Monolithic Integration of Patterned Metal-Dielectric Stacks Overgrown with III-V Semiconductors by Molecular Beam Epitaxy

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Metals and dielectrics have historically been relegated to the periphery of conventional III-V devices due to the challenges associated with integrating amorphous/polycrystalline material with crystalline semiconductor growth. Epitaxially-embedded patterned metals and dielectrics could be useful in a wide variety of photonic and electronic devices to introduce both passive (e.g. polarizers, mirrors, or waveguides), and active (e.g. buried Ohmic contacts and enhanced optical emission) functionality. Monolithic integration of semiconductors, dielectrics, and metals would allow for 3D integration of optoelectronic devices and photonic integrated circuits. This necessitates the study of epitaxial lateral overgrowth processes that allow arbitrarily patterned metal and dielectric structures to be buried within III-V layer stacks. However, during semiconductor overgrowth, the growth parameters must be carefully tailored to prevent the formation of polycrystalline deposits, voids, and dislocations. Such imperfections could introduce optical scattering and recombination sites that reduce the efficiency of devices. Furthermore, at the elevated temperatures necessary for III-V crystal growth, metals can diffuse into the semiconductor, distorting the crystal structure and forming unintentional contact spikes.

To date, the most successful approach to integrate metals into epitaxial layer stacks has focused on crystalline metals, such as rare earth pnictide (e.g. ErAs) films [1] and nanostructures [2]. However, the self-assembled growth of rare earth pnictides makes the integration of arbitrary shaped metals challenging. Prior work on the integration of patterned metals focused primarily on applications to electronic devices, such as metal base transistors [3]. Work on the epitaxial lateral overgrowth of dielectrics has progressed independently from metals, with recent efforts focusing on using buried dielectrics to block the propagation of dislocations in metamorphic heteroepitaxy [4]. This leaves the direct, simultaneous, incorporation of buried metals and dielectrics into III-V materials largely unexplored.

We present patterned tungsten on SiO_2 gratings embedded in molecular beam epitaxy (MBE) grown GaAs to study metal, dielectric, and semiconductor epitaxial integration for device applications. Tungsten and SiO_2 were chosen as they are largely nonreactive with GaAs and stable to the high temperatures necessary for epitaxial growth [5, 6]. Lateral overgrowth of patterned features was achieved by using III-flux modulated periodic supply epitaxy to seed selective growth from a GaAs (001) substrate. Tailoring the crystal plane orientation of the patterned metal stacks results in lateral epitaxial overgrowth that can be integrated into III-V layer structures. Successful lateral epitaxial overgrowth was confirmed by scanning electron microscopy (SEM) and atomic force microscopy (AFM). Fourier transform infrared (FTIR) spectroscopy was used to observe the strong diffraction effects expected from embedded tungsten/SiO_2 grating structures. Further characterization of the optical, electrical, and thermal properties will be presented at the conference.

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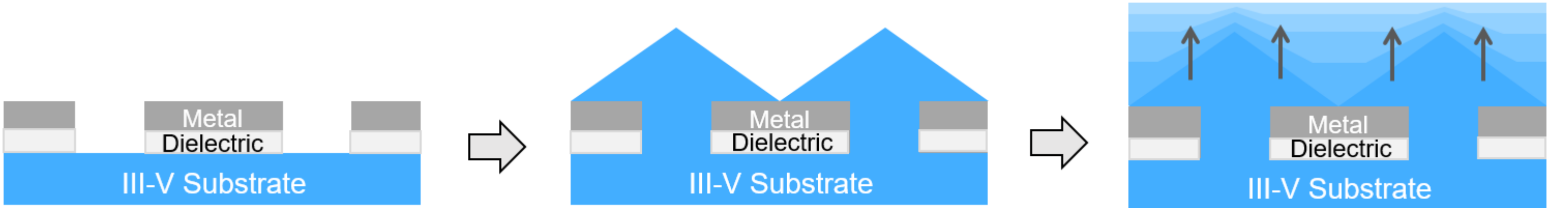

Figure 1: Illustration of the overgrowth process (left-to-right). A pattern is first defined in a metal-dielectric stack on an III-V substrate. Selective growth is then seeded from the III-V substrate to fill in between the pattern, followed by lateral growth along the patterned features until coalescence and eventual restoration of a planar surface.

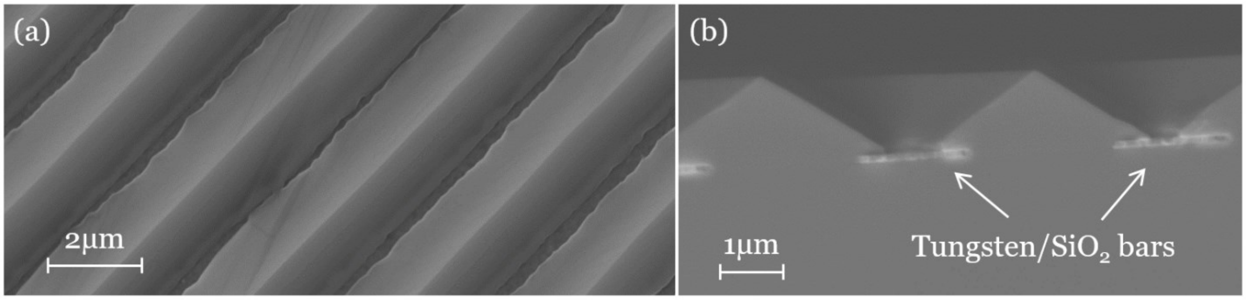

Figure 2: (a) Top-down and (b) cross-sectional scanning electron microscope (SEM) images showing lateral GaAs growth over tungsten on SiO_2 gratings just prior to coalescence.

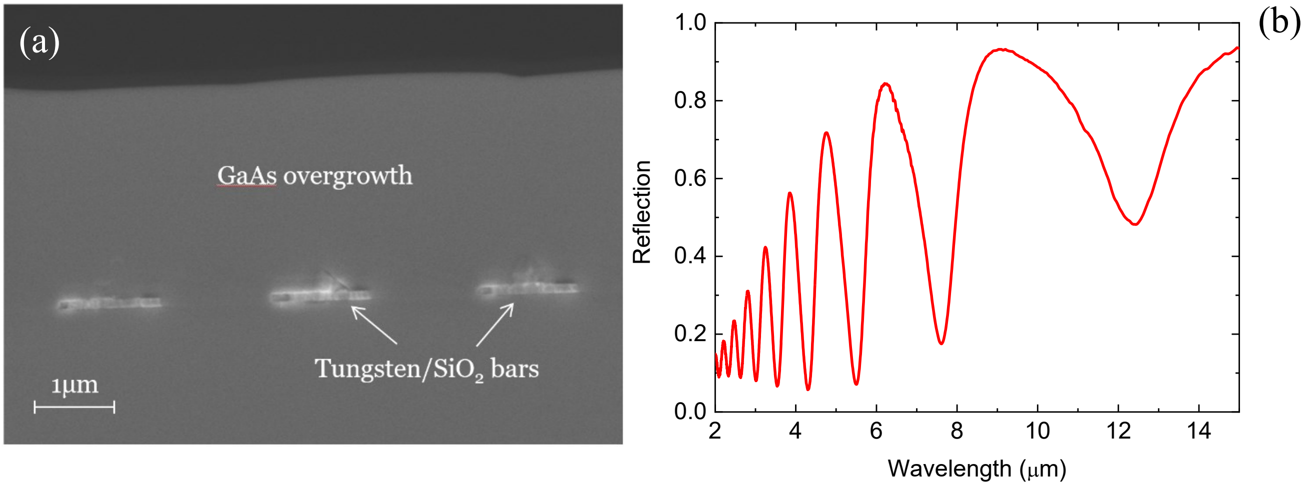

Figure 3: (a) Cross-sectional scanning electron microscope (SEM) image showing planar encapsulation of tungsten-on-SiO_2 gratings within a GaAs matrix. (b) Fourier transform infrared (FTIR) spectroscopy showing strong optical grating diffraction effects in the encapsulated metal-dielectric stack structure.