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THEME

EXPERIMENTAL AND SIMULATION STUDY OF PHONONIC CRYSTAL SENSORS FOR PETROLEUM PRODUCTS CHARACTERIZATION

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ABSTRACT

In this study, we propose a phononic crystal-based sensor for the characterization of refined petroleum products as an alternative to conventional methods such as optical and chemical conductivity techniques, which often suffer from limitations in sensitivity, cost, and complexity. The sensor design is based on the unique wave-filtering properties of phononic crystals, specifically their ability to create band gaps that are highly sensitive to changes in the surrounding medium. Using COMSOL Multiphysics, we conducted numerical simulations to optimize the phononic crystal structure based on its acoustic band gap characteristics and transmission spectra. The sensor's performance was evaluated by simulating and measuring its response to various refined petroleum products, including gasoil, gasoline, diluent, and binary mixtures such as ethanol–gasoline and diluent–gasoil. Experimental measurements of acoustic wave transmission were carried out for each product to validate the sensor's ability to distinguish between different fuel types. The performances of the proposed sensor such as the quality factor and sensitivity were analyzed, demonstrating its potential for real-time characterization of petroleum-based fluids. This work highlights the feasibility of phononic crystal structures as efficient, compact, and cost-effective alternatives for fuel quality monitoring and opens up new possibilities for acoustic sensing in the petrochemical industry.

Key words:phononic crystal 2D,phononic band gap , transmission s21, quality factor and sensitivity

ملخص

في هذه الدراسة، نقترح مستشعرًا يعتمد على البلورات الصوتية لتوصيف المنتجات البترولية المكررة كبديل للطرق التقليدية مثل تقنيات التوصيل البصري والكيميائي، التي غالبًا ما تعاني من قيود في الحساسية والتكلفة والتعقيد .تصميم المستشعر يعتمد على الخصائص الفريدة لتصفية الموجات في البلورات الصوتية، وبشكل خاص قدرتها على إنشاء فجوات نطاقية حساسة للغاية للتغيرات في الوسط المحيط .باستخدام برنامجCOMSOL Multiphysics ، أجرينا محاكاة عددية لتحسين هيكل البلورة الصوتية بناءً على خصائص فجوة النطاق الصوتية وطيف النقل الخاص بها .تم تقييم أداء المستشعر من خلال محاكاة وقياس استجابته لمختلف منتجات النفط المكررة، بما في ذلك الغازوال، البنزين، المذيب، والمخاليط الثنائية مثل الإيثانول-بنزين والمذيب-غازوال .تم إجراء قياسات تجريبية لنقل الموجات الصوتية لكل منتج للتحقق من قدرة المستشعر على التمييز بين أنواع الوقود المختلفة .تم تحليل أداء المستشعر المقترح مثل معامل الجودة والحساسية، مما أظهر إمكانيته في التوصيف الفوري للسوائل القائمة على النفط .تسلط هذه الدراسة الضوء على جدوى هياكل البلورات الصوتية كبدائل فعالة ومضغوطة وفعالة من حيث التكلفة لمراقبة جودة الوقود، وتفتح آفاقًا جديدة للاستشعار الصوتي في صناعة البتروكيماويات

الكلمات المفتاحية "كريستال فونوني ثنائي الابعاد-فجوة النطاق الفونونية-الانتقال الصوتيS21 –معامل الجودة والحساسية**"**

Résumé

Dans cette étude, nous proposons un capteur basé sur des cristaux phononiques pour la caractérisation des produits pétroliers raffinés comme alternative aux méthodes conventionnelles telles que les techniques de conductivité optique et chimique, qui souffrent souvent de limitations en termes de sensibilité, de coût et de complexité. La conception du capteur est basée sur les propriétés uniques de filtrage des ondes des cristaux phononiques, en particulier leur capacité à créer des bandes interdites très sensibles aux changements du milieu environnant. En utilisant COMSOL Multiphysics, nous avons réalisé des simulations numériques pour optimiser la structure du cristal phononique en fonction de ses caractéristiques de bande interdite acoustique et de ses spectres de transmission. La performance du capteur a été évaluée en simulant et en mesurant sa réponse à divers produits pétroliers raffinés, y compris le gasoil, l'essence, le diluant, et des mélanges binaires tels que l'éthanol-essence et le diluant-gasoil. Des mesures expérimentales de transmission des ondes acoustiques ont été réalisées pour chaque produit afin de valider la capacité du capteur à distinguer les différents types de carburants. Les performances du capteur proposé, telles que le facteur de qualité et la sensibilité, ont été analysées, démontrant son potentiel pour la caractérisation en temps réel des fluides à base de pétrole. Ce travail met en évidence la faisabilité des structures de cristal phononiques en tant qu'alternatives efficaces, compactes et rentables pour la surveillance de la qualité des carburants et ouvre de nouvelles possibilités pour la détection acoustique dans l'industrie pétrochimique.

Mots clés : cristal phononic 2D, bande interdite phononique, transmission S21,facteur de qualité et la sensibilité.

Preface

This master thesis was conducted in the context of the Master's program in Energy and renewable energy, taught by the physics department of the Setif University. The research was carried out within the Research Unit in Optics and Photonics (UROP) at the CDTA (Centre de Développement des Technologies Avancées). The research presented in this thesis was carried out between February 2, 2025, and june 25, 2025, at the Photonic Crystal Lab, affiliated with UROP-CDTA. This project was conducted under the supervisor Dr. KANOUNI Fares, a Senior Researcher Class A and team leader at UROP.

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