Ultra-broad band absorber made by tungsten and aluminium

Wei Wang, Ding Zhao, Qiang Li, Min Qiu

State Key Laboratory of Modern Optical Instrumentation, College of Optical Science and Engieering, Zhejiang University, Hangzhou 310027, China

minqiu@zju.edu.cn

Abstract. A broadband absorber comprising tungsten cubic arrays, a alumina layer and a tungsten film, is numerically and experimentally investigated, which exhibits near-unity absorption of visible and near-infrared light from 400 nm to 1150 nm. Benefiting from high melting points of tungsten and alumina, this device has great application potential in solar cells and thermal emission.

1. Introduction

As a critical component, plasmonic absorbers have already attracted plenty of attention and shown great promise for devising solar cells[1], microbolometers[2], biosensors[3], and photodetectors[4,5,6,7,]. Attributing to Kirchhoff's law of thermal radiation, they can also be utilized as thermal emitters [8]. For instance, the emitter serves as a key component to radiate thermal radiation to photovoltaic (PV) cells in thermophotovoltaic (TPV) systems. To achieve high efficient thermoelectric conversion, emitter's thermal radiation spectrum should ideally coincide with the PV cell's response spectrum, which mostly ranges from visible to infrared frequency. Various broadband absorbers of exotic geometry have been proposed during recent years, such as complicated trapezoid [9], truncated spherical voids [10] and tapered pyramid structures [11]. Due to excellent properties and simple fabrication, metal/insulator/metal (MIM) architecture absorbers have become the focus of much attention. In this paper, we present a three-layer MIM plasmonic absorber, which works at the visible and near-infrared region. Broadband absorption from 400 nm to 1150 nm and high operating temperature of this device could match requirements for TPV application.

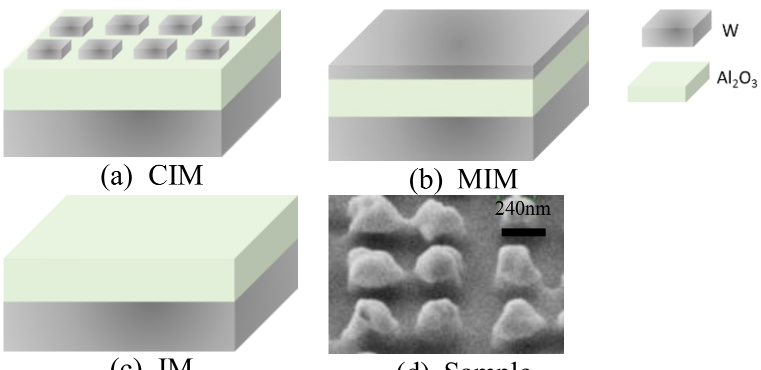


Figure 1. Geometry of CIM, MIM and IM structure. (d) top view of CIM sample.

Journal of Physics: Conference Series **680** (2016) 012039 doi:10.1088/1742-6596/680/1/012039

2. Simulation and experimental results

2.1. Simulation result

Figure 1(a) shows the proposed structure in which Al2O3 dielectric layer sandwiched by a tungsten layer and tungsten blocks. In our simulation, cubic arrays are consisting of tungsten particles with width 225nm, length 225nm, and height 225nm. Distance between each unit cell is 275nm. Height of the Al2O3 layer is 250nm, and tungsten layer below it is 140nm. Here tungsten is thick enough to prevent light from transmitting. Therefor, absorption can be defined by reflection subtracted from one.

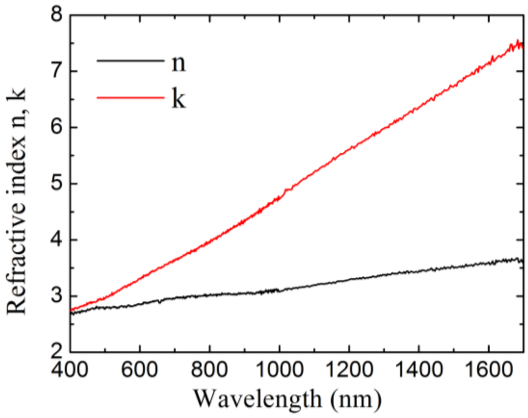


Figure 2. Refractive index of tungsten film ensured by ellipsometer.

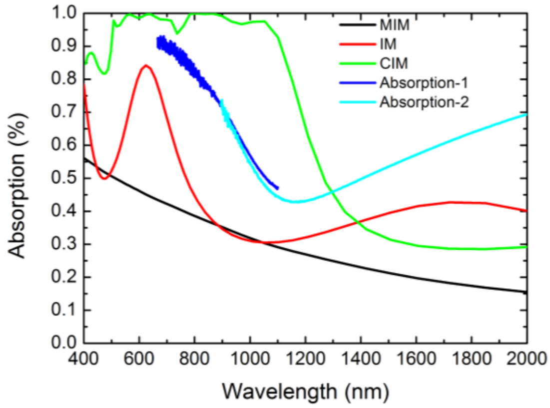
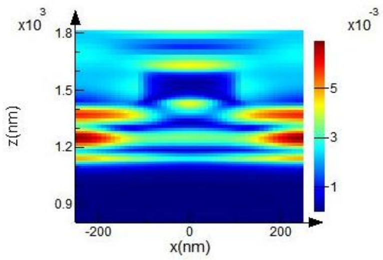
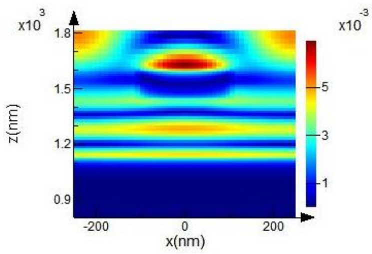


Figure 3. Comparison of absorption property for MIM, IM and CIM structure.

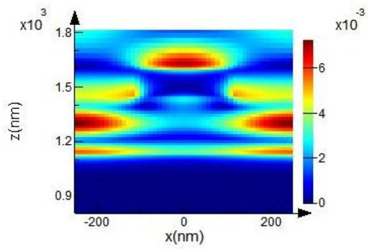
In this paper, tungsten film is fabricated by magnetron sputtering. Variable angle spectroscopic ellipsometry is used to extract the complex optical constants of this film. Refractive index results are shown in figure 2.



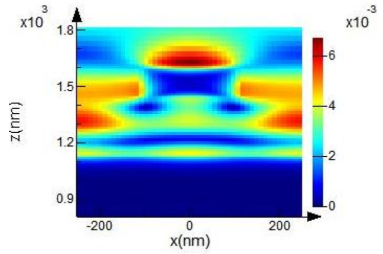
(a) $\lambda = 420$ nm



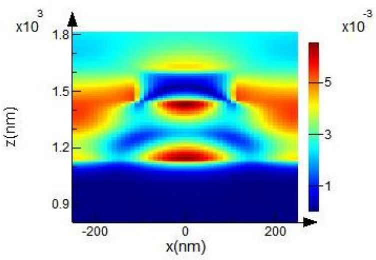
(b) $\lambda = 507$ nm



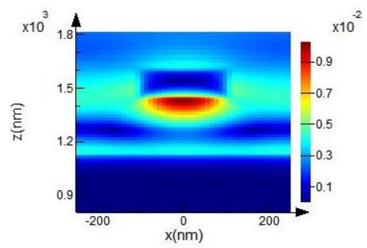
(c) $\lambda = 553$ nm



(d) $\lambda = 624$ nm



(e) $\lambda = 837$ nm



(f) $\lambda = 1050$ nm

Figure 4. Magnetic field profiles at $\lambda = 420\text{ nm}, 507\text{ nm}, 553\text{ nm}, 624\text{ nm}, 837\text{ nm}$ and 1053 nm.

During the simulation process, periodic condition is set as boundary condition. Absorption property of metal-insulator-metal (figure 1b) and insulator-metal (figure 1c) geometry are also simulated as references for cubic-insulator-metal structure (figure 1a). These structure's absorption abilities are shown in Figure 3. CIM structure shows nearly perfect absorption property and its bandwidth range from 400nm to 1150nm which covers visible and near-infrared regions. Compared with IM and MIM geometry's absorption ability, additional tungsten cubic array strongly enhanced its absorption property.

Such high and wide absorption of this device is attributed to the strongly distributed electromagnetic field. Figure 4 shows the magnetic field profiles at the spectrum where resonance appear.

2.2. Experimental result

Tungsten absorber sample is etched by Focused-ion-beam (FIB). Inset in figure 4 shows SEM image of that sample. Line named absorption-1 and absorption-2 in figure 3 both are measured by FTIR at different detector mode. As shown in figure 4, blue line (absorption-1) gradually increases to reach 90% when wavelength decrease to be 620nm.

Experimental absorption result is narrow than numerical result. This is because when FIB etch top tungsten layer, part of Al2O3 layer could be etched out together. This lead to electromagnetic wave couldn't be confined perfectly in the dielectric layer. Thus part of spectrum couldn't be absorbed by this device.

3. Conclusion

In conclusion, we have simulated a nearly perfect broadband absorber spanning from visible to near-infrared spectrum. The experimental result partially agree with theoretical predictions. There still have promotion prospect for broader absorption width which using EBL method which can circumvent the deeper etching deficiency. Furthermore tungsten and aluminium oxide owning high melting point. Such material used in this device enable this absorber would endure more thermal energy transformed from external optical stimulus in applications such as solar thermophotovoltaics (STPV).

References

[1] N. C. Panoiu and R. M. Osgood 2007 Opt. Lett. **32** 2825
[2] P. L. Richards 1994 J. Appl. Phys. **76** 1
[3] B. Sepulveda, L.G. Carrascossa, D. Regarots, M. A. Otte, D. Farina, and L.M. Lechuga 2009 Proc. SPIE **7397** 1
[4] Y. Ahn, J. Dunning, and J. Park 2005 Nano Lett. **5** 1367
[5] Y. Gu, E.-S. Kwak, J. L. Lensch, J. E. Allen, T. W. Odom, and L. J. Lauhon 2005 Appl. Phys. Lett. **87** 43111
[6] O. Hayden, R. Agarwal, and C. M. Lieber 2006 Nat. Mater. **5** 352
[7] J. Rosenberg, R. V. Shenoi, T. E. Vandervelde, S. Krishna, and O. Painter 2009 Appl. Phys. Lett. **95** 161101
[8] J. J. Greffet, R. Carminati, K. Joulain, J. P. Mulet, S. P. Mainguy, and Y. Chen 2002 Nature **416** 61
[9] V. E. Ferry, K. Aydin, R. M. Briggs, and H. A. Atwater, 2011 Nat. Commun. **2** 517
[10] M. Wang, CG Hu, MB Pu, C. Huang, ZY Zhao, Q. Feng, and XG Luo 2011 Opt. Express **19** 20642
[11] E. Rephaeli, and S. Fan 2008 Appl. Phys. Lett. **92** 211107