu h athree dimensionalfiberbragggratingforcesensorforrobot ieeesens j 2018 18 3632 3639 crossref 91 wang j ai f sun q liu li h yan z liu diaphragm basedopticalfibersensorarrayformultipointacoustic detection opt express2018 26 25293 25304 crossref 92 liu wang liao c wang j fu c yang k bai z zhang f nanosilicadiaphragmin fibercavityforgas pressuremeasurement sci rep 2017 7 787 crossref pubmed 93 marque c f peng g webb j highlysensitiveliquidlevelmonitoringsystemutilizingpolymerfiberbragggratings opt express2015 23 6058 6072 crossref pubmed 94 wang w wu n tian niezrecki c wang x miniatureall silicaopticalfiberpressuresensorwithanultrathinuniform diaphragm opt express2010 18 9006 crossref 95 libo anping q fiber opticdiaphragmpressuresensorwithautomaticintensitycompensation sen actuatorsa phys 1991 28 29 33 crossref 96 antunes p domingues f granada andré p mechanicalpropertiesofopticalfibers intechopenaccesspublisher london uk 2012 pp 1 15 97 leal junior campos v frizera marque c low costandhigh resolutionpressuresensorsusinghighlystretchable polymeropticalfibers mater lett 2020 271 127810 crossref 98 moradi h parvin p shahi f ojaghloo fiberopticfabry pérotacousticsensorusingpvcandgodiaphragms osa contin 2020 3 943 crossref 99 safarloo núñez cascajero sanchez gomez r vázquez c polymeropticalfiberplantarpressuresensors designand validation sensors2022 22 3883 crossref pubmed 100 marque c f pospori saez rodriguez nielsen k bang webb j aviationfuelgaugingsensorutilizing multiplediaphragmsensorsincorporatingpolymeropticalfiberbragggratings ieeesens j 2016 16 6122 6129 crossref 101 morais e pons j marque c leal junior liquidlevelsensorwithtwofbgsembeddedinapdmsdiaphragm analysisofthelinearityandsensitivity sensors2022 22 1268 crossref pubmed 102 vorathin e hafizi z aizzuddin lim k anaturalrubberdiaphragmbasedtransducerforsimultaneouspressure andtemperaturemeasurementbyusingasinglefbg opt fibertechnol 2018 45 8 13 crossref 103 leal junior g marque c frizera pons j multi interfacelevelinoiltanksandapplicationsofopticalfibersensors opt fibertechnol 2018 40 82 92 crossref 104 domingues f tavares c leitão c frizera neto alberto n marque c radwan rodriguez j postolache rocon e etal insoleopticalfiberbragggratingsensorsnetworkfordynamicverticalforcemonitoring j biomed opt 2017 22 091507 crossref 105 roper kardos osswald athermo viscoelasticapproachforthecharacterizationandmodelingofthebending behaviorofthermoplasticcomposites compos partaappl sci manuf 2016 90 22 32 crossref 106 vorathin e hafizi z ismail n loman reviewofhighsensitivityfibre opticpressuresensorsforlowpressuresensing opt lasertechnol 2020 121 105841 crossref materials2023 16 1433 26of29 107 leal junior g díaz c marque c frizera pons j 3d printingtechniquesonthedevelopmentofmultiparameter sensorsusingonefbg sensors2019 19 3514 crossref 108 liu peng w liang zhang x zhou x pan l fiber opticmach zehnderinterferometricsensorforhigh sensitivityhigh temperaturemeasurement opt commun 2013 300 194 198 crossref 109 leal junior frizera marque c pons j pons j polymer optical fiber basedsensorsystemforsimultaneous measurementofangleandtemperature appl opt 2018 57 1717 crossref pubmed 110 vorathin e hafizi z aizzuddin lim k ahighlysensitivemultiplexedfbgpressuretransducerbasedonnatural rubberdiaphragmandultrathinaluminiumsheet opt lasertechnol 2018 106 177 181 crossref 111 huang j zhou z wen x zhang adiaphragm typefiberbragggratingpressuresensorwithtemperaturecompensation meas j int meas confed 2013 46 1041 1046 crossref 112 alessandracutolo breglio g interferometricfabry perotsensorsforultrasounddetectiononthetipofanopticalfiber resultsopt 2022 6 100209 crossref 113 inaudi posenato glisic b miller j graver combined static dynamic monitoring civil structure long gaugefiberopticsensors inproceedingsoftheimacxxiiiconferenceandexpositiononstructuraldynamics orlando fl usa 31january 3february2005 p 3 114 philen white kuhl j mettler single modefiberotdr experimentandtheory ieeej quantumelectron 1982 18 1499 1508 crossref 115 spirit blank l raman assistedlong distanceopticaltimedomainreflectometry electron lett 1989 25 1687 1689 crossref 116 bao x webb j jackson 32 kmdistributedtemperaturesensorbasedonbrillouinlossinanopticalfiber opt lett 1993 18 1561 1563 crossref pubmed 117 sekine h fujimoto e okabe takeda n yokobori structuralhealthmonitoringofcrackedaircraftpanelsrepaired withbondedpatchesusingfiberbragggratingsensors appl compos mater 2006 13 87 98 crossref 118 guo h xiao g mrad n yao j fiberopticsensorsforstructuralhealthmonitoringofairplatforms sensors2011 11 3687 3705 crossref 119 hasan samsudin k ramli r b ismaeel areviewofnavigationsystems integrationandalgorithms aust j basic appl sci 2009 3 943 959 120 kapoor r ramasamy gardi vanschyndel r sabatini r acousticsensorsforairandsurfacenavigationapplications sensors2018 18 499 crossref 121 bancroft j b lachapelle g data fusion algorithm multiple inertial measurement unit sensor 2011 11 6771 6798 crossref 122 el diasty pagiatakis arigoroustemperature dependentstochasticmodellingandtestingformems basedinertialsensor error sensors2009 9 8473 8489 crossref 123 diaz c r leal junior marque c frizera pons j antunes p f c andre p b ribeiro r n opticalfiber sensingforsub millimeterliquid levelmonitoring areview ieeesens j 2019 19 7179 7191 crossref 124 wang z wang g kumar marque c min r li x recentadvancementsinresonantfiberopticgyro areview ieee sen j 2022 22 18240 18252 crossref 125 passaro v n cuccovillo vaiani l decarlo campanella c e gyroscopetechnologyandapplications areviewin theindustrialperspective sensors2017 17 2284 crossref pubmed 126 ostroverkhova organic optoelectronic material mechanism application chem rev 2016 116 13279 13412 crossref pubmed 127 leal junior g diaz c r avellar l pons j marque c frizera polymeropticalfibersensorsinhealthcare application acomprehensivereview sensors2019 19 3156 crossref 128 jiao h feng l wang k liu n yang z analysisofpolarizationnoiseintransmissivesingle beam splitterresonatoroptic gyrobasedonhollow corephotonic crystalfiber opt express2017 25 27806 crossref 129 titterton h weston j l moderninertialnavigationtechnologyanditsapplication electron commun eng j 2000 12 49 64 130 jiao h feng l wang j wang k yang z transmissivesingle beam splitterresonatoropticgyrobasedonahollow core photonic crystalfiber opt lett 2017 42 3016 crossref 131 terrel digonnet j f fan resonantfiberopticgyroscopeusinganair corefiber j light technol 2012 30 931 937 crossref 132 sander g strandjord l k qiu hollowcorefiberopticringresonatorforrotationsensing opt infobaseconf pap 2006 me6 2 5 133 h chang x mao h jin z laserfrequencynoiselimitedsensitivityinaresonatoropticgyroscope inproceedingsofthe oecc2010technicaldigest sapporo japan 5 9july2010 volume2 pp 706 707 134 suo x yu h li j wu x transmissiveresonantfiber opticgyroscopeemployingkagomehollow corephotoniccrystalfiber resonator opt lett 2020 45 2227 crossref 135 xiaolin yong w qiang z yunzhou l huanxin l jiaojiao q dongbin z aminiaturized low costandportablefiber bragggratinginterrogationsystemforremotemonitoring optik2021 248 168054 crossref 136 leal junior g díaz c r leitão c pons j marque c frizera polymeropticalfiber basedsensorforsimultaneous measurementofbreathandheartrateunderdynamicmovements opt lasertechnol 2019 109 429 436 crossref materials2023 16 1433 27of29 137 lu q b wang n wang x x yao wang x w huang w reviewofmicromachinedopticalaccelerometers frommgto sub µg opto electron adv 2021 4 200045 crossref 138 butt voronkov g grakhova e p kutluyarov r v kazanskiy n l khonina n environmentalmonitoring comprehensivereviewonopticalwaveguideandfiber basedsensors biosensors2022 12 1038 crossref pubmed 139 leal junior g frizera marque c sánchez r botelho r segatto v pons j polymeropticalfiberstrain gaugeforhuman robotinteractionforcesassessmentonanactivekneeorthosis opt fibertechnol 2018 41 205 211 crossref 140 antunes p f c varum h andre p intensity encodedpolymeropticalfiberaccelerometer ieeesens j 2013 13 1716 1720 crossref 141 lu q wang c bai j wang k lian w lou jiao x yang g subnanometerresolutiondisplacementsensorbasedona gratinginterferometriccavitywithintensitycompensationandphasemodulation appl opt 2015 54 4188 crossref 142 lu q bai j wang k design optimization andrealizationofahigh performancemoemsaccelerometerfroma double device layersoiwafer j microelectromechanicalsyst 2017 26 859 869 crossref 143 leal junior avellar l biazi v soares frizera marque c multifunctionalflexibleopticalwaveguidesensor thebioinspirationforultrasensitivesensorsdevelopment opto electronicadv 2022 5 210098 crossref 144 qiu l liang l li xu g theoretical experimental study fbg accelerometer based multi flexible hinge mechanism opt fibertechnol 2017 38 142 146 crossref 145 kuang k c maalej quek anapplicationofaplasticopticalfibersensorandgeneticalgorithmforstructural healthmonitoring j intell mater syst struct 2006 17 361 379 crossref 146 parida p thomas j nayak j asokan double lcantilever basedfiberbragggratingaccelerometer ieeesens j 2019 19 11247 11254 crossref 147 li tan han x zheng k zhou z diaphragm based fiber bragg grating acceleration sensor temperature compensation sensors2017 17 218 crossref 148 zhang f jiang wang c ni j zhao q broadbandandhighsensitivityfbgaccelerometerbasedondoublediaphragms andh shapedhinges ieeesens j 2020 21 353 359 crossref 149 liu q qiao x jia z fu h gao h yu largefrequencyrangeandhighsensitivityfiberbragggratingaccelerometer basedondoublediaphragms ieeesens j 2014 14 1499 1504 crossref 150 wang h liang l zhou x tu b newfiberbragggratingthree dimensionalaccelerometerbasedoncompositeflexurehinges sensors2021 21 4715 crossref pubmed 151 budinski v donlagic fiber opticsensorsformeasurementsoftorsion twistandrotation areview sensors2017 17 443 crossref pubmed 152 causse chua z k rémy f influencesofage mentalworkload andflightexperienceoncognitiveperformanceand prefrontalactivityinprivatepilots afnirsstudy sci rep 2019 9 7688 crossref 153 huygelier h schraepen b vanee r abeele v v gillebert c r acceptanceofimmersivehead mountedvirtualrealityin olderadults sci rep 2019 9 4519 crossref 154 newman p rich mara j spratford w theeffectofhelmetmassandaircraftaccelerationoncervicalspineloadsduring typicalfastjetaircraftpilotheadmotions j sci med sport2022 25 855 860 crossref 155 vanbenthem k herdman c avirtualrealitycognitivehealthscreeningtoolforaviation managingaccidentriskforolder pilot int j ind ergon 2021 85 103169 crossref 156 venus holtforth g australianandeasabasedpilots dutyschedules stress sleepdifficulties fatigue wellbeing symptomsofdepressionandanxiety transp re interdiscip perspect 2022 13 100529 crossref 157 farahani shahali h new onsettransientglobalamnesia aclinicalchallengeinanairmedicaltransportationpilot withahistoryofcoronavirusdisease2019 airmed j 2022 41 402 405 crossref pubmed 158 yuan j go l k ang x q teo z soh f w republicofsingaporeairforcehelicoptersearch rescueandmedical evacuation a5 yearreview airmed j 2022 41 350 358 crossref 159 arepalli moloney p engineerednanomaterialsinaerospace mrsbull 2015 40 804 811 crossref 160 ji x rao z zhang w liu c wang z zhang zhang b hu servati p xiao x airlinepoint caresystemonseat beltforhybridphysiologicalsignalmonitoring micromachines2022 13 1880 crossref pubmed 161 li singh r wang marque c zhang b kumar advancesinnovelnanomaterial basedopticalfiberbiosensors review biosensors2022 12 843 crossref 162 caucheteur c guo albert j multiresonantfibergratings opt photon news2022 33 42 49 crossref 163 li g xu q singh r zhang w marque c xie zhang b kumar grapheneoxide multiwalledcarbonnanotubes assistedserialquadrupletaperedstructure basedlsprsensorforglucosedetection ieeesens j 2022 22 16904 16911 crossref 164 gong p li x zhou x zhang chen n wang zhang zhao opticalfibersensorsforglucoseconcentration measurement areview opt lasertechnol 2021 139 106981 crossref 165 yang q zhang x kumar singh r zhang b bai c pu x developmentofglucosesensorusinggoldnanoparticlesand glucose oxidasefunctionalizedtaperedfiberstructure plasmonics2020 15 841 848 crossref 166 wang singh r li min r wu q kaushik b k jha r zhang b kumar cardiactroponinidetectionusing gold cerium oxidenanoparticlesassistedhetro corefiberstructure ieeetrans nanobioscience2022 pp 1 crossref materials2023 16 1433 28of29 167 sharma shrivastav gupta b lossymoderesonancebasedfiberopticcreatininesensorfabricatedusingmolecular imprintingovernanocompositeofmos sno ieeesens j 2020 20 4251 4259 crossref 2 2 168 li singh r soares marque c zhang b kumar convexfiber taperedsevencorefiber convexfiber ctc structure basedbiosensorforcreatininedetectioninaquaculture opt express2022 30 13898 13914 crossref pubmed 169 li q ding l zhang wu acholesterolopticalfibersensorbasedoncqds cod cacomposite ieeesens j 2022 22 6247 6255 crossref 170 agrawal n zhang b saha c kumar c pu x kumar ultra sensitivecholesterolsensorusinggoldandzinc oxide nanoparticlesimmobilizedcoremismatchmpm spsprobe j light technol 2020 38 2523 2529 crossref 171 wang z singh r marque c jha r zhang b kumar taper taperfiberstructure basedlsprsensorforalanine aminotransferasedetection opt express2021 29 43793 43810 crossref 172 singh l zhu g singh r zhang b wang w kaushik b k kumar goldnanoparticlesanduricasefunctionalizedtapered fibersensorforuricaciddetection ieeesens j 2019 20 219 226 crossref 173 wei x zhu li j liu l yu j li z ding b wearablebiosensorforsensitivedetectionofuricacidinartificialsweat enabledbyafiberstructuredsensinginterface nanoenergy2021 85 106031 crossref 174 singh l singh r zhang b cheng kumarkaushik b kumar lsprbaseduricacidsensorusinggrapheneoxideand goldnanoparticlesfunctionalizedtaperedfiber opt fibertechnol 2019 53 102043 crossref 175 kaur b kumar kaushik b k novelwearableopticalsensorsforvitalhealthmonitoringsystems areview biosensors 2023 13 181 crossref 176 tennyson r compositesinspace challengesandopportunities woodheadpublishinglimited sawston uk 1995 pp 35 56 177 binder k degennes p g giannelis e grest g hervet h krishnamoorti r leger l mania e raphael e wang q polymersinconfinedenvironments springerscience businessmedia berlin heidelberg germany 1998 178 xu hoa v mechanicalpropertiesofcarbonfiberreinforcedepoxy claynanocomposites compos sci technol 2008 68 854 861 crossref 179 mustapha f aris k wardi n sultan shahrjerdi structuralhealthmonitoring shm forcompositestructure 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