

NOVEL NANOPHOTONIC DEVICES FOR OPTICAL SWITCHING AND MODULATION

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NOVEL NANOPHOTONIC DEVICES FOR OPTICAL SWITCHING AND MODULATION

by

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CERTIFICATE

This is to certify that the thesis entitled “**Novel Nanophotonic Devices for Optical Switching and Modulation**” being submitted by Ms. Priyanka Bhardwaj to the Department of Electrical Engineering, Indian Institute of Technology, Delhi, for the award of the degree of ***Doctor of Philosophy*** in Electrical Engineering, is a record of bonafide research work carried out by her. She has worked under my guidance and supervision and has fulfilled the requirements for the submission of this thesis, which to my knowledge has reached the requisite standard. The results contained in this thesis have not been submitted in part or in full to any other University or Institute for the award of any degree or diploma.

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ABSTRACT

Nanophotonics is an emerging area of research that deals with interaction between light and matter, particularly nanostructures. The work presented in this thesis mainly focuses on nanophotonic devices (such as switches, modulators and power splitters etc.) and their modeling. This thesis is a summary of detailed theoretical studies of several nanophotonic devices having applications in optical switching and optical modulation. We firstly present a numerical study (using 3 D FDTD and MODE solver) of a broadband optical modulator based on phase change material embedded in photonic crystal (PhC) slab waveguide which operates at telecom wavelength 1550 nm, showing a broadband switching capability and ON/OFF extinction ratio of >37 dB. This device is based on the shifting of the mode-gap in photonic bandgap of the PhC slab waveguide when the refractive index of the Phase Change Material layer i.e. Germanium Selenide (GeSe) changes on application of electric field. Further, we investigated an electro-optic switch based on microdisk resonator having Phase Change Material (GeSe) embedded in microdisk resonator, which is based on resonant frequency shift with change in refractive index on applying voltage. We employed Numerical FDTD for optical modeling and Numerical DEVICE for electrical modeling of the same. The third device proposed in this thesis is a high-speed novel electro-optic tunable power splitter that is based on depletion-mode interleaved p-n junction in silicon-based microring resonator. The interleaved p-n junction configuration provides higher interaction between propagating mode and depletion region with moderate optical loss compared to other p-n junction configurations. The ring resonator operates between on-resonance and off-resonance states for a specific resonance wavelength on applying externally applied voltage, which enables it as an optical power splitter. and we have obtained a split ratio tuning range of 0.15 to 7.82, which is a very wide range of tunability with very low

power consumption (35 mW) and low external voltage (0-3.5 V). We have used a commercially available solver (Lumerical DEVICE) to calculate the carrier configuration by applying a reverse bias voltage and the calculated carrier information was imported in the FDTD solver (Lumerical FDTD solutions) to calculate the transmission and optical loss. In addition, we have proposed an optical switch based on 1D and 2D plasmonic nanogratings. This plasmonic switch is based on vanadium dioxide (VO_2) which is a smart material that changes its phase upon exposure to IR radiation or on application of voltage or temperature. VO_2 changes its phase from semiconductor to metallic which in turn changes its optical properties. Thus, the optical behavior of the proposed nanogratings changes upon the change of phase of VO_2 , leading to optical switching. The design of the 1D and 2D gratings can be varied to tunably vary the switching wavelength. Hence, we have designed efficient optical switches that can be employed for ultrafast switching.

सार

नैनोफोटोनिक्स अनुसंधान का एक दिलचस्प और उभरता हुआ क्षेत्र है जो प्रकाश और पदार्थ, विशेष रूप से नैनोस्ट्रक्चर के बीच बातचीत से संबंधित है। नैनोफोटोनिक्स का क्षेत्र फोटोनिक्स और नैनोटेक्नोलॉजी के क्षेत्र को मिला देता है। इस थीसिस में प्रस्तुत कार्य मुख्य रूप से नैनोफोटोनिक उपकरणों (जैसे स्विच, मॉड्यूलैटर और पावर स्प्लिटर्स आदि) और उनके मॉडलिंग पर केंद्रित है। यह थीसिस ऑप्टिकल स्विचिंग और ऑप्टिकल मॉड्यूलेशन में अनुप्रयोगों वाले कई नैनोफोटोनिक उपकरणों के विस्तृत सैद्धांतिक अध्ययन का सारांश है। हम सबसे पहले एक ऑप्टिकल ऑप्टिकल न्यूनाधिक के 3 डी FDTD और MODE सॉल्वर का उपयोग करते हुए एक संख्यात्मक अध्ययन (फोटोनिक क्रिस्टल में एम्बेडेड चरण परिवर्तन सामग्री के आधार पर) प्रस्तुत करते हैं (PhC) स्लैब वेवगाइड दूरसंचार तरंग दैर्घ्य 1550 एनएम पर चल रही है, एक ब्रॉडबैंड स्विचिंग क्षमता और ON / OFF दिखा रहा है विलोपन अनुपात > 37 डीबी। यह डिवाइस पीएचसी स्लैब वेवगाइड के फोटोनिक बैंडगैप में मोड-गैप की शिफ्टिंग पर आधारित है, जब फेज चेंज मैटीरियल लेयर के अपवर्तक सूचकांक यानी जर्मैनियम सेलेनाइड (GeSe) विद्युत क्षेत्र के अनुप्रयोग के लिए बदल जाता है। इसके अलावा, हमने माइक्रोडिस्क गुंजयमान यंत्र पर आधारित एक इलेक्ट्रो-ऑप्टिक स्विच की जांच की जिसमें फेज चेंज मैटीरियल (GeSe) था, जो माइक्रोडिस्क रेज़ोनेटर में सन्निहित था, जो वोल्टेज लगाने पर अपवर्तक सूचकांक में परिवर्तन के साथ गुंजयमान आवृत्ति शिफ्ट पर आधारित है। हमने ऑप्टिकल मॉडलिंग के लिए न्यूमेरिकल FDTD और उसी के इलेक्ट्रिकल मॉडलिंग के लिए न्यूमेरिकल डेविस को नियोजित किया। इस थीसिस में प्रस्तावित तीसरा उपकरण एक उच्च गति वाला उपन्यास इलेक्ट्रो-ऑप्टिक ट्यून करने योग्य पावर स्प्लिटर है जो सिलिकॉन-आधारित माइक्रोनिंग रेज़ोनेटर में कमी-मोड इंटरलेव्ड पी-एन जंक्शन पर आधारित है। इंटरलीव्ड पी.एन. जंक्शन कॉन्फिगरेशन अन्य पी.एन. जंक्शन विन्यासों की तुलना में

मध्यम ऑप्टिकल हानि के साथ प्रचार मोड और घटने वाले क्षेत्र के बीच उच्च अंतःक्रिया प्रदान करता है। रिंग गुंजयमान यंत्र अनुनाद और ऑफ-रेजोनेंस राज्यों के बीच बाहरी अनुलंब वोल्टेज लगाने पर एक विशिष्ट अनुनाद तरंगदैर्घ्य के बीच संचालित होता है, इसे एक ऑप्टिकल पावर स्प्लिटर के रूप में सक्षम बनाता है। और हमने प्राप्त कर लिया है 0.15 से 7.82 के विभाजन अनुपात ट्यूनिंग रेंज, जो बहुत कम बिजली की खपत (35 mW) और कम बाहरी वोल्टेज (0-3.5 V) के साथ ट्यूनीबिलिटी की एक विस्तृत श्रृंखला है। हमने गणना करने के लिए एक व्यावसायिक रूप से उपलब्ध सॉल्वर (ल्यूमेरिकल डिवाइस) का उपयोग किया है। पारेषण और ऑप्टिकल नुकसान की गणना करने के लिए एफडीडीए सॉल्वर (ल्यूमेरिकल एफडीडीटी सॉल्यूशंस) में एक रिवर्स बायस वोल्टेज और परिकल्पित वाहक जानकारी को लागू करके वाहक विन्यास को आयात किया गया था। इसके अलावा हमने एक प्लास्मोनिक नैनोग्रैटिंग (दोनों 1 डी और 2 डी) आधारित ऑप्टिकल स्विच का प्रस्ताव किया है। यह प्लास्मोनिक स्विच वैनेडियम डाइऑक्साइड (VO_2) पर आधारित है जो एक स्मार्ट सामग्री है जो आईआर विकिरण के संपर्क में या वोल्टेज या तापमान के आवेदन पर बहुत तेजी से अपना चरण बदलती है। VO_2 सेमीकंडक्टर से धातु तक के अपने चरण को बदलता है जो बदले में इसके ऑप्टिकल गुणों को बदलता है। इस प्रकार स्विचिंग में ट्यूनीबिलिटी प्राप्त करने के लिए प्रस्तावित नैनोग्रेट्स के ऑप्टिकल व्यवहार में बदलाव किया जा सकता है। इसलिए प्रस्तावित 1 डी और 2 डी प्लास्मोनिक नैनोग्रैटिंग को अल्ट्राफास्ट स्विचिंग के साथ ट्यून करने योग्य स्विच के रूप में उपयोग किया जा सकता है।

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