Light in Memristive Atomic Scale Junction - Memristors go Photonics

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Abstract. Memristive devices are an emerging new type of devices operating at the scale of a few or even single atoms. They largely exploited for emulating the electrical function of synapses and are thus currently investigated for performing in-memory and neuromorphic computing. In this contribution, we report the observation of a novel feature in these devices. We show that memristors can also emit photons during their activity. We identified three mechanisms producing photons with vastly different properties. The crossover between emission regimes depends on the history of the memristor and its operating conductance. Our results suggest that this new generation of memristor pave the way for multidimensional neural networks using both electrons and photons as information carrier.

1 Introduction

Electronic components integrating nanometer scale gap in their design were also crucial to the advent of novel form of computing. Memristors for instance are programmable voltage-dependant resistive devices deployed nowadays in cognitive hardware systems such as artificial neural networks, neuromorphic and reservoir computing [? ]. Memristive operation relies on resistance switching triggered by the electroformation and disruption of conductive pathways within a nanometer-scale dielectric gap [? ]. Charge transport occurs by an electro-chemical reduction of metal ions aggregating to conductive filaments [? ], or by migration of mobile defects, such as oxygen vacancies [? ] and nanoclusters [? ]. In this report, we introduce an atomic scale memristive device capable of emitting photons during resistive switching, superseding thus the need for an external optical source. Our device features the compact footprint of transistors and compatibility with the emerging memristive technology.

2 Results

2.1 Device fabrication and characterization

The devices are typically constituted of two in-plane 70 nm-thick silver electrodes thermally deposited on a 3 nm thin Cr adhesion layer on top of a glass coverslip. The electrodes are terminated by a tapered section forming a 90° angle and are separated by a gap of ranging from 10 to 60 nm. The structures are realized by electron beam lithography complemented by metal deposition and a liftoff process.

2.2 Defect-mediated electroluminescence

The first emission mechanism is based upon the creation of optically-active defect centers induced by the structural changes from resistive switching of the memristor. The atomic rearrangements facilitates the creation of silicon-rich regions within the SiOx matrix. Our investigations suggest that the emission stems from these electroluminescent Si-rich defects[? ]. The blinking dynamics is studied by measuring the photon autocorrelation $\phi^{(2)}(\tau)$ as pictured in Fig. ??.. The red curve is a fit to the data with an anomalous diffusion model representing a continuous time random walk where electron hop between disordered traps having a continuous distribution of escape times.

2.3 Inelastic electron tunneling

When the cycling the memristor, the operation changes from a volatile to a non-volatile state. In this regime, light...
is no longer emitted by charge injection in defects centers, 
but by inelastic electron tunneling whereby an electron in-
jected in the gap has a small probability to lose its energy 
by exciting optical modes. Under this circumstance, the 
correlative dependence between photons emitted and cur-
rent variation changes.

Figure 2. (a) Extract of a cycling sequence showing the photon 
counts and the current for a pulse train of 1.6 V, 400 ms period 
and 200 ms duration. Series of normalized spectra emitted by the 
memristive gap upon application of different pulse amplitudes 
$V_b = 1.6 \text{ V (top)}, V_b = 1.8 \text{ V (middle), and } V_b = 2 \text{ V (bottom).}$ 
The vertical flags are the marking the quantum limit given by 
$h\nu = eV_b$.

Figure 3. (a) Examples of driving pulses for which the device in 
an overbias regime. The kinetic energy of the electron (1.24 eV) 
is smaller than the photon energy (>1.2 eV). (b) Linear depen-
dence of the photoncount (log scale) with $1/\sqrt{IV_b}$ expected from 
radiatively decaying hot electron gas.

2.4 Overbias emission

During the crossover between volatile to non-volatile type 
switching, we observe a transient response with the oc-
currence of fluctuating current. Figure ??(a) shows se-
quences of 1.24 V voltage pulses. At this voltage, any 
emission mechanism promoted by a single electron pro-
cess would be emitted in the nearly blind spectral region 
of the detector. The optical activity suggests that the mem-
ristive device releases photons in an overbias emission 
regime [? ]. Opposite to single electron process, overbias 
light emission is the manifestation of a radiatively decay-
ing of hot electron distribution produced when electrical 
power is lost in a system with characteristic dimensions 
smaller than the electron mean-free path. In this picture, 
the logarithm of the photon count rate is expected to be a 
function of the parameter $1/\sqrt{IV_b}$. Figure ??(b) confirms 
this effect.

3 Conclusion

We report that resistive switching in filament-type memris-
tive junction may be accompanied by light emission. We 
show in our experiments that three mechanisms are at play 
depending on the nature and the dynamics of the switch-
ing. The new memristive photon source discussed here 
features an atomic-sized footprint and a straightforward 
and scalable fabrication process. As the emitted photons 
are associated with a resistive state change, our findings 
can be exploited in optical memristive neural networks to 
identify weight changes from the corresponding memris-
tor.