様　式　Ｃ－１９、Ｆ－１９－１、Ｚ－１９　（共通）

科学研究費助成事業　　研究成果報告書

平成 ２９ 年　 ６ 月 ２６ 日現在

機関番号：１２６０１
研究種目：基盤研究(B)（一般）
研究期間：2014～2016
課題番号：２６２８９０１３

研究課題名（和文）Plasmonic nanostructures realizing miniaturized infrared spectrometric image-array-sensor for endoscopy

研究課題名（英文）Plasmonic nanostructures realizing miniaturized infrared spectrometric image-array-sensor for endoscopy

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交付決定額（研究期間全体）：（直接経費）　　13,100,000円

研究成果の概要（和文）：近年、プラズモン共鳴状態の金属ナノ構造体における高強度光閉じ込め効果に起因する、光とナノ構造体の相互作用について新しい知見が得られた結果、ナノ構造体の様々な状態変化はその構造体の光学応答によって観測されている。光学応答の検出はプラズモン共鳴の近接場特性によって支配されるため、電気マイクロ回路を形成し、光学近接場変動を直接監視する構造が望ましいと考えられる。ここでは、分解能及びインピーダンス変調において高性能なプラズモンナノチャネル構造に基づいた、電子的に読み取り可能なフォトキャパシタを実証する。このプラズモンフォトキャパシタのアレイは小型の赤外線分光画像アレイセンサの実現への貢献が期待される。

研究成果の概要（英文）：Interaction of light with metal sub-wavelength structures has revealed new properties of light, such as light ability to pass through an array of nanoholes. Strong light confinement on the metal structures in the form of a plasmon resonance was found to be at the origin of this far field property. The optical properties of plasmonic structures have been used to monitor changes in their physical, chemical, and biological environments. The detection of this response in the far field is governed by the near-field properties of plasmon resonances. The micro integration on chips of these structures is difficult because of the far field readout. Thus, structures that form an electrical micro-circuit and directly monitor the optical near-field variation without resorting to far-field optical detection would be more desirable. Here, we demonstrate an electronically readable photocapacitor based on a plasmonic nanochannel structure with high spectral resolution and large impedance modulation.

研究分野：生産工学・加工学

キーワード：ナノマイクロ加工　メタマテリアル・表面プラズモン

１．研究開始当初の背景

Different strategies have been employed to achieve strong light confinement on nanostructures, namely, isolated nanostructures (e.g., oblong particles dispersed in a solution) and periodic array of two-dimensional horizontal nanostructures on substrates (e.g., nano antenna on a substrate). Plasmonic resonances in V-groove nanostructures have also been reported, suggesting the use of a new class of vertical plasmonic resonances. This research focuses on the use of metal nanofins for light confinement using plasmonic resonance on the vertical plane of the nanofins. Here, we use the nanofins to confine light in vertical channels made of a semiconducting materials and at the same time detect light that is absorbed in the channel by measuring the change in impedance of the capacitor formed by the channel embedded between the metallic nanofins. That is, the nanofins serve two purposes, namely, light confinement (plasmonic structure) and light detection (electrode). The proposed structure is therefore an electronically readable plasmonic photocapacitor. The structure consists of periodic high-aspect-ratio semiconducting walls sandwiched between metallic layers forming a U-cavity. This structure sustains sharp and strong resonances that realize both dispersion and detection of light, thus is amenable to miniaturization. Indeed the metallic layers can be used to measure the impedance of the capacitors formed by the channel embedded between the metallic layers. Furthermore, the absorption resonance of the designed structure can be controlled by varying the period of the structure. Therefore, the proposed structure can be made to absorb light selectively at different wavelengths, so that both dispersion and detection of light are realized with the same structure and an array of these structures can be fabricated on-chip. The concept shown in FIG. 1 enables the realization of a spectrometric image array sensor.

２．研究の目的

The goal of this research project is to design, fabricate and evaluate an electronically readable photocapacitor based on a plasmonic nanochannel structure, which monitors the change in incident light wavelength with high spectral resolution and large impedance modulation. The proposed plasmonic structure will be characterized for absorption resonance sharpness and strength, control of the resonance wavelength, and electrical responsivity. The proof of concept is realized with silicon for fabrication convenience, however, the concept can be extended to other semiconductor materials, so that the range of wavelength detection of the proposed device can be extended beyond the near infrared region to the infrared region.

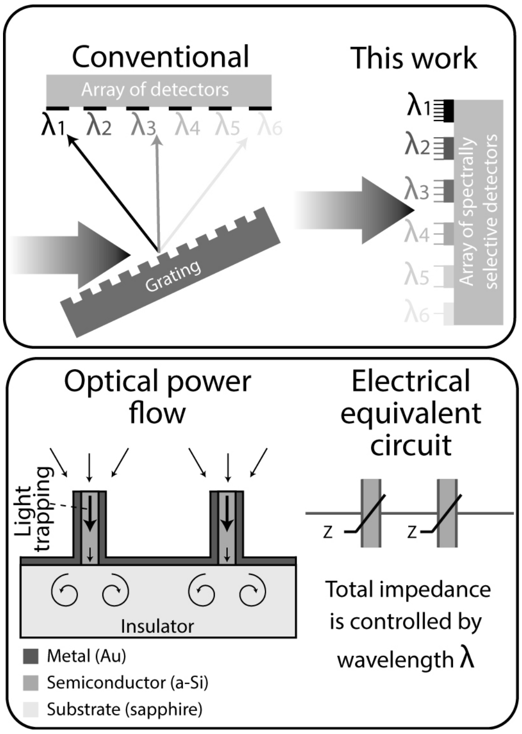

FIG. 1 Device concept showing both dispersion and detection of light by the same structure.

３．研究の方法

The fabrication technique of the proposed plasmonic structure was established (FIG. 2). The fabrication technique relies on top-down electron beam lithography followed by deep reactive ion etching to obtain the vertical nanochannels. A

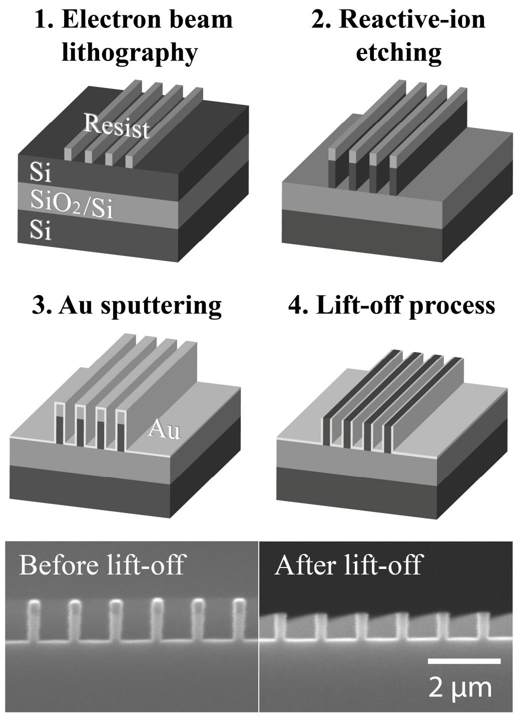

FIG. 2 Scheme of the fabrication technique (top) and fabricated structure before and after the lift-off process (bottom).

A silicon-on-insulator wafer is first coated with a resist. The resist is patterned using electron lithography so that a line and space pattern is formed. The resist is used as a mask for the deep reactive ion etching step. After the reactive etching step, vertical walls made of silicon are obtained. The tops of the walls are still covered with resist. Then, conformal coating of the metal layer is performed. Finally, a lift off step is used to remove the top resist coated by metal, so that the vertical walls made of silicon are sandwiched between metallic layers. This structure formed a capacitor that can be used to monitor the response of the structure to light. The structure was investigated by simulation of the near field and far field (FIG. 3). The reflectance shows a sharp dip (Point A in Fig 3), which corresponds to the coupling of surface plasmons as seen in the near field. The quality of the fabricated structure was evaluated by comparing the measured and simulated reflectance. The spectral response was characterized for light energy larger and smaller than the bandgap of the semiconductor material which is used for the vertical channels. The sensitivity was determined using a resonant circuit combined with lock-in amplification. The resonant detection is obtained with an RLC circuit and the resonance frequency is determined in dark by finding the minimum voltage across the resistor. The sensitivity is determined by measuring the increase in the voltage caused by illumination.

４．研究成果

The proposed structure consists of metallic U-cavities and semiconductor channels, which are used to focus and confine light at the semiconductor–metal interfaces. At these interfaces, light is efficiently converted into photocarriers that change the electrical impedance of the structure. The mechanism of the spectrally selective light absorption in the hybrid structure was clarified. The absorption resonance originates in the coupling of horizontal surface plasmon mode of the U-cavity with channel mode. The channel mode sustains stationary-surface-plasmons in the channel with antinodes at the channel entrances enabling light concentration and nodes at the channel exits enabling light confinement. As a result of the coupling, a sharp and strong absorption resonance is readily adjustable by varying the geometrical parameters of the U-cavity while keeping the channel parameters unchanged. The capacitance modulation of the structure in response to light produces a light-to-dark contrast ratio larger than 10^3. A reflectance spectrum with a bandwidth of 16 nm and a 6% modulation depth is detected using a reactance variation of 3 kΩ with the same bandwidth (FIG. 4). The control of the absorption wavelength was realized by varying the period of the plasmonic structure (FIG. 5). The hybrid structure sustains sharp, strong and controllable resonances that realize both dispersion and detection of near infrared light, thus is amenable to miniaturization and therefore offers a practical means of monitoring changes induced by the near field and thus could be deployed in pixel arrays of image sensors for miniaturized spectroscopic applications. It is envisioned that an array of the plasmonic photocapacitors could be used to realize a miniaturized infrared spectrometric image-array-sensor.

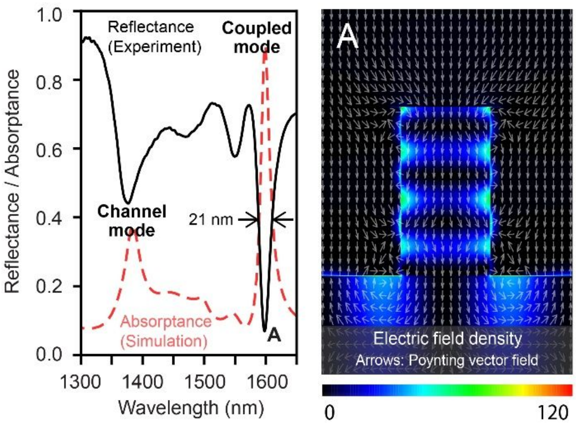

FIG. 3 Reflectance (far field) and electric field distribution (near field) properties of the proposed structure.

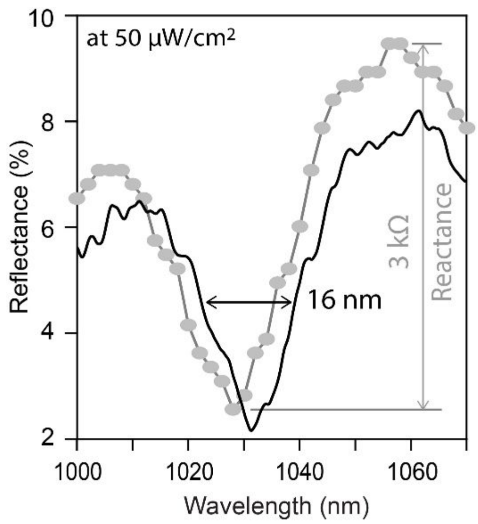

FIG. 4 Optical response (reflectance) and electrical response (reactance) of the proposed structure.

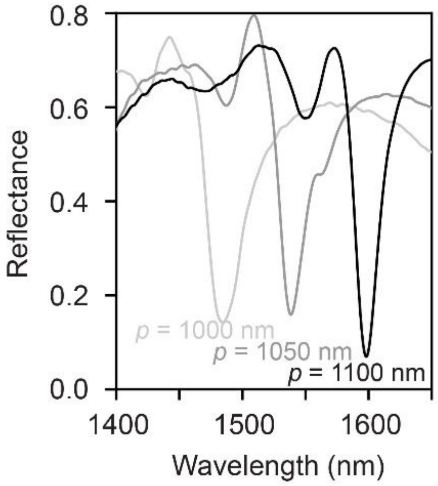

FIG. 5 Control of the reflectance dip wavelength by varying the period of the structure.

５．主な発表論文等
（研究代表者、研究分担者及び連携研究者には下線）

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〔図書〕（計 0 件）

〔産業財産権〕

○出願状況（計 1 件）

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権利者：国立大学法人東京大学
種類：特許
番号：特願 2014-015066
出願年月日：2014/01/30
国内外の別： 日本

○取得状況（計 0 件）

名称：
発明者：
権利者：
種類：
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取得年月日：
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ホームページ等
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