Intense THz to IR emission from random 2D metallic nanostructures

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***Abstract*— We report an intense (~10mW) and ultra-broadband (~150 THz) THz to infrared (IR) source with a Gaussian wavefront, emitted from nano-pore-structured metallic thin films with femtosecond laser pulse excitation. The underlying mechanism has been proposed as thermal radiation. In addition, an intense coherent THz signal was generated through the optical rectification process simultaneously with the strong thermal signal. This unique feature opens up new avenues in biomedical research.**

I. INTRODUCTION

There has been considerable interest in the potential applications of radiation from the THz to IR range, which are also known as sub-millimeter waves, because these waves can penetrate many materials to reveal the corresponding spectral signatures. A considerable amount of research has been conducted on the use of femtosecond lasers to generate THz radiation from nanostructured metal surfaces, including planar (percolated) metal films, corrugated films (shallow gratings), and ordered arrays of metallic nanoparticles. However, the THz emission from the aforementioned sources is too weak for many applications.

In the present study, we used a randomly roughened surface to realize momentum matching over a wide range of wave vectors. In addition to providing the coupling mechanism, the surface roughness features also served to localize and further enhance the surface plasmons. After irradiating a surface with a femtosecond laser pulse, a fraction of the absorbed laser energy is retained in the surface layer of the sample and then dissipates into the bulk sample via heat conduction as residual thermal energy. It has been determined that a significant amount of residual energy can be deposited in samples through surface roughness effects, exothermic chemical processes and ambient gas pressure effects. The residual energy causes the temperature of the bulk sample to increase. After reaching thermal equilibrium, the bulk sample then acts as a thermal radiation source.

In this study, we identified strong THz to IR thermal radiation from a randomly roughened metallic surface. We optimized the design of the metal deposition parameters to realize mW-level radiation intensity and an ultra-broadband (~150 THz) frequency spectrum. An intense coherent THz signal was generated through the optical rectification process simultaneously with the strong thermal signal. The coherent THz signal was also enhanced with the pump fluence because the laser absorptivity was enhanced by the thermal effect of the metal surface.

II. RESULTS

The substrate was a 60um thick anodic-aluminum-oxide (AAO) membrane with a 200 nm pore diameter (Whatman, Germany). The pore density was approximately 50%. The metal was deposited on the membrane by magnetron sputtering. The metallic thin films had a nominal thickness of 100 nm and exhibited a random nanoscale surface roughness because of the through-pore structure of the AAO membranes.

We used a Fourier-transform Michelson interferometer to quantitatively characterize the THz radiation spectra emitted by our samples. An amplified Ti:sapphire laser having a central wavelength of 800 nm, pulse energy of 1.3 mJ, pulse duration of 100 fs, and a repetition rate of 1 kHz was used. The optical beam was focused normally on the sample with a spot diameter of 6 mm. The radiation was detected using a Golay cell that was equipped with a 6-mm-diameter diamond input window (Microtech SN:220712-D), which exhibited a nearly flat response over a broad spectral range (0.1-150 THz).

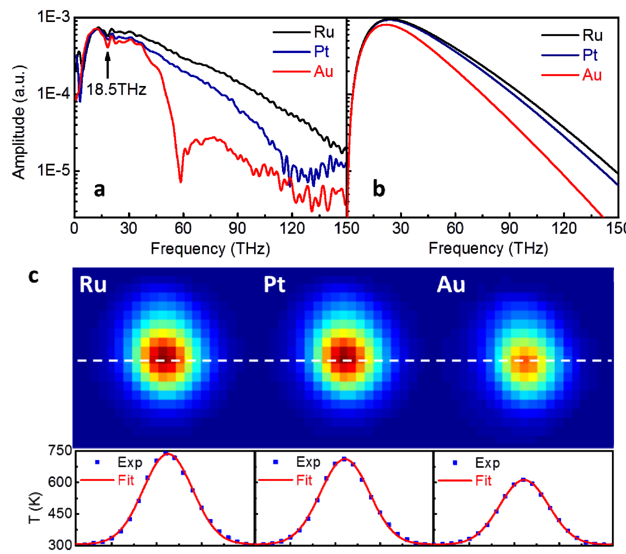

Fig. 1. (**a**) Measured radiation spectra for 100-nm-thick ruthenium (Ru), platinum (Pt) and gold (Au) films; (**b**) simulated frequency spectra; (**c**) measured laser-induced surface temperatures of the samples; the bottom panel shows a cross section (white line) of the temperature distribution; blue squares denote the experimental data; red curves are Gaussian fits.

III. SUMMARY

In conclusion, we have demonstrated that a random metallic nanostructure can be used to up-scale the THz power of compact, laser-driven tabletop systems, representing a new platform for exploring broadband THz emission from artificial nanostructured materials.

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